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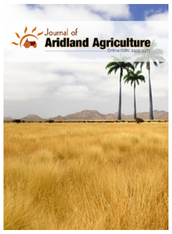
Research Article



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Characteristics of soil physical properties based on soil profile depth in forest stands and upland farms in Andisols

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ABSTRACT

Information on the effect of forest stands and upland farms on soil physical properties is important for soil management. This study evaluated the effect of forest stands and upland farms on the physical properties of Andisols soils in the Mount-Merbabu National Park, Indonesia. A total of 108 soil samples were collected from each Pine, Acacia, Puspa (*Schima noronhae* Theaceae), Bintamin (*Cupressus* sp.), mixed, and upland farms at soil depths of 0-10, 10-20, 20-30, 30-50, 50-70 and 70-100 cm with three replications at each depth. The results showed that the sand fraction was in the range of 40.7%-73.8%, the silt fraction was in the range of 21.2%-42.6%, and the clay fraction was in the range of 3.2%-9.9%. Soil permeability shows that the value decreases with soil depth and shows different rates between forest stands and upland farms. The highest permeability in forest stands is found in Puspa stands 0-10 cm depth (7.50 cm h^{-1}) and 20-30 cm depth (14.36 cm h^{-1}) in the upland farms, the lowest rate is found in Pine stands 70-100 cm depth (3.07 cm h^{-1}) and 70-100 cm (1.23 cm h^{-1}) in the upland farms. Porosity shows a decreasing value with soil depth where the highest porosity is found in mixed stands at a depth of 10-20 cm (66.17%) and the lowest porosity in Puspa stands at a depth of 70-100 cm (44.41%). Upland farms shows a higher sand fraction content (0-100 cm depth) than forest stands, and forest stands show a higher silt fraction content (0-100 cm depth). Puspa stands have higher permeability than other forest stands (0-10 cm depth).

KEYWORDS: Soil physical properties, Forest stands, Upland farms, Soil profile depth

INTRODUCTION

The importance of knowing soil's physical properties such as texture, permeability, and porosity lies in their significant influence on various agricultural and environmental processes. These properties affect the management of soil moisture content, soil infiltration rate, water and air movement, nutrient availability, and soil biota (Bisai *et al.*, 2016). Understanding soil physical properties is essential for making informed decisions regarding soil management, irrigation, fertilization, and land use. In addition, knowledge of these properties is essential for assessing the suitability of soils for various uses, such as agriculture or rainwater catchment. Therefore, a comprehensive understanding of soil physical properties is fundamental for sustainable agricultural production and environmental management (Jat *et al.*, 2018).

Soil physical properties are interconnected, and changes in one can affect another, which can have a significant impact on soil health and productivity (Almendro-Candel *et al.*, 2018). Important physical properties to know include soil texture, permeability, and porosity. The texture is the main physical property that controls the dynamics of soil organic matter (SOM) (Tisdall & Oades, 1982), soil structure, soil microbiology (Hattori, 1988), water flow (Prove *et al.*, 1990), and nutrient sorption and desorption (Wang *et al.*, 2001). Soil permeability affects the transport of water and nutrients in the soil, which has implications for agricultural and environmental processes (Preston *et al.*, 2014). Soil porosity affects the movement of water, air, and nutrients within the soil, which is critical for plant growth and overall soil health (Harcourt & Awatere, 2022). Porosity as well as the pore size distribution in the soil can affect various soil hydraulic properties such as hydraulic conductivity, water retention, infiltration, and water holding capacity (Luxmoore, 1981; Pagliai & Vignozzi, 2002; Kutílek & Jendele, 2008; Indoria *et al.*, 2020).

Andisols are soils formed from volcanic ash or other volcanic ejecta. They are characterized by unique chemical and physical properties, including high water holding capacity and high fertility (Nanzyo *et al.*, 1993). Andisols are very important in agriculture due to their properties that make them very suitable for a wide range of crops. Andisols play an important role in supporting plant growth due to their unique chemical and physical properties, including a high specific surface of inorganic colloids, which allows the soil to absorb large amounts of organic matter (Arnalds, 2013).

The soil physical properties of forests and upland farms are important to know. Soil physical properties also affect the natural distribution of forest tree species, growth, and forest biomass production. Forest soils have unique physical properties that are critical to their productivity and sustainability (Hatten & Garrett, 2019). Forest soils can have a wide range of textures, which can affect water holding capacity, nutrient availability and root growth (Osman, 2013). Forest soils can have high porosity due to the presence of organic matter and soil fauna, which can affect water holding capacity, nutrient availability, and root growth (Schoenholtz *et al.*, 2000). Different land uses, both natural forests and cultivated land such as upland farms, can certainly cause different physical properties. Cultivated soil will have different physical properties compared to forest (Septianugraha & Abraham, 2014). Intensive tillage on upland farms causes soil compaction due to pressure from agricultural tools on subsoil (Febria *et al.*, 2014).

Knowledge of the variations in soil physical properties under different land uses is imperative in soil management, for their significant influence on various agricultural and environmental processes. Therefore, the objectives of the study were to investigate the variations in soil physical properties; soil texture, permeability, and porosity under different types forest stands and upland farms in the Mount-Merbabu National Park, Central Java, Indonesia.

MATERIALS AND METHODS

Description of Research Location

This research was conducted in the Mount-Merbabu National Park, Central Java, Indonesia from July 2022 to Mei 2023; within an area between latitude 7°24′5″ S to 7°29′4″ S, and between longitude 110°19′0″ E to 110°29′5″ E. The soil type at the research site is Andisols. The elevation of the study site ranges from 1766-1925 masl, with a slope of 15-75%, and annual rainfall of 2799 mm yr^{-1} (Table 1).

Soil Sampling

Determination of "sites" in each vegetation stands was carried out using the Stratified-Purposive Sampling method based on soil types and continued with the type of vegetation stands. Stands type observed were Pine (*Pinus merkusii* Pinaceae), Puspa (*Schima noronhae* Theaceae), Acacia (*Acacia decurren* Fabaceae), Bintamin (*Cupressus* sp.), mixed, and upland farms (Table 1). Soil samples were taken at each soil profile with a depth of 0-100 cm (0-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, 50-70 cm, 70-100 cm) in each forest stands and upland farm; and 3 replications at each depth. Both undisturbed and disturbed soil samples were taken from each soil depths. Undisturbed soil samples were taken by core sampler to measure the soil bulk density and permeability. Meanwhile, for soil texture and particle density analysis, it is used disturbed soil samples.

Soil Analysis

Soil texture was determined using the Bouyoucous hydrometer method (Bouyoucos, 1962), destroying organic matter by burning it with hydrogen peroxide (H_2O_2). Soil particles were dispersed and crushed with sodium carbonate (Na_2CO_3) and sodium hexametaphosphate ($NaPO_3$) in distilled water and amyl alcohol was used to destroy soil solution foam. Then the particle size distribution was determined in percent (Tufa *et al.*, 2019).

Permeability measurements were carried out using the Constant Head Permeameter Method (Purwakusuma *et al.*, 2024). The undisturbed soil samples with the copper ring (height=4 cm, outer diameter=7.9 cm and inner diameter=7.6 cm) was immersed in water in a soaking tub up to a height of 3 cm from the bottom of the tub for 24 hours. The purpose of immersion in water is to remove all air from the soil pores, because this permeability is determined in the saturated phase. The soil sample is added to the permeameter device, then water is flowed into the device. After the water level in the measuring device is constant, the water dripping in a certain time interval is measured, and then to obtain the permeability value, the average value is taken from the measurements (Norfadilah *et al.*, 2020).

Soil porosity is estimated from bulk density and particle density values. Soil porosity is calculated using the following formula (Jaramillo, 2014):

$$\text{Soil Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100\%$$

Table 1: General condition of the research sites

Forest stands	Elevation (masl)	Type of soil	Latitude Longitude	Slope (%)	Rainfall* (mm yr^{-1})
Acacia (*Acacia decurren* Fabaceae)	1866	Andisols	7°29'8.05" S 110°27'30.08" E	75	2799
Pine (*Pinus Merkusii* Pinaceae)	1876	Andisols	7°29'1.15" S 110°27'26.63" E	65	2799
Bintamin (*Cupressus* sp.)	1846	Andisols	7°28'56.32" S 110°27'35.25" E	15	2799
Puspa (*Schima noronhae* Theaceae)	1925	Andisols	7°28'46.14" S 110°27'36.25" E	23	2799
Mixed (Puspa, Bintamin, Pine)	1895	Andisols	7°28'52.88" S 110°27'30.54" E	20	2799
Upland farms	1766	Andisols	7°29'11.97" S 110°27'39.98" E	60	2799

Source: *Field Observations (2022) and BPS-Statistics Indonesia (2021)

Statistical Analysis

The statistical analysis used was an ANOVA test to test the differences in soil physical properties at various soil depths in forest stands and upland farms. DMRT test with a 95% confidence level was used to compare parameters that were significantly different (Herawati *et al.*, 2024). Pearson correlation test to determine the relationship between soil physical properties (Tang *et al.*, 2015). All statistical analyses were performed using IBM SPSS Statistics 25.

RESULTS AND DISCUSSION

Soil Texture

Figure 1 shows that the highest average sand fraction is found in upland farms (68.8%) and Bintamin stands (68.1%). The sand fraction in Pine stands has the lowest value compared to all stands (57.5%). The highest silt fraction was found in Pine stands (35.3%), Acacia stands (31.6%), and Puspa stands (31.4%). The lowest silt fraction was found in upland farms (26.4%) and Bintamin stands (26.7%). The highest clay fraction was found in Pine stands (7.3%) and the lowest in mixed stands (3.7%), while in upland farms (4.9%).

Figure 2 shows the DMRT test where the highest sand fraction was found at a depth of 50-70 cm in Bintamin stands (73.8%) and the lowest in Pine stands (48.7%). The silt fraction has a value that tends to be inversely proportional to the sand fraction where the higher the sand fraction, the lower the silt fraction. The highest silt fraction was found at a depth of 50-70 cm in Pine stands (42.6%) and the lowest in Bintamin stands (21.9%). Figure 2 shows that the clay fraction has a small percentage compared to sand and silt. The highest clay fraction value was found in Pine stands at a depth of 30-50 cm (9.9%) and the lowest clay fraction was found in mixed stands at a depth of 10-20 cm (3.2%).

The sand fraction has the largest percentage compared to the silt and clay fractions. According to McDaniel *et al.* (2012), the parent material of Andisol soils comes from volcanic materials. The sandy texture of Andisol soils can be caused by the presence of volcanic glass which is a non-crystalline amorphous material formed from the rapid cooling process of lava. Its presence in Andisol soils contributes to its sandy texture. This volcanic material has undergone relatively little weathering and is sandy in texture. The clay fraction has the smallest percentage compared to other fractions which is below 10%. The low clay fraction in the research location can occur because Andisols is a soil that has not been too developed. According to Apriani *et al.* (2019), that the low clay fraction can be caused by the weathering of rocks that become the parent material of the soil has not developed further into clay.

The sand fraction content (soil depth 0-100 cm) on the upland farms is higher than the forest stands, while the forest stands has a higher silt fraction content (soil depth 0-100 cm) than the upland farms (Figure 3). This is allegedly to be because land (soil) on forest stands have a higher infiltration capacity

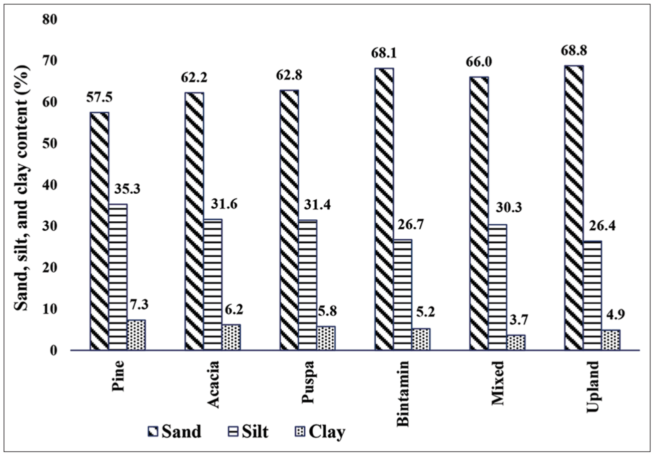

Figure 1: Average percentage comparison of sand, silt, and clay content in forest stands and upland farms

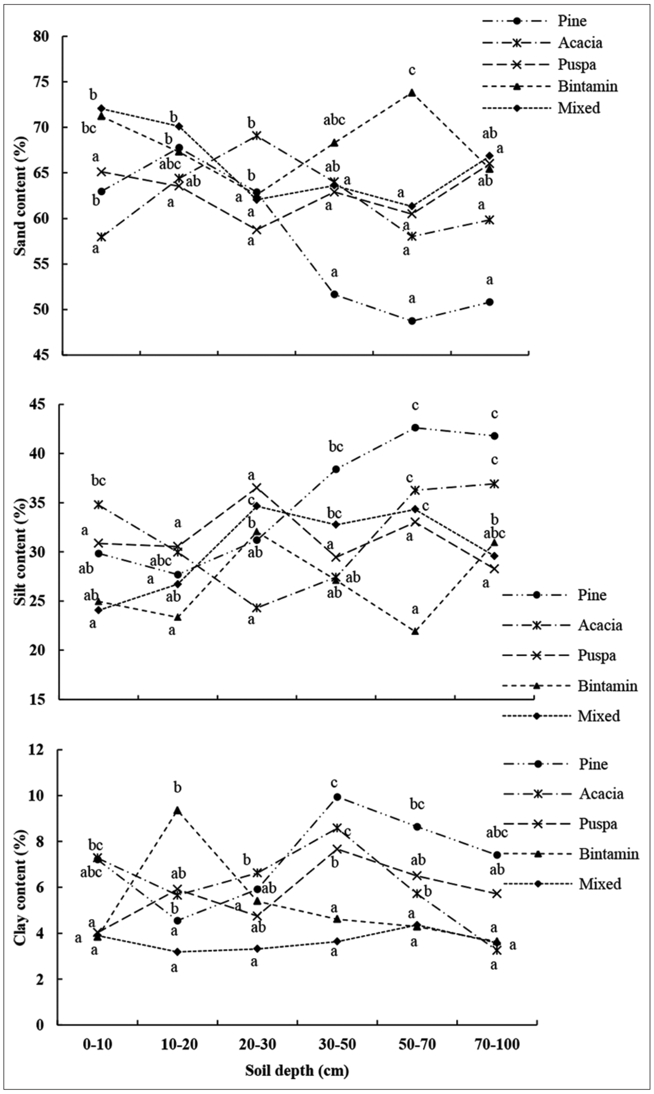

Figure 2: Sand, silt and clay content at 0-100 cm in soil depth different forest stands. Different letters indicate significant differences among soil depth (DMRT α=0.05)

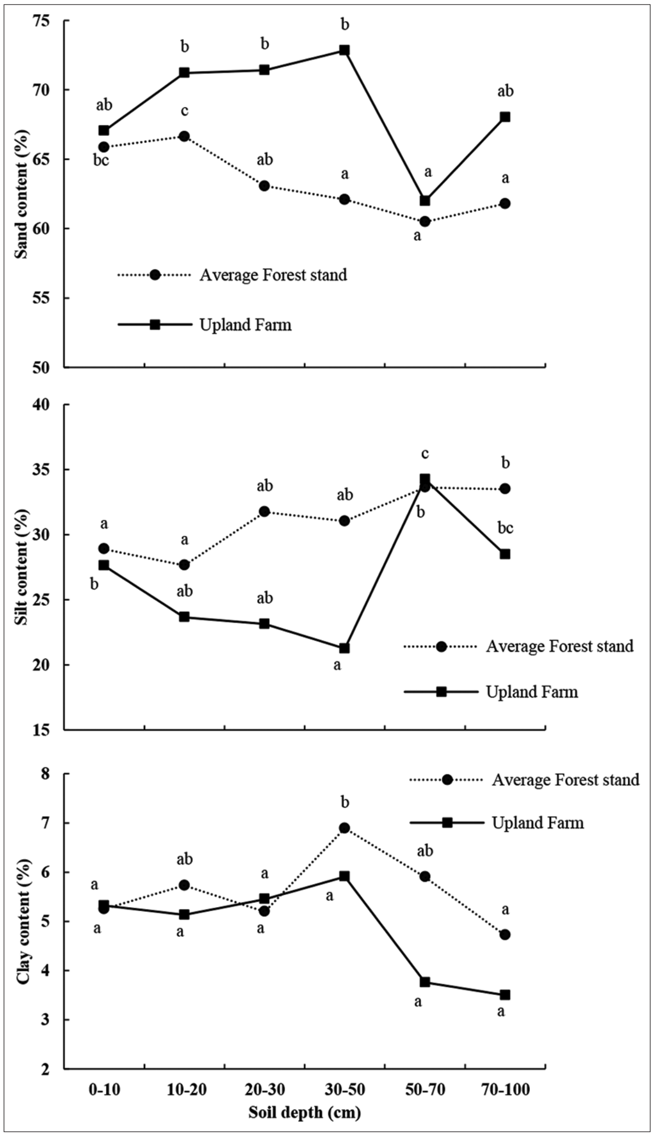

Figure 3: Average of sand, silt and clay content at 0-100 cm in soil depth between forest stands and upland farms. Different letters indicate significant differences among soil depth (DMRT α=0.05)

(80-95% of rainfall) than land on upland farms (30-70% of rainfall), so that the soil profile in forest stands is relatively more saturated with water, the soil pores are more filled with water, and resulting in the soil fractions (sand, silt, clay) being more waterlogged and resulting in the sand fraction (≥50 μm-2 mm) breaking down into silt fractions (2-50 μm) smaller. According to Injiliana *et al.* (2020), in the top soil layer (0-10 cm) the lower silt fraction on the upland farms can be caused by soil erosion. Erosion can cause the loss of topsoil. Eroded soil tends to have a coarser texture because fine particles are carried away by water and wind during the erosion process.

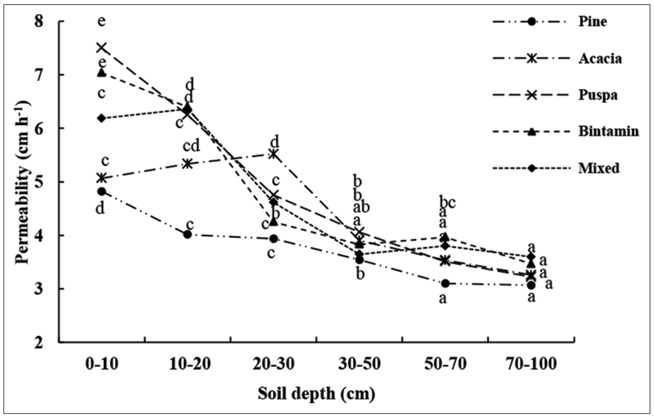

Figure 4: Soil permeability at 0-100 cm in soil depth different forest stands. Different letters indicate significant differences among soil depth (DMRT α=0.05)

Table 2: Soil permeability at 0-100 cm soil depth in forest stands and upland farms

Soil depth (cm)	N	Pine	Acacia	Puspa	Bintamin	Mixed	Upland farms
		Permeability (cm h^{-1})					
0-10	3	4.82^{d}	5.07^{c}	7.50e	7.04e	6.19^{c}	13.02^{c}
10-20	3	4.01^{c}	5.33^{cd}	6.25^{d}	6.40^{d}	6.36^{c}	12.77^{c}
20-30	3	3.94^{c}	5.52^{d}	4.75^{c}	4.25^{c}	4.62^{b}	14.36^{d}
30-50	3	3.54^{b}	3.90^{b}	4.06^{b}	3.83^{ab}	3.64^{a}	3.72^{b}
50-70	3	3.10^{a}	3.53^{a}	3.51^{a}	3.97^{bc}	3.80^{a}	1.85^{a}
70-100	3	3.07^{a}	3.26^{a}	3.22^{a}	3.47^{a}	3.60^{a}	1.23^{a}
SE (±)		0.15	0.22	0.37	0.34	0.28	0.37
Level of significance		**	**	**	**	**	**
CV%		4.54	4.56	4.62	4.63	3.86	6.83

Figures in a column having same letter (s) do not differ significantly according to DMRT. **=Significant at 5% level of probability, N=Number of samples, CV=Co-efficient of variation, SE=Standard error of means

Soil Permeability

Based on the results of ANOVA analysis, there is a significant difference between the permeability of soil depth in forest stands and upland farms (Table 2). Table 2 and Figure 4 shows the results of the DMRT test of soil permeability in forest stands have relatively close values and tend to decrease with increasing soil depth. The highest permeability in forest stands is found in Puspa stands at a depth of 0-10 cm (7.50 cm h^{-1}). The lowest permeability was found in Pine stands at a depth of 70-100 cm (3.07 cm h^{-1}). Soil permeability in Andisol tends to be good, but Andisol soils are very sensitive to erosion (Vincencius *et al.*, 2017).

Figure 4 shows the permeability rate of soil in forest stands. Permeability rates in forest stands have different rates; as the depth of the soil profile increases, the level of permeability tends to decrease. Figure 5 shows the average permeability values in forest stands and upland farms at a depth of 0-100 cm. The permeability rate on the upland farms shows a high value at a depth of 0-30 cm whereas the highest value is at a depth of 20-30 cm (14.36 cm h^{-1}).

The high permeability value in upland farms can be caused by tillage. According to Minangkabau *et al.* (2022), tillage aims to create crumbly soil structure conditions, thus creating good soil aeration and making it easier for water to seep through.

According to Suripin (2001), cultivated soil will increase infiltration capacity because the soil becomes loose so that soil permeability increases. Permeability in the upland farms experienced a drastic decrease at a depth of 30-50 cm and the lowest value was at a depth of 70-100 cm (1.23 cm h^{-1}). Soil permeability at a depth of 50-100 cm in the upland farms decreased due to soil compaction. According to Mulyono *et al.* (2019), tillage affects the value of soil permeability. Compaction by heavy tillage equipment during tillage can drastically reduce the soil's ability to absorb water as the soil becomes compacted and the soil pores become closed.

Soil Porosity

Based on the results of ANOVA analysis, showed a significant difference between porosity in soil depth in forest stands and upland farms except in Puspa stands and Bintamin stands (Table 3). Figure 6 shows that soil porosity in forest stands has fluctuating values at each depth. The highest soil porosity was found in mixed stands at a depth of 10-20 cm (66.17%). The lowest porosity was found in Puspa stands at a depth of 70-100 cm deep (44.41%). Puspa, mixed, and Bintamin stands show the greatest porosity value produced at a depth of (10-20 cm) and there is a tendency to decrease porosity values as the depth of soil increases. This can be due to the compaction of the soil. According to Surya *et al.* (2017), soil compaction affects the porosity value of soil. The deeper the soil, the more the soil density will increase due to the pressure of the soil layer above it, making the soil denser and reducing soil porosity.

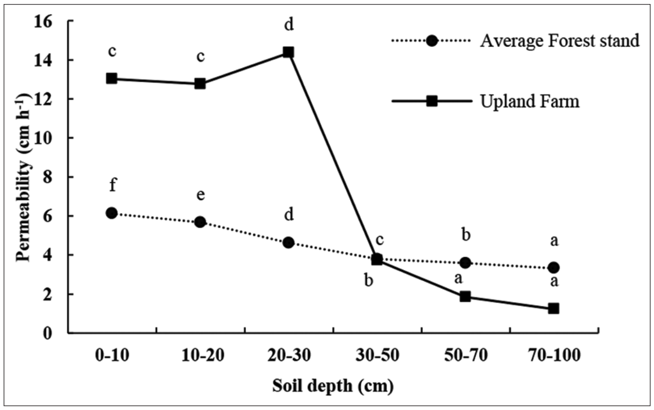

Figure 5: Average of soil permeability at 0-100 cm in soil depth between forest stands and upland farms. Different letters indicate significant differences among soil depth (DMRT α=0.05)

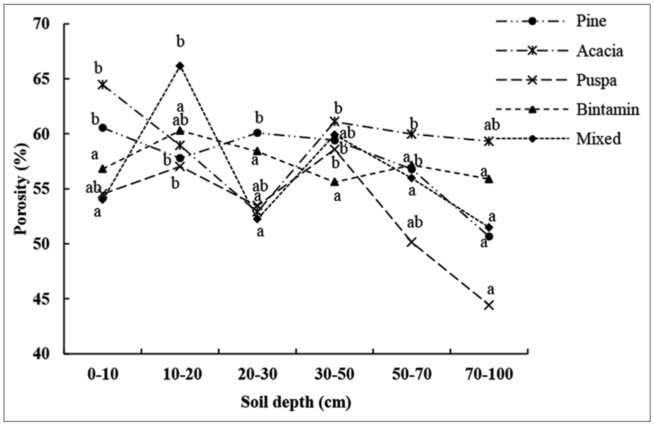

Figure 6: Soil porosity at 0-100 cm in soil depth different forest stands. Different letters indicate significant differences among soil depth (DMRT α=0.05)

Figure 7 shows a comparison of soil porosity values in forest stands and upland farms. Soil porosity on upland farms with the largest value is at a depth of 0-10 cm and the deeper the soil depth on upland farms has a soil porosity value that tends to be lower. According to Nita *et al.* (2015), soils that have undergone processing tend to have high soil porosity values. Tillage can make the soil structure loose and improve soil aeration. A decrease in the porosity value of Andisols soil at greater depths can be caused by tillage. Tillage can increase the porosity value at the top depth, but at the bottom depth, it will decrease the porosity value due to the pressure that causes soil compaction.

Relationship soil Physical Properties

Table 4 shows the results of the correlation test between observation parameters in various forest stands of Mount-Merbabu National Park and upland farms. Sand fraction was significantly and positively correlated with soil permeability in Pine stands (r=0.652**) and mixed stands (r=0.634**). While silt fraction was significantly and negatively correlated with permeability in Pine stands (r=-0.631**), Acacia stands (r=-0.519*), and mixed stands (r=-0.626**). This shows that soil particle size can affect soil permeability. According to Minangkabau *et al.* (2022), soil texture affects soil permeability. The coarser texture of the soil, the greater the soil permeability because water or air can enter through the soil pores because the soil is not tight. The finer the soil particles, the lower the permeability rate (Yulnafatmawita *et al.*, 2007).

Soil texture in Puspa stands, Bintamin stands, and upland farms showed no correlation with soil permeability. This could be because not only soil texture affects soil permeability. According

Table 3: Soil porosity at 0-100 cm soil depth in forest stands and upland farms

Soil depth (cm)	N	Pine	Acacia	Puspa	Bintamin	Mixed	Upland farms
		Porosity (%)					
0-10	3	60.54^{b}	64.45^{b}	54.53^{ab}	56.81^{a}	54.00^{a}	65.52^{b}
10-20	3	57.78^{b}	58.93^{ab}	57.02^{b}	60.28^{a}	66.17^{b}	57.99^{ab}
20-30	3	60.08^{b}	52.89^{a}	53.44^{ab}	58.40^{a}	52.24^{a}	57.35^{ab}
30-50	3	59.41^{b}	61.10^{b}	58.57^{b}	55.61^{a}	59.92^{ab}	56.39^{a}
50-70	3	56.78^{b}	59.97^{b}	51.29^{ab}	57.15^{a}	55.95^{a}	51.22^{a}
70-100	3	50.65^{a}	59.32^{ab}	44.41^{a}	55.88^{a}	51.49^{a}	51.49^{a}
SE (±)		1.03	1.09	1.58	1.18	1.63	1.45
Level of significance		*	*	ns	ns	*	*
CV%		5.58	6.02	10.71	9.88	9.57	7.80

Figures in a column having same letter (s) do not differ significantly according to DMRT. *=Significant at 5% level of probability, N=Number of samples, CV=Co-efficient of variation, SE=Standard error of means, ns=not significant

Table 4: Person's correlation test soil physical properties in forest stands and upland farms

Parameters	N		Sand	Silt	Permeability
Pine stands					
Silt	18	r	-0.961** (p=0.000)		
Permeability	18	r	0.652** (p=0.003)	-0.631**(p=0.005)	
Porosity	18	r	0.233 (p=0.352)	-0.261 (p=0.261)	0.618**(p=0.006)
Acacia stands					
Silt	18	r	-0.954** (p=0.000)		
Permeability	18	r	0.466 (p=0.051)	-0.519* (p=0,027)	
Porosity	18	r	-0.435 (p=0.071)	0.322 (p=0.193)	-0.289 (p=0.245)
Puspa stands					
Silt	18	r	-0.929** (p=0.000)		
Permeability	18	r	0.096 (p=0.706)	-0.046 (p=0.855)	
Porosity	18	r	-0.056 (p=0.826)	-0.180 (p=0.667)	0.342 (p=0.165)
Bintamin stands					
Silt	18	r	-0.880** (p=0.000)		
Permeability	18	r	0.200 (p=0.427)	-0.385 (p=0.114)	
Porosity	18	r	0.017 (p=0.947)	-0.049 (p=0.845)	0.147 (p=0.559)
Mixed stands					
Silt	18	r	-0.983** (p=0.000)		
Permeability	18	r	0.634** (p=0.005)	-0.626** (p=0.005)	
Porosity	18	r	0.226 (p=0.368)	-0.216 (p=0.390)	0.369 (p=0.132)
Upland farms					
Silt	18	r	-0.954** (p=0.000)	1	
Permeability	18	r	0.324 (p=0.190)	-0.400 (p=0.100)	1
Porosity	18	r	0.062 (p=0.808)	-0.188 (p=0.454)	0.639** (p=0.004)

N=Number of samples, r=Correlation coefficient, *=Significant (<0.05), **=Significant (<0.01)

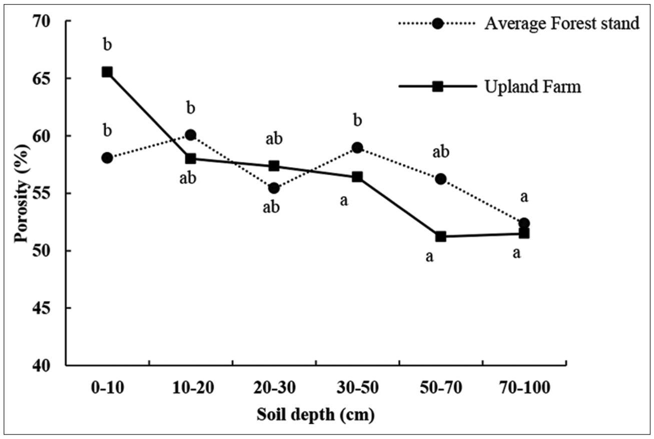

Figure 7: Average of soil porosity at 0-100 cm in soil depth between forest stands and upland farms. Different letters indicate significant differences among soil depth (DMRT α=0.05)

to Patterson (2021), it is important to note that soil permeability is not only determined by soil texture, but also by other factors such as soil structure, organic matter content, and the presence of root channels and soil biota. Therefore, although soil texture is a key factor in determining soil permeability, it must be considered together with other soil properties to accurately assess soil permeability.

The relationship between porosity and permeability can be seen in Pine stands (r=0.618**) and upland farms (r=0.639**) which shows a significant and positive correlation, which means that the higher the porosity, the higher the soil permeability (Table 4). According to Zheng *et al.* (2018), the relationship between porosity and permeability is linear, so if porosity is high then permeability will also be high. The more porous a soil is, the greater its permeability as long as the pores are interconnected. Soil porosity affects water storage, while soil permeability affects soil water movement and flow. Therefore, soils with high porosity and well-connected pore spaces will have higher permeability.

Sand, silt, and clay fractions in all forest stands and upland farms showed no correlation with soil porosity. According to Nimmo (2004), soil texture and porosity are two different soil properties that can be influenced by various factors. Porosity can change between different soil layers and solid rock types as you go deeper into the soil, and this depends on the size of the pore space and how well the layers are connected.

CONCLUSIONS

The sand and silt fractions show inversely proportional values. The clay fraction has the lowest value compared to the sand and silt fractions. The sand fraction content (soil depth 0-100 cm) on the upland farms is higher than the forest stands, while the forest stands has a higher silt fraction content (soil depth 0-100 cm) than the upland farms. Soil permeability rates tend to decrease with soil depth. Soil porosity fluctuated relatively in all stands but tended to decrease with soil depth. Sand fraction is positively correlated with soil permeability in Pine stands and mixed stands. Silt is negatively correlated with permeability in Pine stands and mixed stands. Soil porosity correlates with permeability in Pine stands and upland farms. Soil porosity was not correlated with soil texture in all forest and upland farms.

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