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Study of Soil Physical Properties Based on Land Use Units for Agriculture (Ricefield, Dryland, and Moorland)

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ABSTRACT

Sub-watersheds are formed from the interaction process of soil-forming factors such as geology, topography, and organisms. Each interaction process results in different characteristics of soil physical properties. Physical characteristics can serve as the main reference in planning, implementing, and evaluating appropriate management of Sub-watershed Areas. The purpose of this study is to examine the characteristics of soil physical properties in the Manten Sub-watershed. This research uses an exploratory approach with a field survey approach through 3 stages of activities, namely pre-survey, survey, and post-survey. Each land use was repeated five times to represent the area of each land use. The parameters observed include texture, bulk density, particle density, permeability, and porosity. The results show that the physical properties of the soil in the Catchment area of the Manten Sub-watershed, Malang Regency, are very different in each land unit. Soil texture is dominated by the loam class (T1, T4, T5, S1, S2, S3, K3, and K4). Based on the research results of soil physical properties in the catchment area of the Manten sub-watershed, moorland use has better soil physical properties than dry field and paddy field land uses. The poor soil physical properties in dry field and paddy field land uses may be caused by excessive land cultivation and low soil organic matter content.

1. INTRODUCTION

Soil plays an important role in supporting plant growth and production. If supported by good physical, chemical, and biological properties, the soil usually shows an ideal level of fertility as a growing medium. The level of soil health and quality is influenced by soil conditions and land use. Exploitation stops all or part of the soil's functions (Rachman *et al*., 2017). The Catchment Area (CA) is the most important part of a watershed because within the watershed there are sub-watersheds and then sub-watersheds. Rainwater that is collected in the CA will flow through surface runoff, subsurface flow, and groundwater flow into the river flow, which then forms the watershed (Gultom *et al*., 2022). Land use change activities occurring in the upstream watershed area not only affect where these activities take place but will also cause impacts in the downstream area in the form of changes in discharge fluctuations and transport of sediment and dissolved materials in other water flow systems. In the 2011 integrated Brantas RPDAS (Watershed Management Plan), it is stated that the level of erosion hazard that needs attention covers an area of 268,261.93 ha or 22.57%, which is mostly spread across the upper and middle Brantas regions with details of "Moderate" erosion hazard level of 105,388.96 ha (8.87%); "Severe" erosion hazard level of 90,212.76 ha (7.59%) and "Very Severe" erosion hazard level of 72,660.61 ha (6.11%) (Kurniawati, 2014).

The catchment area is bounded by ridges of hills and/or the highest elevation in an area (Ichsan, 2022). The area that provides springs and supplies water to the surrounding area depends on the condition of the surrounding ecosystem, especially in the catchment area of a sub-watershed. The Manten sub-watershed catchment area has an area of 176 km^2 located in Malang Regency. The Manten sub-watershed catchment area covers four sub-districts, namely Bululawang, Poncokusumo, Tajinan, and Wajak sub-districts. Soil physical properties play an important role in the conservation of soil and water resources, including the ability of plant roots to penetrate, the ability of soil to store water, drainage systems, soil aeration, and the availability of nutrients for plants. As a result, a decrease in soil capability can result in an overall decrease in environmental functions (Asdak, 2018).

The purpose of this research is to obtain information about the physical properties in the Catchment Area of the Manten Sub-Watershed, Malang Regency. With a better understanding of the physical characteristics of the Manten Sub-Watershed Catchment Area, it is hoped that the surrounding community can better consider the existing conditions and carry out proper land management in accordance with the physical properties in the Manten Sub-Watershed Catchment Area, Malang Regency. This is also expected to reduce damage due to improper land management which causes damaged land conditions and increases degraded land.

2. MATERIALS AND METHODS

This research is located in the Catchment Area of the Manten Sub-Watershed, Malang Regency, which covers four sub-districts: Bululawang, Tajinan, Wajak, and Poncokusumo Sub-Districts at coordinates 8°5'4.10" - 8° 3'4.77" South Latitude and 112°37'36.19" - 112°49'29.44" East Longitude (Figure 1). The analysis activities were carried out from February to April 2024 at the Land Resources Laboratory of Universitas Pembangunan Nasional (UPN) "Veteran" East Java. The research was conducted using a survey method within 3 land uses, namely moorland (*kebun*), dry fields (*tegalan*), and rice fields (*sawah*). The equipment used in this research includes ArcGIS software, sample rings, hammers, crowbars, knives, meter tape, plastic, and hoes.

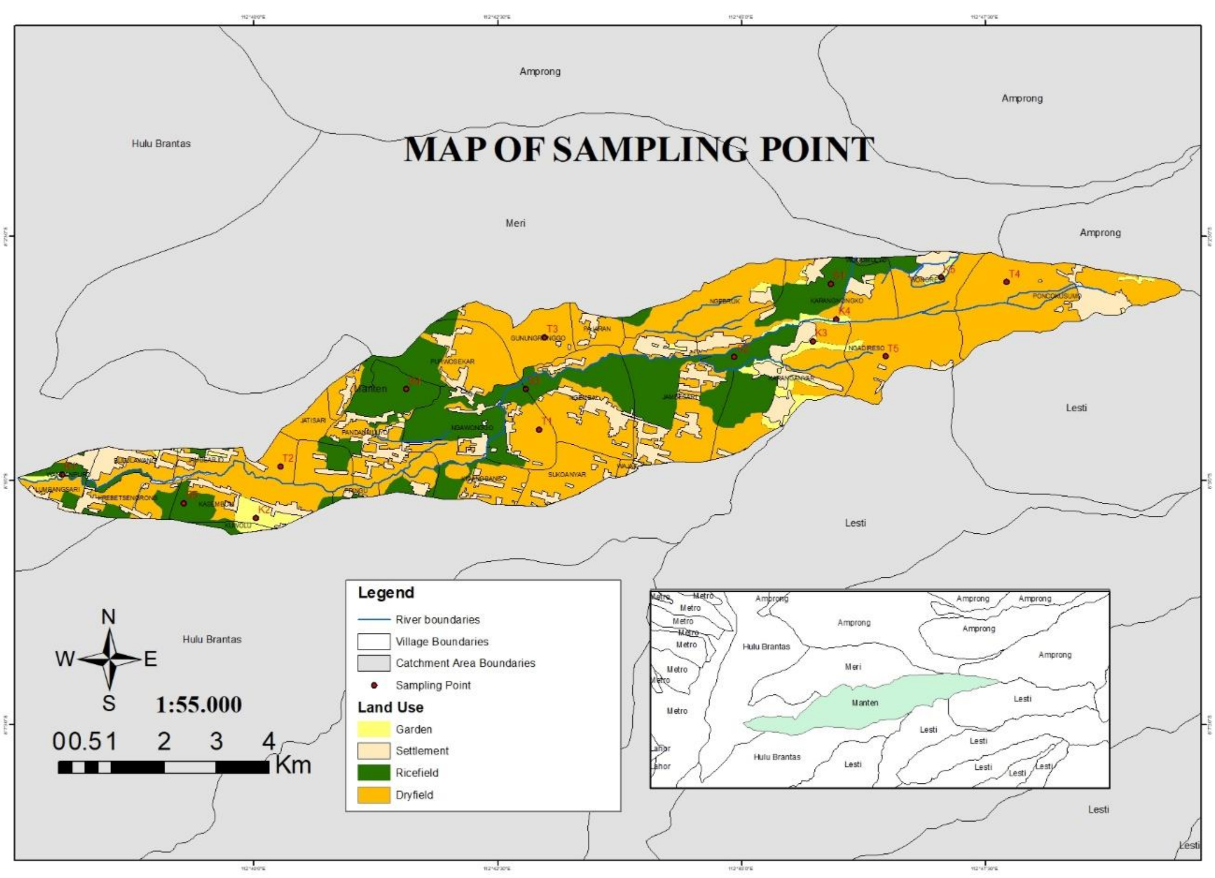


Figure 1. Map of sampling points

2.1. Determination of sample points

The determination of the land unit sample points in this study was done by overlaying 3 map types, namely administrative map, land use map, and catchment area map of the Manten Sub-Watershed. The determination of soil sample points used the purposive sampling method or randomly based on the land use obtained through the overlay map of the sub-watershed catchment area and land use. The results of the 1:55,000 scale land unit map overlaywith ArcGIS were used to determine the sampling points. GIS software combines mathematical models and algorithms to analyze spatial data and explain land conditions and the surrounding environment (Mujiyo *et al.,* 2024).

2.2. Sampling

To represent the area of the catchment area, five replications were carried out for each existing land use. For each land use, three points/three replications were taken to represent each sample area unit. Soil sampling in this study was taken at depths of 0 - 30 cm and 30 - 60 cm. To represent the area of the catchment area, five replications were carried out for each existing land use (Table 1). The code used for land use unit include T for dryfield, S for ricefield, and K for moorland. For each land use there are five replications so there are codes 1 - 5. Soil sampling in this study was taken at depths of 0 - 30 cm and 30 - 60 cm.

2.3. Laboratory analysis

Soil parameters including texture, bulk density, particle density, total porosity, and soil permeability were observed in this research. Tabel 2 summarized the method used to analyze these parameters. Soil texture was measured by the pipette method; ring volumetric method was used to calculate soil bulk density; and a pycnometer was used to calculate soil particle density. Soil permeability was calculated using the constant head equation method. Soil physical properties data were processed using Microsoft Office Excel and using regression test.

Table 1. Code of sampling points

No	Code of Sampling	Region/District	Land Use
1.	T1	Wajak	Dryfield (Tegalan)
2.	T2	Tajinan	
3.	T3	Tajinan	
4.	T4	Poncokusumo	
5.	T5	Poncokusumo	
6.	S1	Poncokusumo	Ricefield (Sawah)
7.	S2	Poncokusumo	
8.	S3	Wajak	
9.	S4	Tajinan	
10.	S5	Bululawang	
11.	K1	Bululawang	Moorland (Kebun)
12.	K2	Bululawang	
13.	K3	Poncokusumo	
14.	K4	Poncokusumo	
15.	K5	Poncokusumo	

Table 2. Analysis parameters

No.	Parameters	Method	Reference
1.	Bulk Density	Ring volumetric	Kurnia *et al*. (2006)
2.	Texture	Pipet	Kurnia *et al*. (2006)
3.	Particle Density	Gravimetric	Kurnia *et al*. (2006)
4.	Porosity	-	Kurnia *et al*. (2006)
5.	Permeability	Constant head permeameter	Kurnia *et al*. (2006)

3. RESULTS AND DISCUSSION

The Manten Sub-Watershed Catchment Area has an area of 173 km^2 covering four sub-districts, namely Bululawang, Wajak, Tajinan, and Poncokusumo Sub-Districts. Each sub-district passed by the Manten Sub-Watershed has a different area. Bululawang Sub-District has an area of 49.36 km^2, Wajak Sub-District has an area of 94.56 km^2, Tajinan Sub-District 40.11 km^2, while Poncokusumo Sub-District is 102.99 km^2. The average elevation of the Bululawang Sub-District area is 406 meters above sea level, Wajak Sub-District with an elevation of 513 meters above sea level, Tajinan Sub-District with an elevation of 497 meters above sea level, while the elevation of the Poncokusumo area is 685 meters above sea level.

The Manten Watershed also has its upstream in the southern part of Poncokusumo Sub-District, passing through the central part of Malang Regency and ending at the Karangkates Dam, together with the Amprong and Bango Rivers. The most common land uses in the Manten Sub-Watershed area are gardens, rice fields, and dry fields. Dry field land use is the most dominant land use in the Manten Sub-Watershed area.

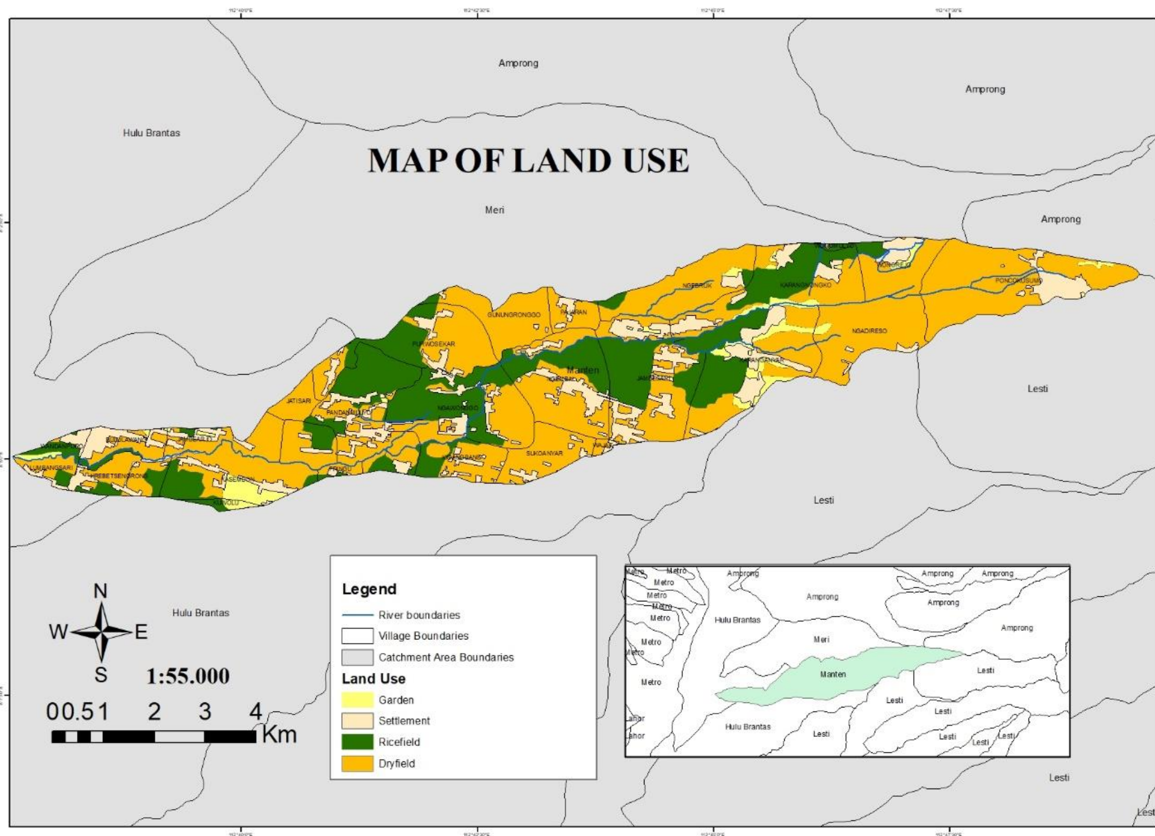


Figure 2. Map of land use in Manten Sub-Watershed

The land unit map is a component of the land unit formed from the overlay of three types of maps, namely the land use map, the Sub-Watershed catchment area map, and the administrative. For each land use (gardens, rice fields, and dry fields), 5 replications were carried out to represent the area of each land use in the Manten Sub-Watershed catchment area, Malang Regency. Based on the results of the map overlay, the Manten Sub-Watershed catchment area obtained 15 types of land units. The characteristics of the land units can be seen in Figure 1. The results of the analysis of soil physical properties characteristics obtained were the parameters of soil texture, bulk density, particle density, total soil porosity, and permeability. The results of the analysis are presented in each table showing the results of the analysis for each observation parameter. The following are the results of the land characteristic assessment according to the physical properties of the soil at each point and land use:

3.1. Texture

Based on the analysis of soil texture, it is indicated that the research location is predominantly characterized by clay soil texture in each land unit T1, T4, T5, S1, S2, S3, K3, and K4. Soil texture reveals the relative content of particles from sand, silt, and clay fractions. Soil texture is used to indicate the size of soil particles, especially when compared to various soil categories. According to Naharuddin *et al.* (2020), clay texture is typically characterized by a balanced ratio of sand, silt, and clay fractions. Clayey soil has a balanced ratio of sand, silt, and clay fractions. Due to its very fine particles, clay soil has a high water storage capacity. Clay particles have a large surface area, thus capable to retain a significant amount of water. Clayey soil has a moderate infiltration rate and moderate water holding capacity.

Table 3. Soil texture category in the research locations

Point Sampling	%Fraction			Category
	Sand	Silt	Clay	
T1	48	39	13	Loam
T2	28	50	22	Silt Loam
T3	18	54	28	Silty Clay Loam
T4	39	47	14	Loam
T5	39	38	23	Loam
S1	35	44	21	Loam
S2	46	36	18	Loam
S3	21	57	22	Loam
S4	13	63	24	Silt Loam
S5	9	61	30	Silty Clay Loam
K1	22	55	23	Silt Loam
K2	25	57	18	Silt Loam
K3	43	44	13	Loam
K4	43	42	15	Loam
K5	21	62	17	Silt Loam

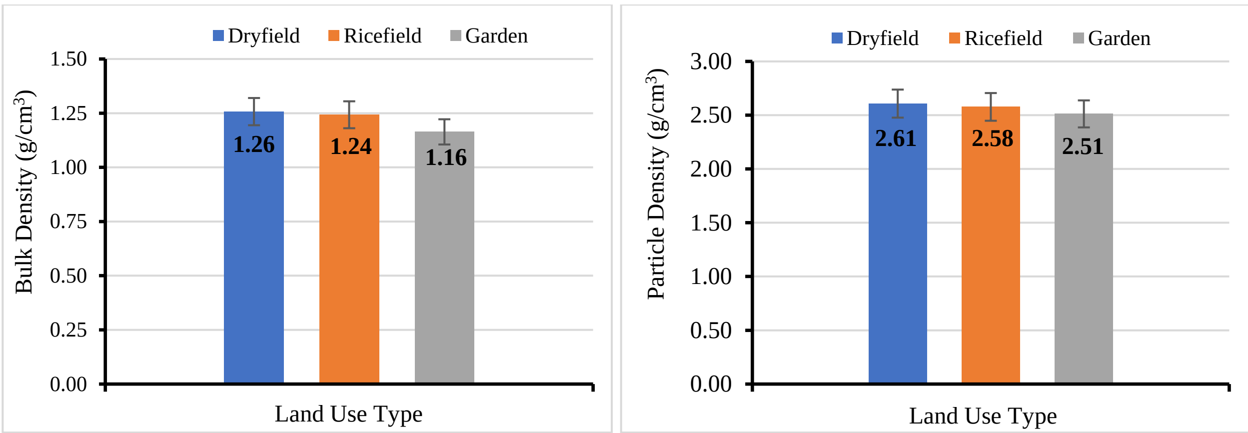
Note: T = Dryfield; S = Ricefield; K = Moorland

Land units T2, S4, K1, K2, and K5 have a silty loam texture class, while land units T3 and S5 have a silty clay loam texture class (Table 3). Soils with a silty loam texture have a higher water holding capacity. The silty loam texture is considered a very suitable soil type for agriculture because it has a balanced composition between coarse and fine particles, allowing efficient nutrient absorption. The fine fraction is characterized by small particles and a large surface area, possessing significant water retention capacity (Rosyidah & Wirosoedarmo, 2013).

3.2. Bulk Density

Bulk density (BD), or soil volume weight, is the mass of the solid phase of the soil divided by the total volume of the soil. It is closely related to soil compaction, drainage and aeration, as well as other physical properties (Haryati, 2014). Soil bulk density indicates the level of soil compaction which can affect other soil physical properties. The lowest average BD value based on land use is found in moorland use with a value of 1.16 g/cm^3, paddy fields with a value of 1.24 g/cm^3, and dry fields have the highest average with a value of 1.26 g/cm^3 (Figure 3a) The low BD value in moorland is due to land management with the addition of organic matter. So the soil in the moorland land is looser and there is no soil compaction. According to Brouwer & Jenkins (2015), for healthy agricultural soils, a good BD value is less than 1.2 g/cm^3. The higher the soil BD, the denser the soil, making it difficult for roots to penetrate (Kasih *et al.*, 2019). Soils with good aggregates and high organic matter will have low bulk density because the soil is more crumbly. According to Susanti *et al.* (2019), organic matter in the soil has a significant influence, as they can reduce the bulk density value because organic matter is much lighter than minerals.

Polysaccharide production increases with the addition of organic matter, which increases soil aggregation and decreases soil BD (Prabhavathi & Ramakhrisna, 2019). The average value for dry field (tegalan) land use is also higher than other land uses. This can be caused by one factor because dry fields do not have permanent ground cover, which can result in raindrops falling directly onto the soil, causing soil compaction. According to Putri *et al*. (2017), soil processing in dry fields is more intensive compared to other land uses, which causes destructuring to occur more frequently, leading to an increase in soil bulk density. A soil bulk density value greater than 1.2 g/cm^3 means that the soil has undergone a compaction process.



(a) (b)

Figure 3. Bulk density (a), and particle density (b) of soil in the three land use units: dry field, rice field, and moorland

3.3. Particle Density

The ratio of the total mass of the solid phase of the soil (without pores) and the volume of the solid phase is called the particle density (PD). The average values for each land use also differ, where the highest average soil PD value is in dry land at 2.61 g/cm^3, followed by rice fields with a value of 2.58 g/cm^3, and the lowest value is in moorland with a value of 2.51 g/cm^3 (Figure 3b). The PD value is also influenced by the condition of organic matter in the soil. The higher the organic matter content, the lower the PD in that land. This is because moorland use has a higher organic matter content than ricefields and dry fields. The addition of organic matter to the moorland is done more frequently than in other lands, resulting in a lower PD. The addition of organic matter in the soil reduces soil PD (Nabayi *et al*., 2021) and increases soil aggregation (Wen *et al*., 2024). The addition of organic matter can increase the amount of soil pore space and form a crumbly soil structure and decrease soil PD. Particle density is an indicator of low soil porosity and soil compaction. Soil compaction increases bulk density, thereby reducing water infiltration capacity into the soil, which ultimately leads to increased runoff and erosion (Patle *et al*., 2019).

3.4. Porosity

Soil porosity (P) is the proportion of total pore space in the soil that is filled by water and air compared to the total soil volume (P = BD/PD)*100%). The results of the soil porosity research (Figure 4) show that the porosity values for each land use are above 50%. The land with the highest average is moorland with a value of 53.63%. Dry field land has a high value due to land cultivation and the addition of organic matter. The lower soil porosity in dry fields and paddy fields compared to moorlands is because these lands are unable to obstruct raindrops. According to Kusuma & Yulfiah (2018), porosity is the total proportion of void spaces in the soil that is filled by water and air. Factors such as particle size and soil density affect porosity. The arrangement of solid particles influences the number and characteristics of pore spaces. The pore size in the soil structure will determine how much void space is available and its properties. Porosity in the Manten Sub-Watershed catchment area ranges from 46.20% to 57.66%. The total pore space includes the space between soil aggregates and the sand, silt, and clay fractions as well as macropores. Soils with a large pore size distribution usually have low moisture storage capacity but high ability to allow water and air to pass through (Arifin, 2011). According to Surya *et al*. (2017), soil porosity, the total pore space, is influenced by soil organic matter and humus, with interactions between these and the soil particles, resulting in a more stable soil structure and an increase in pore space.

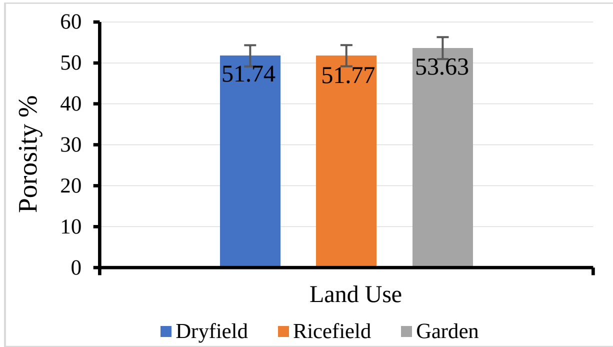


Figure 4. Soil porosity (a), and its relation to soil bulk density at the three land use units: dry field, rice field, and moorland

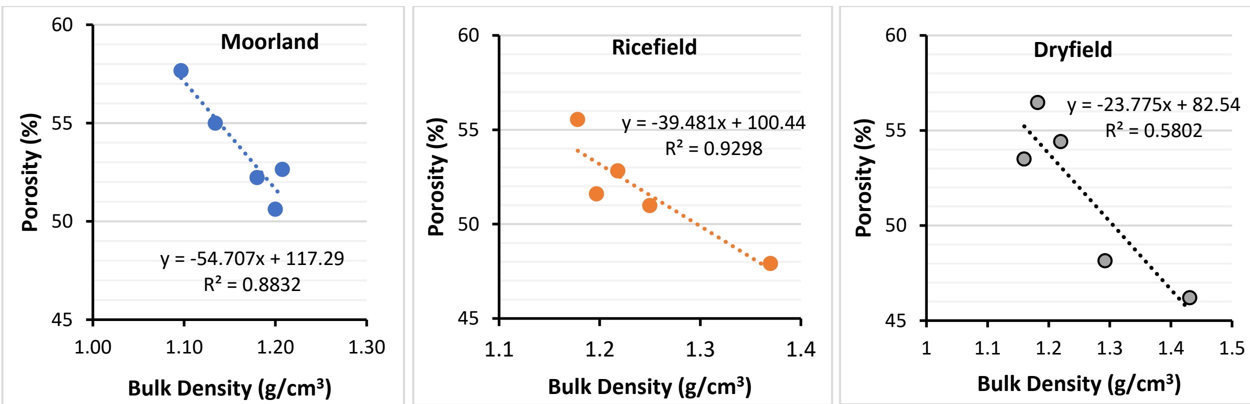


Figure 5. Relation of soil bulk density to soil porosity for three land use units: moorland, rice field, and dry field.

Based on the results of the regression test between bulk density and soil porosity for each land use (Figure 5), different R^2 values were observed. In moorland, it was found that 88% of the porosity is influenced by bulk density, while the remaining 12% is affected by other factors. In rice fields, the R^2 value was 93%, indicating that porosity is influenced by bulk density, whereas the smallest R^2 value was found in dryland fields, at 58%, suggesting that porosity is also influenced by bulk density. Porosity in moorland had the highest value compared to dryland and rice fields. This aligns with Bintoro *et al*. (2017), who stated that porosity plays a significant role in determining soil bulk density; when soil pores are large or abundant, the bulk density value tends to be low. The level of soil porosity is dependent on bulk density; as bulk density increases, soil porosity decreases.

3.5. Permeability

Soil permeability is highly dependent on pore characteristics, which are determined by the stability of soil aggregates. Cavities within stable soil aggregates allow for rapid water flow, while in unstable soil aggregates, these cavities tend to be closed due to damage to the soil aggregates. According to Jiao *et al*. (2020) in more detail, permeability is a measure of the rate at which water penetrates the soil vertically, measured in units of cm/hour. If the rate of water infiltration is too slow, surface runoff becomes greater, thereby increasing the risk of erosion. Based on the research results (Figure 7), the permeability results for the three land uses show different average values. It can be seen from the average results according to land use that the land use with the highest average is moorland, followed by dry fields, and the lowest is rice field land use. The highest average value is in garden land at 6.01 cm/hour, dry field land at 2.67 cm/hour, and paddy field land at 2.38 cm/hour. Moorland use has a high value due to intensive soil cultivation activities. Intensive soil management indeed has a significant effect on soil porosity, so the permeability value is also affected. Meanwhile, the lowest soil permeability is in paddy field land use. Paddy field land use is usually dominated by clay fractions where clay fractions have properties that make it difficult for water to pass through. The difference in permeability values is also influenced by factors such as porosity, texture, structure, and soil organic matter content. Research conducted by Suharyatun *et al*. (2023) indicates that soil texture is one of the main factors affecting soil permeability. Coarse-textured soil has high permeability, while fine-textured soil such as clay has low permeability. Soil permeability is influenced by organic matter content, soil bulk density, soil porosity, and soil aggregate stability (Naharuddin *et al*., 2020).

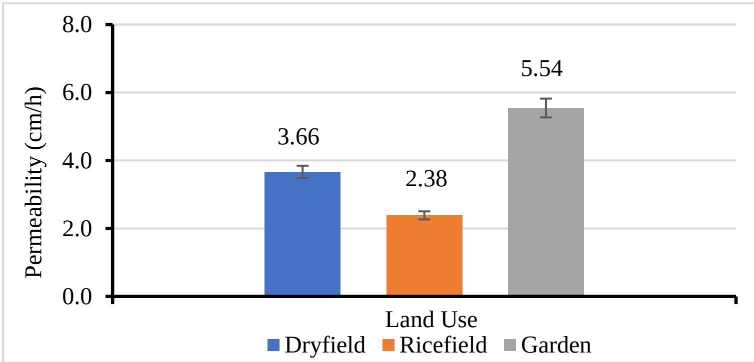


Figure 5. Soil permeability at the three land use units: dry field, rice field, and moorland

4. CONCLUSION

The physical properties of the soil indicate that loam texture predominates in the research location (T1, T4, T5, S1, S2, S3, K3, and K4), where the content of sand, silt, and clay particles is relatively balanced. Based on the research results of soil physical properties in the catchment area of the Manten sub-watershed, moorland use has better soil physical properties than dry field and paddy field land uses. Moorland has the lowest bulk density (1.16 g/cm^3) and particle density (2.51 g/cm^3) among rice fields and dry fields. Moorland also has higher permeability and porosity values than other land uses. The poor soil physical properties in dry field and paddy field land uses may be caused by excessive land cultivation and low soil organic matter content.

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