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Impact of Land Use on Soil Water Retention in Inceptisols of the Upper Konto Watershed

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ABSTRACT

The Upper Konto Watershed in Malang Regency is an area with various types of land use that have the potential to influence soil physical properties and soil water retention. Soil water retention is the ability of soil to absorb and retain water, which is closely related to the availability of water that plants can utilize. One of the soil types that dominate this region is inceptisol, which can face constraints in water retention, mainly when land use changes or inappropriate management practices occur. This study aims to analyze the impact of different types of land use on soil water retention characteristics in the Inceptisols of the Upper Konto watershed. The research method was conducted through field surveys and laboratory analysis. A survey was conducted on 16 Land Map Units (LMUs) derived from the overlay of land use, soil type, and slope maps. A total of 64 soil samples were collected for laboratory analysis. The observed variables included soil texture, bulk density, particle density, soil porosity, soil aggregate stability, soil organic matter, and soil water retention at pF 0, 2.5, and 4.2. The results revealed that land use types have a significant influence on soil physical properties as well as water retention characteristics. Specifically, it was found that forest land with the Udic Eutrandepts soil type had the highest water retention capability (0.39 $cm^3 cm^{-3}$). In comparison, dry farmland with the same soil type had the lowest water retention capability (0.06 $cm^3 cm^{-3}$). These findings illustrate the stark differences in the ability of soils to retain water between different land use types.

Keywords: Land use, soil water retention, soil physical properties

INTRODUCTION

The ability of soil to absorb and retain water necessary for plant growth is a critical component of soil health and productivity. Differences in soil water retention reflect the functions of soil hydrological and ecological influences (Yi et al., 2012). Knowledge of soil water retention properties is a critical parameter in soil and water management practices for sustainable agriculture (Shwetha and Varija, 2015).

The Upper Konto watershed is diverse in *landform*, potentially resulting in differences in land use (Kurniawan et al., 2010). This watershed had a considerable change in land cover during the 15 years between 1990 and 2005. The most significant percentage reduction occurred in forest land cover, which was 6,800 ha in 1990 and only 5,000 ha in 2005 (Suprayogo, 2017). According to Perhutani KPH Malang (2011), about 25% of the original trees in the Konto watershed have been cut down. The base area reduction rate is about 8% per year. The soil physical properties and water retention capacity of the Upper Konto watershed are likely to be affected by land use change.

Inceptisols are one of the soil types found in the Upper Konto watershed. These soils are relatively young with a moderate level of development, so the physical and chemical characteristics of the soil are essential in determining water retention. Soil water retention in inceptisols can be a problem, especially if there is a change in land use or improper management practices. Improper agricultural practices can impair the ability of inceptisols to store water, resulting in drought or excess water problems in agricultural fields (Zhang et al., 2018). Similarly, improper tillage practices and fertilizer use can reduce the soil's ability to store water in inceptisols used for agriculture (Liu et al., 2020). This study aims to analyze the impact of land use on soil water retention in the Inceptisols of the Upper Konto watershed of Malang Regency.

MATERIALS AND METHODS

Place and Time of Research

The research was done in the Upper Konto watershed covering Pujon District and Ngantang District (Figure 1) in Malang Regency in October - November 2022. The Upper Konto watershed covers an area of approximately 23,804 hectares (Kurniawan et al., 2010). The Upper Konto watershed is geographically situated between 655000 to 665000 meters East and 9132000 to 9142000 meters North within zone 49 (Wijaya, 2010).

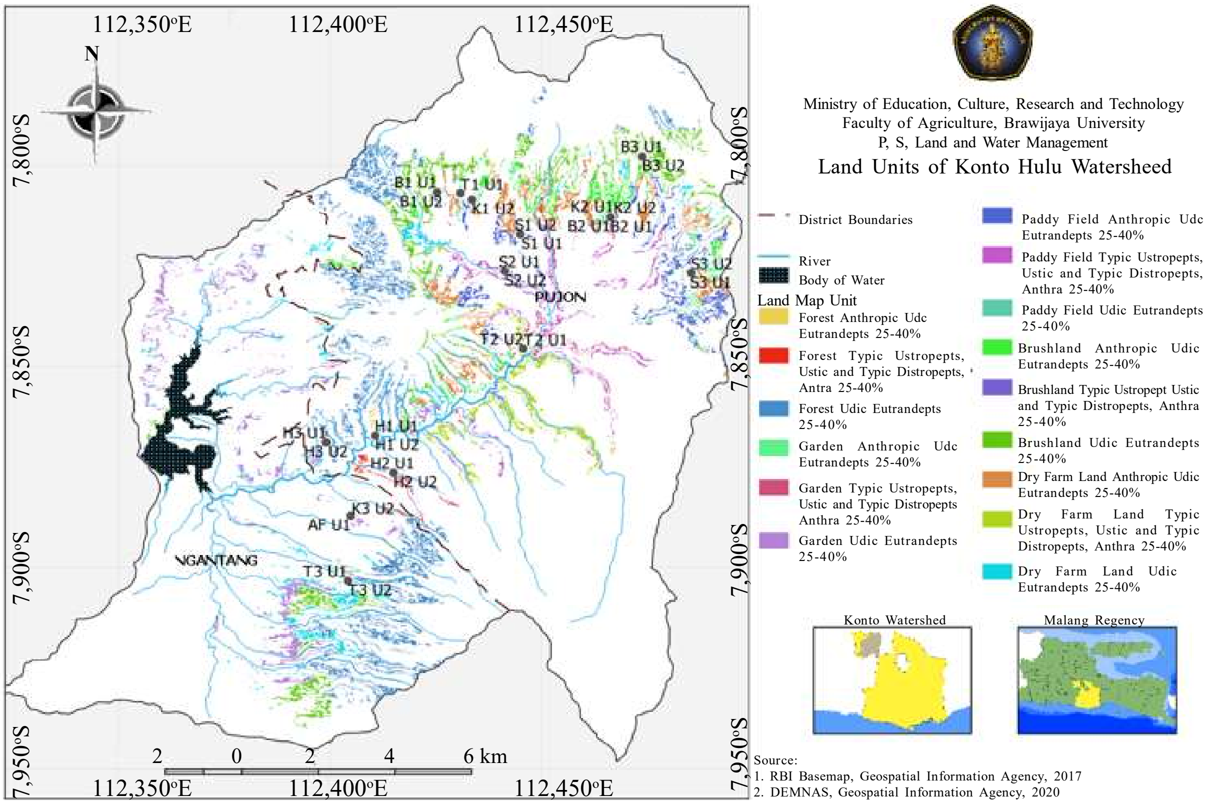
Research Design and Implementation

The research design used a group randomized design at 16 points of the Land Map Unit (SPL) based on six types of land use: (1) forest,(2) pine garden, dry farm land, paddy field, brushland, and (6) agroforestry. The soil sampling method is conducted intetionally (purposive sampling), taking into account specific factors in the process of selecting or determining samples in line with the research objectives (Baso et al., 2014). The soil types selected were Anthropic Udic Eutrandepts, Typic Ustropepts, and Udic Eutrandepts. The location is on a 25-40% slope (steep). Soil samples were taken at 0-30 cm and 30-60 cm. According to Suganda et al. (2006), the soil samples taken were *undisturbed* and *disturbed*.

Laboratory Analysis

Laboratory analysis was conducted at the Soil Physics Laboratory and Soil Chemistry Laboratory, Faculty of Agriculture, Universitas Brawijaya, from January to April 2023. The analysis included texture analysis (pipette method), bulk density (ring gravimetric method), soil density (pycnometer volumetric method), porosity, aggregate stability (wet sieve method), and soil C-organic analysis (Walkey and Black method).

Soil water retention was analyzed using the methods pioneered by Richards and Fireman (1943), which apply pressure to soil samples using specialized equipment, including an automatic compressor, a pressure plate apparatus, and a pressure membrane apparatus.



Source:
1. RBI Basemap, Geospatial Information Agency, 2017
2. DEMNAS, Geospatial Information Agency, 2020
3. Field Data, Ermawati, 2023
4. Soil Type, Faculty of Agriculture, Brawijaya University

Figure 1. Land Map Units of Konto Watershed.

Retention values were assessed at pressures of 0 atm (pF 0), 0.33 atm (pF 2.54), and 15 atm (pF 4.2). For pF 0, the sample is fully saturated by immersing it in water to about 3/4 of the container's height for 24 hours or until the soil is completely saturated. For pF 2.54, a pressure plate apparatus applies a pressure of 0.33 atm (344 cm of water column height) for approximately one week to reach equilibrium. At pF 4.2, either the pressure plate or pressure membrane apparatus applies 15 atm (15,495 cm of water column height) for another week.

Data Analysis

The data obtained during the study were tabulated using the Microsoft Excel program. Data were subjected to a normality test (Saphiro-Wilk normality test) and then to a Multivariate Analysis of Variance (MANOVA) at the 5% level and Duncan's Multiple Range Test (DMRT). The relationship between observation parameters was tested with a Pearson correlation and regression test to determine the influence between observation parameters.

RESULTS AND DISCUSSION

Land Use and Soil Physical Properties

At a depth of 0-30 cm (Figure 2), the land use with the highest percentage of sand was Anthropic Udic Eutrandepts brushland (37.99%). In contrast, the lowest percentage of sand was Anthropic Udic Eutrandepts paddy fields (7.76%). The highest percentage of silt was in the Udic Eutrandepts pine garden (47.6%), while the lowest percentage of silt was in the Typic Ustropepts pine garden (17.88%). The highest clay percentage was the Typic Ustropepts pine garden (58.01%), while the lowest was the Udic Eutrandepts forest (17.53%).

At a depth of 30-60 cm (Figure 3), the land use with the highest percentage of sand was Anthropic Udic Eutrandepts dry farmland (37.08%), while the lowest percentage of sand was Anthropic Udic Eutrandepts paddy field (6.34%). The highest percentage of silt is in the Udic Eutrandepts forest (51.37%), while the lowest percentage of silt is in the Anthropic Udic Eutrandepts pine garden (22.39%). The highest percentage of clay was in the Anthropic Udic Eutrandepts paddy field (64.73%), while the lowest was in the Udic Eutrandepts forest (19.16%).

Different land uses vary in the composition of sand, silt, and clay fractions. This variation shows that soil composition can be influenced by land use, soil management, and other environmental factors. Supported by research by Emile et al. (2013) in Senegal, they found that converting forest land into peanut fields caused changes in soil texture. Delsiyanti's (2016) research on six different land units also showed varying sand, silt, and clay fractions percentages. Particle size distribution varies widely due to the interaction effect of land use, soil type, and soil depth.

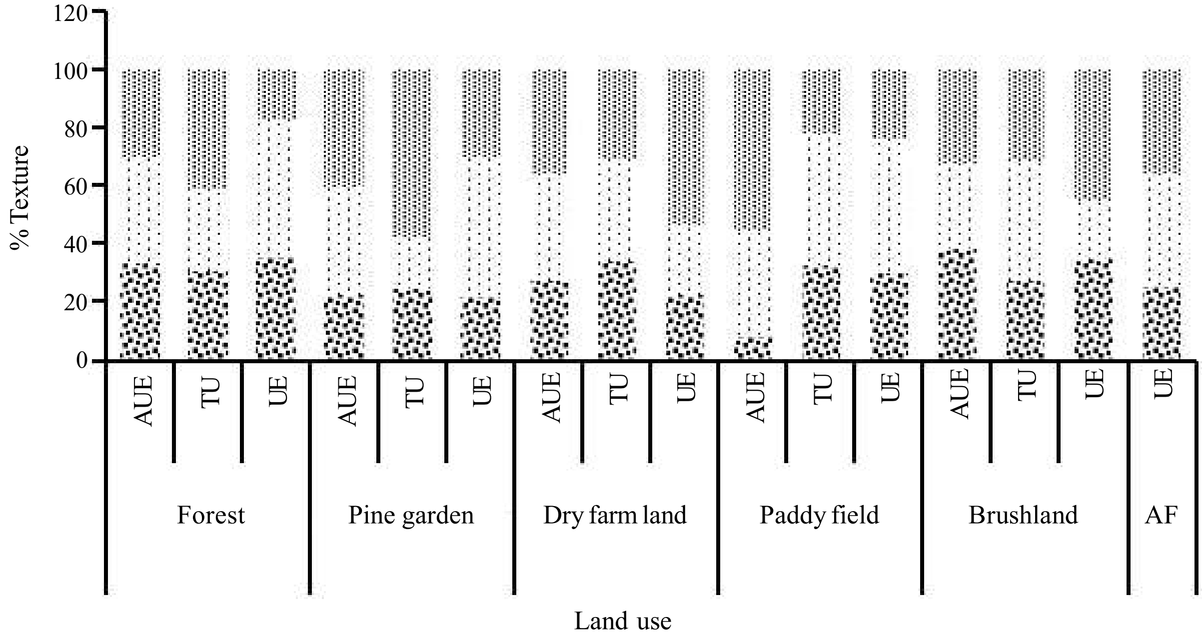


Figure 2. Soil texture at 0-30 cm depth. Description: AUE: Anthropic Udic Eutrandepts; TU: Typic Ustropepts; UE: Udic Eutrandepts. ▩ : % sand, ⁝ : %silt, ▦ : % clay.

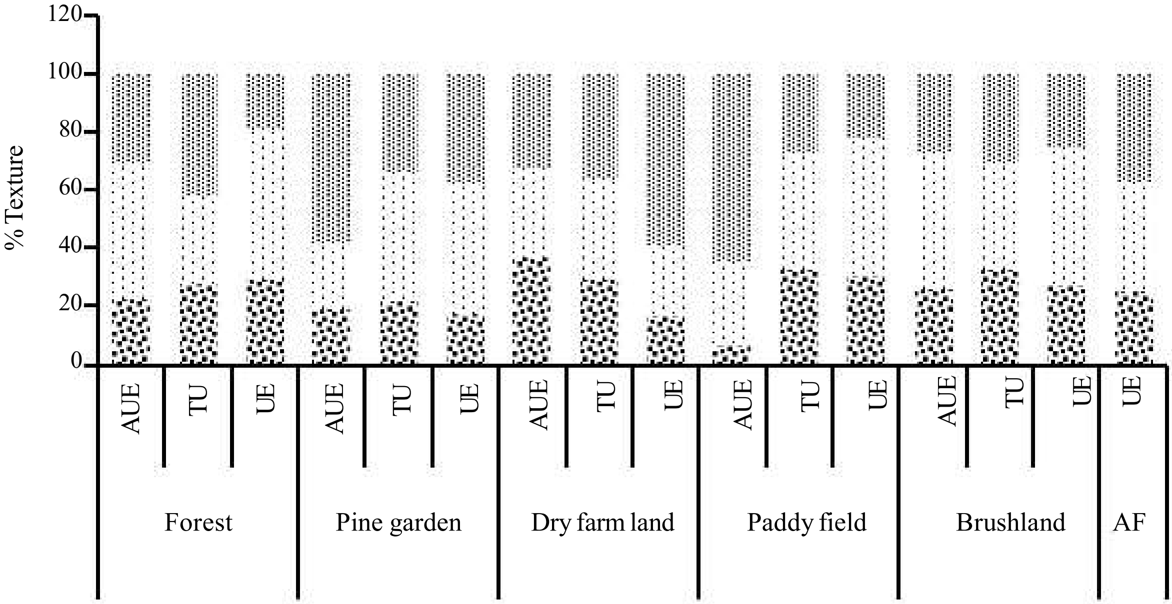


Figure 3. Soil texture at 30-60 cm depth. Description: AUE: Anthropic Udic Eutrandepts; TU: Typic Ustropepts; UE: Udic Eutrandepts. ▩ : % sand, ⁞ : %silt, ▦ : % clay.

Land use significantly influenced the value of soil bulk density, soil density, soil porosity, soil aggregate stability, and soil organic matter content (Table 1). Soil bulk density in forest land use is relatively lower than other land uses at depths of 0-30 cm and 30-60 cm. The highest soil bulk density value was found in the land use of Udic Eutrandepts dry farmland (1.11 g cm^{-3}), which is not significantly different from other soil types and the Anthropic Udic Eutrandepts brushland. The lowest soil bulk density value was in forest Anthropic Udic Eutrandepts (0.72 g cm^{-3}), which is not significantly different from other soil types and agroforestry Udic Eutrandepts. Forests have relatively lower soil bulk density values compared to other land uses at depths of 0-30 cm and 30-60 cm. It indicates that soils from the natural forest have a higher concentration of nutrients and better physical conditions when compared to the other land use types (Asmare et al., 2023).

It is supported by research by Nanganoa et al. (2019) that land use influences soil bulk density. Research by Keesstra et al. (2016) found that increasing vegetation cover can decrease soil bulk density under various soil management techniques. The research results by Rezaei et al. (2018) showed that agricultural lands, such as pine gardens and dry farmlands, have higher soil bulk density than natural lands, such as forests. Shete et al. (2016) also showed that seasonal plantation crops increase the frequency of soil disturbance, thereby affecting the bulk density of the soil.

Land use has a significant effect on soil aggregate stability. Forest land had a higher DMR (diameter of mean mass) index than other types of land use. The DMR value was highest in Typic Ustropepts forest (4.28 mm) and not significantly different from Udic Eutrandepts agroforestry. Compared to other land use types, the DMR index of paddy fields has the lowest value. The lowest DMR value is in Typic Ustropepts paddy fields (1.33 mm). Referring to the classification of Islami and Utomo (1995), generally, the stability of aggregates in the study site, which ranged from 1.33 mm to 4.28 mm, is included in the stable and very stable classes.

Forest land use has the highest DMR index. Forests have a higher input of soil organic matter content than others, increasing the soil's aggregation process. In addition, forests are thought to have more plants and roots, contributing to soil aggregation and aggregate stability. Previous research has shown that forest vegetation can increase soil aggregation, improve soil physical properties, and reduce soil erosion (Misra et al., 2020). Paddy fields have the lowest DMR index compared to other uses due to the need for more human processing activities to add organic matter as an adhesive material for soil aggregation (Isnawati, 2018). Previous research by Ghazavi et al. (2016) found that the intensity of tillage in wetland agriculture can cause a decrease in soil aggregation and increase erosion.

In all land uses, soil organic matter content values ranged from 0.77% to 2.34%. These values

Table 1. Soil bulk density, soil density, soil porosity, DMR index, and organic matter of soils in different land use types.

Land Use	Soil Bulk Density (g cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.74^{a}	0.72^{a}	0.8^{a}	0.78^{a}	0.8^{a}	0.74^{a}
Pine Garden	0.95^{cde}	1.02^{cde}	1.05^{e}	1.03^{e}	0.97^{bc}	0.84^{ab}
Dry Farm Land	0.94^{cde}	0.98^{cde}	0.94^{cde}	0.98^{cde}	1.11^{e}	1^{e}
Paddy Field	0.94^{de}	1.09^{de}	1.09^{e}	0.82^{ab}	0.81^{ab}	0.83^{ab}
Brushland	1.04^{e}	1^{e}	0.96^{cd}	0.91^{cd}	0.75^{a}	0.75^{a}
Agroforestry					0.8^{a}	0.78^{a}

Land Use	Soil Density (g cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	2.16	2.19	2.26	2.31	2.37	2.28
Pine Garden	2.19	2.25	2.35	2.23	2.3	2.31
Dry Farm Land	2.36	2.22	2.27	2.22	2.31	2.23
Paddy Field	2.48	2.32	2.43	2.26	2.11	2.11
Brushland	2.04	2.16	2.18	2.28	2.21	2.28
Agroforestry					2.34	2.39

Land Use	Porosity (%)					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	65.68^{f}	67.16^{f}	64.82^{f}	66.21^{f}	66.32^{f}	67.51^{f}
Pine Garden	56.58^{bcd}	54.63^{bcd}	55.09^{abc}	53.89^{abc}	57.89^{e}	63.64^{e}
Dry Farm Land	58.42^{bcde}	55.99^{bcde}	58.42^{bcde}	55.99^{bcde}	51.81^{ab}	55.29^{ab}
Paddy Field	53.21^{bcde}	53.21^{bcde}	55.02^{de}	63.68^{de}	61.8^{e}	60.46^{e}
Brushland	49.07^{a}	53.45^{a}	55.78^{cde}	60.38^{cde}	66.36^{f}	67.27^{f}
Agroforestry					66.02^{f}	67.42^{f}

Land Use	DMR (mm)					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	3.88^{fg}	3.49^{fg}	4.25^{g}	4.28^{g}	4.23^{g}	3.89^{fg}
Pine Garden	3.65^{ef}	3.32^{ef}	3.22^{bc}	2.13^{bc}	2.58^{b}	2.51^{b}
Dry Farm Land	3.04^{cd}	3.04^{cd}	2.73^{bcd}	2.73^{bcd}	2.32^{ab}	2.58^{b}
Paddy Field	1.37^{a}	1.58^{a}	1.33^{a}	1.53^{a}	1.39^{a}	1.58^{a}
Brushland	2.7^{bcd}	2.73^{bcd}	3.14^{de}	3.14^{de}	3.14^{de}	3.14^{de}
Agroforestry					3.89^{fg}	3.89^{fg}

Land Use	Soil Organic Matter (%)					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	2.21^{g}	2.15^{g}	2.08^{g}	2.34^{g}	2.03^{f}	2.02^{f}
Pine Garden	1.81^{e}	1.8^{e}	1.81^{e}	1.82^{e}	1.8^{e}	1.77^{e}
Dry Farm Land	1.06^{cd}	0.93^{cd}	1.05^{cd}	0.94^{cd}	0.95^{ab}	0.84^{ab}
Paddy Field	0.93^{ab}	0.82^{ab}	0.91^{a}	0.77^{a}	0.9^{bc}	0.99^{bc}
Brushland	1.03^{cd}	0.93^{cd}	1.04^{cd}	0.93^{cd}	1.06^{d}	0.98^{d}
Agroforestry					2.12^{g}	2.09^{g}

Note: Numbers accompanied by unequal letters in the same column indicate significant differences through the DMRT test .

include very low to medium criteria based on the classification by Agus (2005). Forests have a higher soil organic matter content than other land use types. Soil organic matter content in forests ranged from 2.02% to 2.34%. The highest soil organic matter content was found in Typic Ustropepts forest (2.34%), which is not significantly different from Udic Eutrandepts agroforestry. Paddy fields and dry farmlands have soil organic matter content that tends to be lower than other land uses. Soil organic matter content in paddy fields ranged from 0.77% to 0.99%. The lowest soil organic matter content in Typic Ustropepts paddy fields (0.77%) is similar to Udic Eutrandepts dry farmlands.

Land use has an impact on macro, meso, and micropores. Forests, brushlands, and agroforestry have higher macro and meso pore values than other land use types. Macro pores are highest in Anthropic Udic Eutrandepts forest (0.36 cm^3 cm^{-3}), and meso pores are highest in Udic Eutrandepts agroforestry (0.44 cm^3 cm^{-3}). Paddy fields and dry farmlands tend to have low macro and meso pore compared to other land uses. Macro pores are lowest in Anthropic Udic Eutrandepts paddy fields (0.08 cm^3 cm^{-3}), and meso pores are lowest in Udic Eutrandepts dry farmlands (0.06 cm^3 cm^{-3}). Micro pores were highest in Udic Eutrandept's dry farmland (0.44 cm^3 cm^{-3}) and lowest in Udic Eutrandept brushland (0.19 cm^3 cm^{-3}). The distribution values of soil pore distribution on land use, soil type, and soil depth are presented in Table 2.

Effect of Land Use on Available Water Retention

Forests and agroforestry can retain soil water under moist, slightly dry, and dry conditions and have high available water retention. In contrast, land uses such as dry farm land, paddy fields, pine gardens, and brushland tend to have lower soil water retention. Land use treatments significantly affected water retention at pF 0, 2.5, 4.2, and available water. Water

Table 2. Scatter values of soil pore distribution in different types of land use.

Land Use	Macro Pore (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.36^{g}	0.29^{efg}	0.35^{g}	0.27^{bcde}	0.31^{defg}	0.22^{defg}
Pine Garden	0.19^{abc}	0.13^{abc}	0.19^{abc}	0.26^{cdef}	0.29^{defg}	0.27^{defg}
Dry Farm Land	0.18^{bcde}	0.19^{bcde}	0.29^{bcde}	0.1^{bcde}	0.14^{ab}	0.21^{abcd}
Paddy Field	0.08^{a}	0.09^{a}	0.09^{ab}	0.14^{ab}	0.08^{a}	0.09^{a}
Brushland	0.35^{g}	0.34^{g}	0.25^{cdef}	0.24^{cdef}	0.35^{g}	0.26^{fg}
Agroforestry					0.17^{abcd}	0.19^{abcd}
Land Use	Meso Pore (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.33^{e}	0.3^{cde}	0.29^{bcde}	0.27^{bcde}	0.39^{e}	0.21^{cde}
Pine Garden	0.15^{ab}	0.19^{ab}	0.13^{abc}	0.26^{abc}	0.24^{bcd}	0.27^{bcd}
Dry Farm Land	0.21^{bc}	0.2^{bc}	0.15^{ab}	0.19^{ab}	0.06^{a}	0.11^{a}
Paddy Field	0.19^{ab}	0.21^{bc}	0.28^{bc}	0.22^{bc}	0.19^{ab}	0.21^{bc}
Brushland	0.37^{e}	0.33^{e}	0.29^{bcde}	0.31^{cde}	0.32^{de}	0.36^{e}
Agroforestry					0.29^{bcde}	0.44^{de}
Land Use	Micro Pores (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.25^{abc}	0.29^{abc}	0.25^{ab}	0.26^{ab}	0.26^{bc}	0.31^{bc}
Pine Garden	0.39^{d}	0.34^{d}	0.29^{bc}	0.29^{bc}	0.26^{bc}	0.31^{bc}
Dry Farm Land	0.27^{bc}	0.32^{bc}	0.34^{cd}	0.34^{cd}	0.36^{d}	0.44^{d}
Paddy Field	0.3^{cd}	0.39^{d}	0.28^{bc}	0.28^{bc}	0.36^{d}	0.39^{d}
Brushland	0.23^{ab}	0.23^{ab}	0.28^{bc}	0.29^{bc}	0.23^{ab}	0.19^{a}
Agroforestry					0.22^{ab}	0.22^{ab}

Description: Numbers accompanied by unequal letters in the same column indicate significant differences through the DMRT test.

retention at pF 0 was highest in the Udic Eutrandepts forest (0.96 cm^3 cm^{-3}) and lowest in the Udic Eutrandepts paddy field (0.63 cm^3 cm^{-3}). Water retention pF 2.5 was highest in the Udic Eutrandepts forest (0.66 cm^3 cm^{-3}) and lowest in the Typic Ustropepts paddy field (0.42 cm^3 cm^{-3}). Water retention pF 4.2 was highest in Udic Eutrandepts dry farmland (0.44 cm^3 cm^{-3}) and lowest in Udic Eutrandepts brushland (0.19 cm^3 cm^{-3}). The results of this study show that land use significantly influences soil water retention at different levels of water potential and available water (Table 3).

Available water retention is calculated as the difference between field capacity and permanent wilting point. Forests, brushlands, and agroforestry tend to have higher available water retention than other land uses. Available water was highest in Udic Eutrandepts forest (0.39 cm^3 cm^{-3}). Paddy fields and pine gardens tend to have low available water retention. The lowest available water is in Udic

Table 3. Soil water retention values (pF 0; 2.5; 4.2) and available water in different land use type.

Land Use	Soil Water Retention at pF 0 (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.94^{de}	0.88^{cd}	0.89^{cd}	0.8^{cd}	0.96^{e}	0.74^{cd}
Pine Garden	0.73^{ab}	0.66^{ab}	0.61^{ab}	0.8^{cd}	0.79^{ab}	0.85^{cd}
Dry Farm Land	0.66^{ab}	0.71^{ab}	0.78^{ab}	0.63^{ab}	0.66^{ab}	0.66^{ab}
Paddy Field	0.66^{ab}	0.69^{ab}	0.65^{a}	0.64^{a}	0.63^{a}	0.69^{ab}
Brushland	0.95^{e}	1^{e}	0.82^{cd}	0.84^{cd}	0.90^{cd}	0.81^{cd}
Agroforestry					0.68^{bc}	0.85^{cd}

Land Use	Soil Water Retention at pF 2.5 (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.58^{c}	0.59^{c}	0.54^{abc}	0.53^{abc}	0.66^{d}	0.52^{c}
Pine Garden	0.54^{abc}	0.53^{abc}	0.42^{a}	0.55^{a}	0.5^{abc}	0.58^{abc}
Dry Farm Land	0.48^{ab}	0.52^{ab}	0.49^{abc}	0.53^{abc}	0.42^{a}	0.55^{a}
Paddy Field	0.55^{bc}	0.6^{bc}	0.56^{abc}	0.5^{abc}	0.55^{bc}	0.6^{bc}
Brushland	0.6^{c}	0.56^{c}	0.57^{c}	0.6^{c}	0.55^{c}	0.55^{c}
Agroforestry					0.51^{c}	0.55^{c}

Land Use	Soil Water Retention at pF 4.2 (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.25^{abc}	0.29^{abc}	0.25^{ab}	0.26^{ab}	0.26^{bc}	0.31^{bc}
Pine Garden	0.39^{d}	0.34^{d}	0.29^{bc}	0.29^{bc}	0.26^{bc}	0.31^{bc}
Dry Farm Land	0.27^{bc}	0.32^{bc}	0.34^{cd}	0.34^{cd}	0.36^{d}	0.44^{d}
Paddy Field	0.36^{d}	0.39^{d}	0.28^{bc}	0.28^{bc}	0.36^{d}	0.39^{d}
Brushland	0.23^{ab}	0.23^{ab}	0.28^{bc}	0.29^{bc}	0.23^{a}	0.19^{a}
Agroforestry					0.22^{ab}	0.22^{ab}

Land Use	Soil Available Water (cm^3 cm^{-3})					
	Anthropic Udic Eutrandepts		Typic Ustropepts		Udic Eutrandepts	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Forest	0.33^{e}	0.3^{cde}	0.29^{bcde}	0.27^{bcde}	0.39^{e}	0.21^{cde}
Pine Garden	0.15^{ab}	0.19^{ab}	0.13^{abc}	0.26^{abc}	0.24^{bcd}	0.27^{bcd}
Dry Farm Land	0.21^{bc}	0.2^{bc}	0.15^{ab}	0.19^{ab}	0.06^{a}	0.11^{a}
Paddy Field	0.19^{ab}	0.21^{bc}	0.28^{bc}	0.22^{bc}	0.19^{ab}	0.21^{bc}
Brushland	0.37^{e}	0.33^{e}	0.29^{bcde}	0.31^{cde}	0.32^{de}	0.36^{e}
Agroforestry					0.29^{bcde}	0.33^{e}

Note: Numbers accompanied by unequal letters in the same column indicate significant differences through the DMRT test.

Eutrandepts dry farmland (0.06 cm^3 cm^{-3}). The conversion of forests into agricultural land significantly increased surface runoff, while soil water content decreased (Truong et al., 2022). Agricultural practices such as fertilizer use and excessive irrigation can alter soil's physical properties, reduce the ability of soil to store water, and reduce water availability (Lu et al., 2019). Land use practices can affect soil organic matter content loss through soil erosion and mineralization. Appropriate land use and soil management practices are required to maintain or improve soil water retention capacity (Mudgal et al., 2014).

Factors Affecting Available Water

Soil bulk density was negatively correlated with available water (r= -0.323**, $p<0.01$). It means an inverse relationship exists between soil bulk density and available water. Soil bulk density can affect water availability in a particular soil or substrate. The higher the bulk density of the soil, the more difficult it is for water to accumulate and become available to plants or other living organisms. Soil bulk density is one of the most important physical properties influencing soil water retention characteristics (Shwetha and Varija, 2015).

Soil bulk density is proportional to soil density, which indicates the proportion of solids and pore space in the soil. Soil bulk density has a negative effect on water retention; the higher the soil bulk density value, the lower the water retention. In line with research by Jensen et al. (2010), which involved the analysis of soil bulk density and water availability in soil, the results showed that soils with higher bulk density had relatively lower water contents. Under these conditions, water is not readily available to plants, and plant growth can be inhibited.

Soil porosity positively correlates with available water (r= -0.271*, $p<0.05$). It means that increasing soil porosity can increase available water. Porosity measures how much pore space or cavity exists in a material such as soil or substrate. Porosity can affect water availability in the soil because the pores can store and move water. Research by Vogel et al. (2010) showed that optimal soil porosity increased plant water availability and improved wheat productivity. Good porosity facilitates water movement, aeration, and root penetration, all contributing to adequate water availability. In addition, research by Ma et al. (2014) showed that the high porosity of the soil substrate increased water availability and good drainage, which positively impacted plant growth and health.

Aggregate stability is positively correlated with available water (r=0.241). It means the more stable the soil aggregates, the more available water. Soil aggregate stability refers to the strength and stability of the aggregate against erosion and degradation. Aggregate stability can affect water availability in the soil by affecting water infiltration, drainage, and storage capacity. In line with the research of Shao et al. (2023), there is a positive relationship between aggregate stability and water retention in sandy desert soils. Aggregate stability affects water infiltration and flow through the soil, affecting water retention. Soil aggregate stability directly impacts soil pore size distribution, which affects soil water retention and water movement in the soil, thereby affecting air movement.

Soil organic matter content is positively correlated with available water (r=0.208). It means that higher soil organic matter content can increase available water in line with the research of Zhang et al. (2020), who examined the relationship between soil organic matter content and soil water retention in various soil types. The results showed that soil organic matter content positively contributed to soil water retention, and the effect was more substantial in soils with higher clay content. In addition, Li et al. (2021) showed that soil organic matter positively impacts soil water retention, which in turn contributes to water availability for plants in the region. Regression between soil bulk density, soil porosity, DMR index, and soil organic matter content on soil water retention are described in Figure 4.

Different pore sizes are involved in various soil functions. Macropores (>50 nm diameter) play an essential role in protecting microorganisms due to the size of the accommodation (Quilliam et al., 2013). Mesopores (2 nm, diameter < 50 nm) and micropores (diameter < 2 nm) store water and solutes necessary for metabolic activities (Brewer, 2012). The relationship between these pores and soil moisture content is that macro pores, meso pores, and micropores each have an essential role in the storage and movement of water in the soil.

Macropores were positively correlated with available water (r=0.407**, $p<0.01$). It indicates that the more macropores in the soil, the higher the plant water availability. Pan et al. (2018) showed that macropores have a significant role in the water infiltration and soil drainage.

Available water equals mesopores, indicating that the presence of mesopores significantly influences water availability. Research by Douaik et al. (2020) observed mesopores' effect on soil water retention. This study showed that mesopores

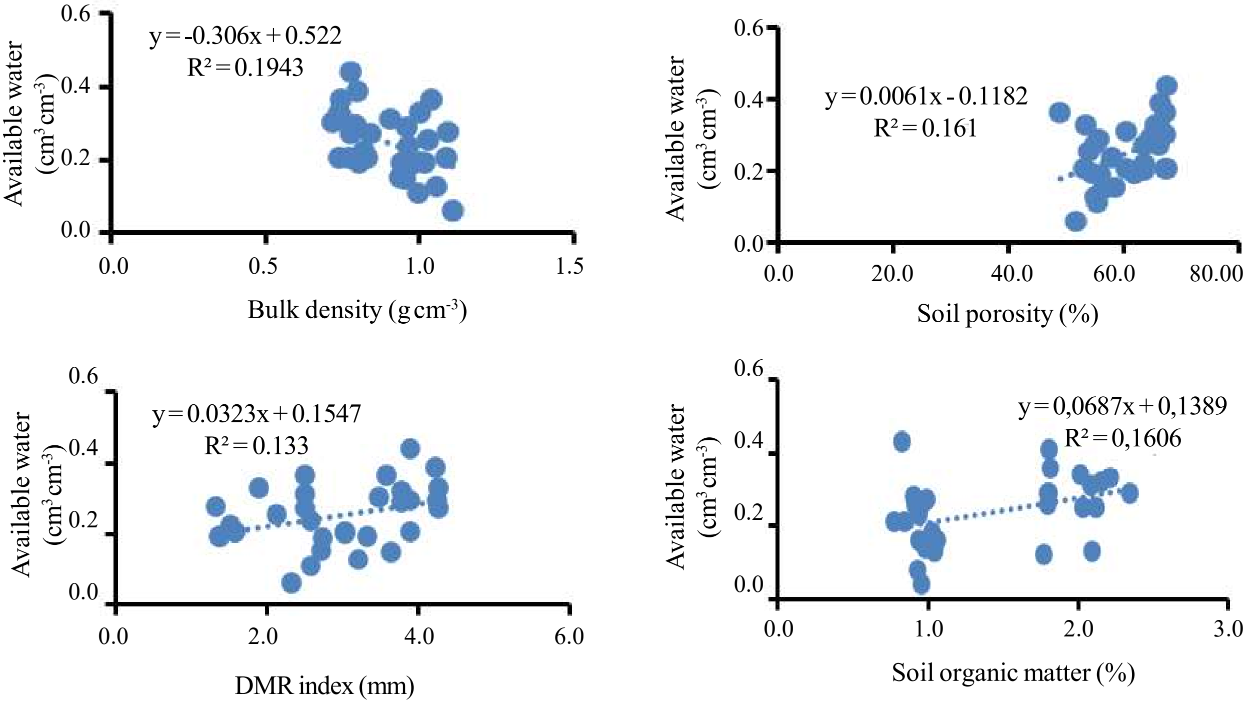


Figure 4. Regression between soil bulk density, soil porosity, DMR index, and soil organic matter content on soil water retention.

contribute to stable water retention and can be accessed by plants. Mesopores provide moderate water storage capacity, which supports water availability for plants in times of water shortage. In this study, micropores were strongly negatively correlated with available water (r= -0.785**, $p<0.01$), meaning that the higher the micropores, the lower the available water content. Schjønning et al. (2017) do not support the results, which showed that micropores are positively related to available water. However, other studies are similar. Research by Kay et al. (2014) looked at micropores' effect on soil water availability. This study showed that a high proportion of micropores in clay soil negatively affects plant water availability. Narrow micropores lead to poor water drainage and reduced availability of water accessible to plants. The regression of macropores and micropores to soil water retention is described in Figure 5.

CONCLUSIONS

Different land uses significantly impact soil physical properties, including bulk density, porosity, aggregate stability, organic matter content, and pore distribution. These changes directly affect the soil's water retention capacity at various pF (water potential) values. Udic Eutrandepts forests exhibit

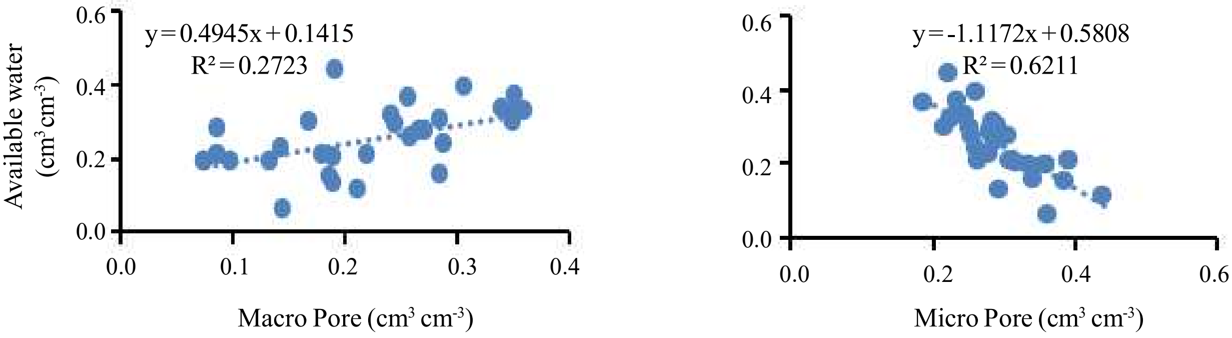


Figure 5. Regression of macropores and micropores to soil water retention.

the highest available water retention (0.39 cm^3 cm{ ^{3}), while Udic Eutrandepts cultivated fields show the lowest (0.06 cm^3 cm{ ^{3}). This disparity highlights the potential of forests to retain water within the soil profile and provide a more substantial water supply compared to other land uses. To ensure sustainable agriculture and environmental protection, it is crucial to implement sustainable land management practices that preserve and enhance soil water storage capabilities.

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