

Characterization and Classification of Soils under Various Land Use Types in Dalisodo Village, Wagir Sub-District, Malang Regency

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Abstract

This study aims to examine the physical and chemical properties of soil, morphology, and soil classification in Dalisodo Village, Wagir District, Malang Regency, and their implications for land management. Observations were conducted at three locations representing different land-use types: Napier grass monoculture, coffee agroforestry, and open grass. Soil morphology was described in the field, while physical and chemical analyses were conducted using standard laboratory methods. The results indicate that the soil is predominantly clay-textured, with a granular to subangular blocky structure, an acidic pH, and a very low to moderate organic carbon content. N, P, and K levels vary from low to moderate, CEC ranges from moderate to high, and base saturation ranges from low to very high. Soil classification reveals a dominance of Inceptisols and Vertisols in Udic soil moisture regimes, with soil profiles characterized by Typic Hapluderts (Point 1), Dystric Eutrudepts (Point 2), and Chromic Hapluderts (Point 3). These findings provide important information for land management, as vertisols require attention to drainage, water retention, and liming to optimize productivity. Inceptisols require organic amendments and soil fertility management to support sustainable agricultural or agroforestry systems. Emphasis on soil classification helps determine appropriate land management strategies, improves fertilizer efficiency, and supports the sustainability of the region's agricultural ecosystem.

1. Introduction

Soil classification is a fundamental tool for understanding soil properties and informing land management decisions. Proper knowledge of soil morphological and physiochemical characteristics is essential for sustainable agriculture, effective land-use planning, and informed local policy decisions. Soil consists of solid, liquid, and gaseous components, forming distinct layers through natural processes such as accumulation, decomposition, and transformation of organic and mineral materials (Soil Survey Staff, 2014). These processes result in diverse soil properties, including differences in texture, structure, color, and chemical composition, which in turn influence soil fertility, water retention, and suitability for various land uses (Herdiansyah et al., 2020). Accurate classification of soils based on these properties facilitates better understanding of land potential and constraints, allowing for more informed management decisions (Gyasi et al., 2023).

Assessment of soil development relies on both morphological and genetic criteria. Morphologically, soil is described based on the completeness of genetic horizons, horizon boundaries, and the depth of the solum. Genetically, it is evaluated through the degree of weathering and changes in physical, chemical, and mineralogical properties (Manik et al., 2017). Knowledge of soil morphology provides insights into the evolutionary processes within the soil body, helping to interpret past and present soil formation conditions and serving as essential information for soil classification (Iyanti et al., 2023). Such information is critical for linking soil characteristics to land-use planning, sustainable agriculture, and environmental management.

The balance between land use and land's capacity to support it is a key factor in determining appropriate land management strategies. Exceeding the land's carrying capacity can lead to decreased productivity, land degradation, and compromise sustainable agricultural practices (Moniaga, 2011). Soil classification, therefore, is not only a scientific exercise but also a practical tool for regulating land use, optimizing productivity, and ensuring sustainability (Rajamuddin, 2014). Standardized soil names and classifications also facilitate communication among soil scientists and practitioners worldwide, enable evaluation and comparison of land management strategies, and reflect the level of advancement in soil science and technology within a region (Subardja et al., 2014).

Despite the availability of general soil data for Malang Regency, detailed information on the morphological and physicochemical properties of soils under different land-use types in Dalisodo Village, Wagir, Sub-District, is lacking. This gap limits the ability to implement effective land management strategies, optimize agricultural practices, and support local policy development. Establishing a baseline database of soil characteristics in the village is, therefore a crucial first step in guiding sustainable agricultural development (Lobry de Bruyn & Prager, 2024). This study aims to characterize the morphological and physicochemical properties of soils under various land use types in Dalisodo Village. The findings are expected to provide practical recommendations for sustainable land management, crop selection, and soil conservation practices, while contributing to the scientific understanding of soil variability and classification in the region.

2. Research Methods

2.1. Research Location

The research was conducted from June to September 2024 at Dalisodo Village, Wagir Sub-District, Malang Regency. The village boasts a diverse topography, comprising upper, middle, and lower slope positions, which significantly influence soil formation and land use. Three representative profile points were selected to capture the variability in land use: Point 1 is cultivated with Napier grass (used as fodder), Point 2 features young coffee agroforestry combined with banana, river tamarind, and cassava, and Point 3 is covered with natural grass, which is not actively managed.

The distribution of profile points is presented in Figure 1, while the detailed location and environmental conditions of the soil sampling are shown in Table 1. The study focuses on describing soil morphological properties and presenting the results of physical and chemical soil analyses. This location provides a representative setting for examining the relationship between soil characteristics and land use in the village.

Table 1. Location of soil profiles in Agroedupark Wagir

Observation code	Coordinate(Lat., Long)	Elevation (masl)	Vegetation (Land Use)
Point 1	7°59'16.53" S 112°33'57.34" E	583	Monoculture Napier grass (<i>Pennisetum purpureum</i>)
Point 2	7°59'16.35" S 112°33'58.49" E	605	Coffee, Leuceaena, Cassava, Banana
Point 3	7°59'21.00" S 112°33'57.13" E	610	Open grassland

2.2. Field Observation

The study involved characterizing and describing soil profiles, sampling the soil, and analyzing its physical and chemical properties. Characterization and description were conducted on three soil profiles. Soil samples were taken from the horizons identified in these 3 soil profiles for laboratory analysis. The required climate data, including rainfall and humidity, were collected over the last 10 years (2014-2024) from online data sources of the Meteorology, Climatology, and Geophysics Agency (MCGA/BMKG) at the Karangploso station in Malang Regency. The data were tabulated and processed using the Java Newhall Simulation Model (jNSM) version 1.6.1, a soil climate simulation model, to determine the soil moisture and soil temperature regimes.

2.3. Data Analysis

Laboratory analysis of soil samples encompassed both physical and chemical properties of the soil. These analyses were conducted at the Soil and Agronomy Laboratory of Tribhuwana Tungadewi University, Malang and the Agricultural Instrument Standardization Agency (AISA/BSIP), East Java. The methods for analyzing soil samples and evaluating the results of chemical soil properties followed the technical guidelines for chemical analysis of soil, water, and fertilizers by Eviati et al. (2023).

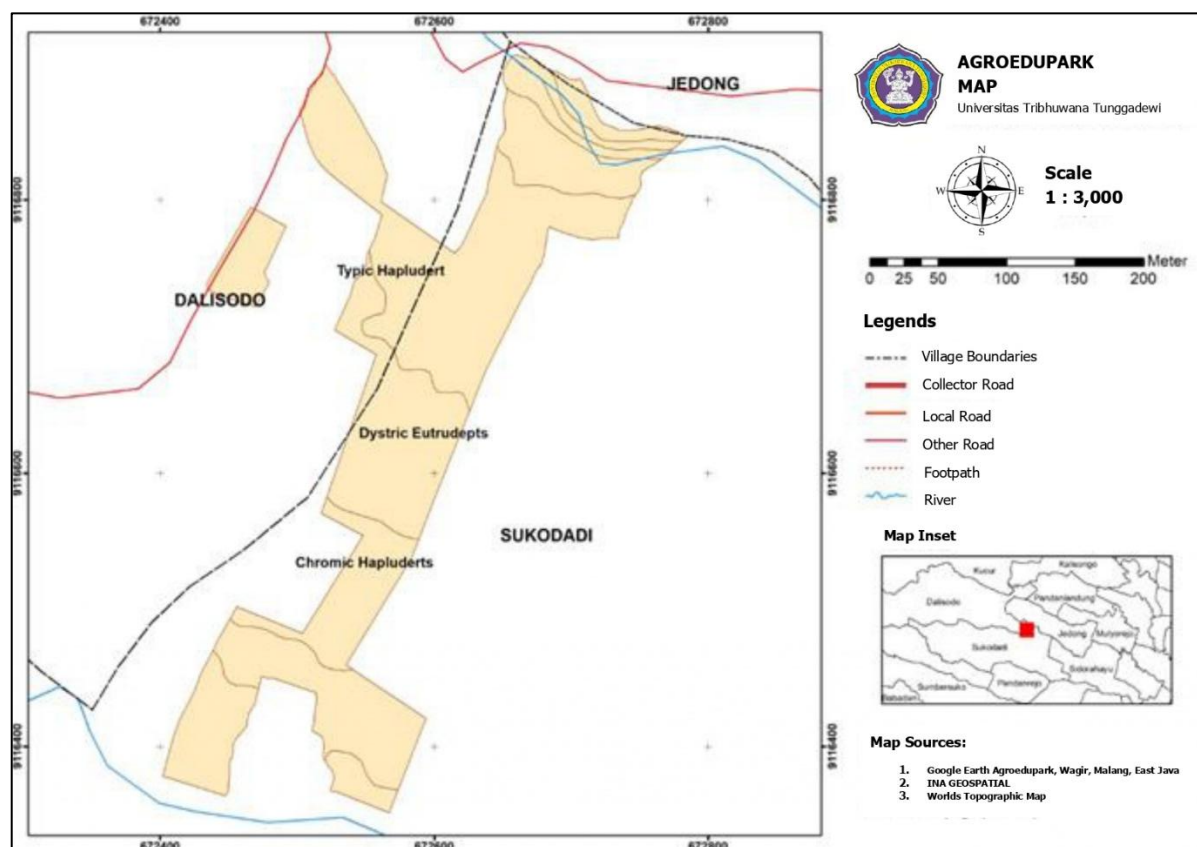


Figure 1. Location of the study site and soil sampling

Analysis methods included: determining soil texture (sand, silt, clay fractions) using the hydrometer method, pH in H₂O and KCl (sample to solvent ratio 1:2.5), Organic C (Walkley and Black), Total N (Kjeldahl), Total P (25% HCl), Total K (25% HCl), Available P (Bray), exchangeable bases (Ca, Mg, K, Na), and Cation Exchange Capacity (CEC). The soil's physical and chemical properties were evaluated according to the technical guidelines for chemical analysis of soil, water, and fertilizers (Agricultural Instrument Standardization Agency/BSIP, 2023). Soil classification was based on the 12th edition of the Keys of Soil Taxonomy (2014).

3. Results and Discussions

3.1. Soil Temperature Regime and Soil Moisture Regime

The soil temperature and moisture regimes in Dalisodo Village were determined based on field observations, climate data, and laboratory analyses. Average monthly temperature and rainfall data for 2014-2024 were obtained from the Meteorology, Climatology and Geophysics Agency (MCGA/BMKG) Karangploso Station, Malang Regency (Figure 2).

Soil temperature ranged from 22.2°C in September to 22.9°C in April, showing relatively stable and warm conditions throughout the year. Based on this, the soil temperature regime is classified as isohyperthermic, meaning that soil temperature remains relatively warm throughout the year without experiencing drastic changes. This is evident from the temperature range, which stays consistently above 22 °C. Rainfall distribution indicates a wet season in December (482.7 mm) and a drier period in September (114.9 mm). Despite this variation, soil moisture remains generally sufficient to support plant growth, justifying the udic moisture regime classification. These regimes reflect the combined influence of topography, soil properties and local climate on water availability and thermal conditions in the soil.

Understanding the soil temperature and moisture regimes has practical implications for agricultural management. The udic moisture regime suggests that crops can be grown year-round with minimal irrigation, while the isohyperthermic temperature regime supports consistent biological activity and nutrient cycling. In soils with a udic moisture regime, water remains available in the rooting zone for most of the year, with fewer than 90 days of shortage under typical conditions (Buol, 2013). Soils labeled with the 'iso' prefix have ΔT (different temperature) of under 6°C between the warmest and coolest periods of the year at 50 cm depth (Rodriguez et al., 2010). These conditions favor crop growth and soil fertility, as stable moisture and warm temperatures enhance microbial activity and nutrient availability (Hu et al., 2024). These findings inform the selection of suitable crops,

planning and implementation of planting schedules, and optimization of soil management strategies to enhance productivity in Dalisodo Village.

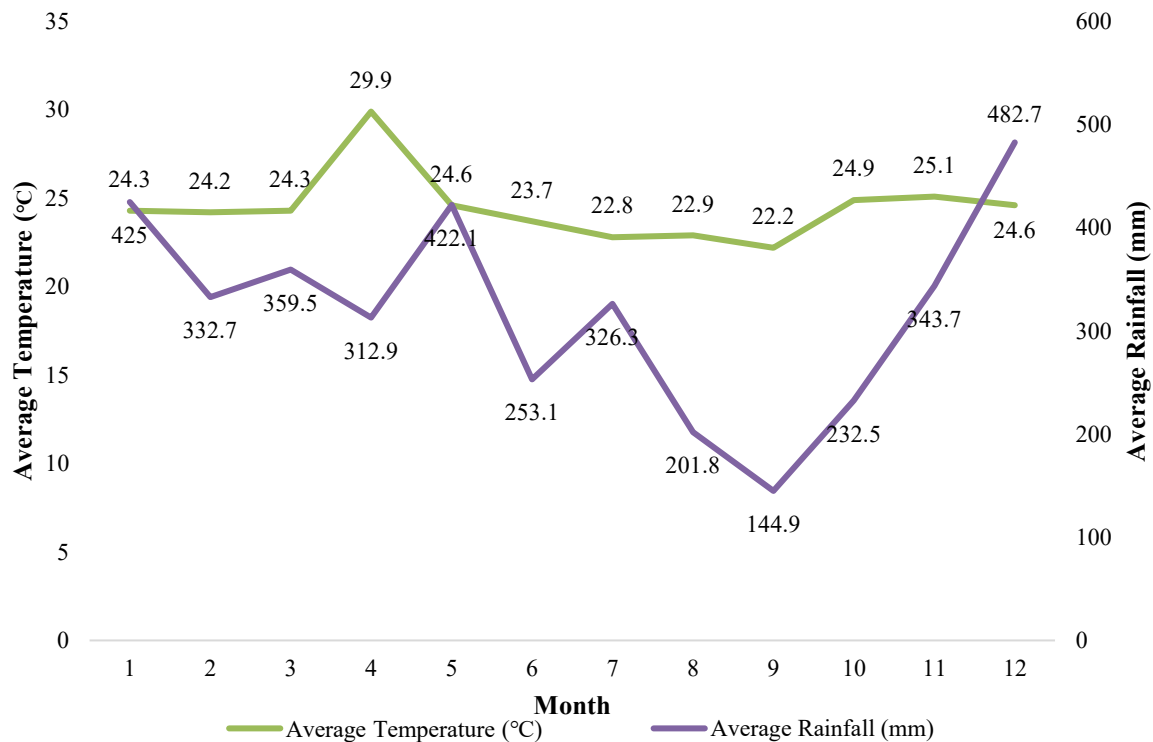


Figure 2. Average monthly temperature and rainfall from 2014 to 2024

Source: Meteorology, Climatology and Geophysics Agency (MCGA/BMKG) Karangploso Station, Malang Regency (Processed data).

3.2. Land Physiography

The research area in Dalisodo Village is located in a hilly landscape that forms a small valley system (Table 2). Each exhibits variations in slope, drainage, relief, runoff, permeability, soil depth, and vegetation (Figure 3). The first profile (point 1) was established on the lower slope, which is currently utilized for Napier grass cultivation. It has a 26.28% slope with very slow drainage and moderate permeability. The macro relief is hilly, while the microrelief consists of low gilgai formations. The depth is very shallow, which limits root development and restricts plant growth. The dominant vegetation consists of grasses, indicating that this soil has limited capacity to support deep-rooted or woody plants.

Table 2. Land physiography at the observation points

Observation code	Slope (%)	Drainage	Relief		Runoff	Permeability	Contact	Vegetation
			macro	micro				
Point 1	26.28	Very slow	hilly	Low gilgai	surface	Moderate	Very shallow	Napier grass
Point 2	44.90	Slightly Slow	hilly	Low gilgai	surface	Moderate	Shallow	Coffee, banana, Leucaena, Cassava
Point 3	41.40	Moderately slow	hilly	Low gilgai	surface	Moderately fast	Slightly deep	Open grassland



Figure 3. Land physiography at the observation points
(a) Point 1: Napier grass, (b) Point 2: Coffee agroforestry, (c) Point 3: open grassland

The second profile (Point 2) was situated on the middle slope, managed under an agroforestry system dominated by coffee, banana, and leucaena. Point 2 has a steeper slope of 44.90% with slightly slow drainage and moderate permeability. The macro relief is hilly, with a low gilgai microrelief. The soil depth is shallow, which influences its ability to support woody vegetation. The presence of coffee, banana, *Leucaena*, and cassava suggests that the soil can sustain perennial crops, although it has limited water retention and nutrient storage capacity. Soils on steeper slopes tend to have better drainage but are also more susceptible to erosion and nutrient depletion. Research conducted by van Varseveld et al. (2009) and Zhang et al. (2020) indicates that steep hillslopes tend to generate more sufficient runoff, which can accelerate soil erosion and nitrogen loss.

Meanwhile, the third profile (Point 3) was positioned on the opposite slope, also at the middle slope, but at a slightly higher elevation than Point 2. The land is mostly covered by natural grass and remains uncultivated. It has a 41.40% slope, with moderately slow drainage and moderately fast permeability. The macro relief is hilly, with low drainage and moderately fast permeability. The soil depth is slightly deeper, allowing for deeper root penetration and enhanced water and nutrient absorption.

3.3. Soil Physical Properties

The physical characteristics of the soil at three observation points show variation in the distribution of sand, silt, and clay fractions, which influence soil texture and physical properties (Table 4). In general, the observation points indicate a dominance of clay loam texture, which implies a high water retention capacity but also slows down water movement within the soil. At Point 1, Horizon 1 is dominated by 57% clay, 16% sand, and 27% silt, classifying it as a clay-textured soil. This type of soil has a high water-holding capacity but tends to have slow drainage and fewer pores, which can limit the movement of air and water within the soil. Soils with higher clay content tend to retain more water, resulting in increased water content at field capacity (McCarty et al., 2016).

At Point 2, Horizon 1 has a clay texture with 24% sand, 28% silt, and 48% clay, indicating high water retention but limited aeration and infiltration capacity. In Horizon 2, the sand fraction increases to 30% with 30% silt and 33% clay, resulting in a clay loam texture. This texture provides a balance between water retention and drainage. In Horizon 3, the sand content further increases to 60%, with 21% silt and 19% clay, forming a sandy loam texture. This texture allows for faster infiltration and drainage compared to the upper horizons. Sandy loam textures, which promote speedier infiltration and drainage, particularly in lower horizons, exhibit low cation exchange capacity and limited water-holding ability (McCarty et al., 2016). Research conducted by Wang et al. (2021) confirmed that soils with clay and loam textures exhibit superior moisture content and water retention capacity compared to sandy soils, with significantly higher values observed across various soil layers.

Thus, in Point 3, Horizon 1 has a clay texture (63% clay, 20% sand, and 17% silt), making the soil highly plastic and slow-draining. Horizon 2 has a clay loam texture, comprising 42% sand, 20% silt, and 38% clay, which offers a balance between water retention and drainage. Meanwhile, Horizon 3 reverts to a clay texture, with a higher clay content (53%) compared to Horizon 2, which increases water-holding capacity but also slows down water movement within the soil.

Table 4. Soil textures at the observation points

Sample	Soil Fraction (%)			Soil Texture
	Sand	Silt	Clay	
Point 1				
Horizon 1	16	27	57	Clay
Point 2				
Horizon 1	24	28	48	Clay
Horizon 2	37	30	33	Clay Loam
Horizon 3	60	21	19	Sandy Loam
Point 3				
Horizon 1	20	17	63	Clay
Horizon 2	42	20	38	Clay Loam
Horizon 3	24	23	53	Clay

3.4. Soil Chemical Properties

In general, the soil chemical properties at the tree observation points exhibit variation in acidity levels, organic matter content, macronutrients (N, P, K), cation exchange capacity (CEC), and base saturation, which influence soil fertility and nutrient availability (Table 5). Soil pH ranges from 5.09 to 6.84 in H₂O, indicating acidic to slightly acidic characteristics. Meanwhile, the pH in KCl is lower, ranging from 3.60 to 4.50, suggesting possible aluminum saturation and higher acidity levels in some horizons. This condition can affect nutrient availability, particularly phosphorus, which is more susceptible to fixation in acidic soils. Increased soil acidity, resulting from the enhanced solubilization of aluminum as the pH declines, causes the concentration of Al³⁺ to rise compared to its hydroxylated forms, promoting the complete desorption and leaching of exchangeable cations, which in turn reduces the availability of macronutrients (Garzón et al., 2011; Olego et al., 2014).

Total nitrogen (Total-N) content varies from 0.09 to 0.25%, with the highest values found in observation points with higher organic matter content. Although nitrogen is present in moderate amounts, its levels are relatively low for optimal plant growth. Therefore, some observation points may require nitrogen supplementation through organic or inorganic fertilization to enhance soil fertility. Moreover, the organic carbon (Organic-C) content ranges from 0.79 to 3.07%, with higher values observed in deeper horizons at Point 3. This pattern may be related to clay translocation and vertical mixing processes typical of vertisols, where shrink-swell activities redistribute organic materials into deeper layers, leading to higher carbon content below the surface (Six et al., 2002). A relatively high organic content indicates a good decomposition process and the potential for natural nutrient addition. Inceptisol has a higher SOC content due to more pedogenic processes, greater soil depth, and finer texture (Dengiz et al., 2019). The organic matter content in vertisols varies from 5 to 10 ppm, depending on several influencing factors, including both the quantity and composition of organic matter, which play a role in forming clay-organic complexes that occur across molecular to macroscopic scales (Coulombe et al., 1996).

Available phosphorus (P-Available) in the studied soil is generally low, ranging from 1 to 19 ppm, while total phosphorus (Total-P) varies between 6 and 27 mg/100g. The noticeable gap between total and available phosphorus suggests that a large portion of P exists in forms unavailable to plants, likely bound to soil minerals or fixed by aluminum and iron oxides, or under acidic conditions. This pattern is evident, for instance, in Horizon 3 of Point 2, where total-P is relatively moderate (8 mg/100 g). Still, the available P is only 1 ppm, implying strong P fixation and low mobility. Inorganic soils typically contain around 0.5% total phosphorus by weight, yet only about 0.1% is plant-available due to limited solubility and high fixation potential (Patle et al., 2021). The highest available P value (19 ppm) recorded at Point 1, Horizon 1, coincides with a high organic matter content (1.35%), suggesting that organic matter decomposition contributes to enhanced mineralization processes. According to Li et al. (2016), enrichment of soil organic matter (SOM) can facilitate phosphorus release through biochemical processes involving protein, carbohydrate, and lipid decomposition, which occurs under redox conditions and promotes the reduction of ferric (Fe³⁺) to ferrous (Fe²⁺) iron, releasing phosphorus previously bound to Fe oxides. Consequently, higher rates of organic matter mineralization can indirectly improve phosphorus availability by modulating soil pH and decreasing phosphorus fixation (Naher et al., 2004; McLaughlin et al., 2011).

Table 5. Soil chemical properties at the observation points

Sample	pH		Organic-C (%)	Total-N (%)	Available P (ppm)	Total-P (mg/100 g)	Total-K (mg/100 g)	CEC (cmol/kg)	CEC (cmol/kg)				Base Saturation (%)
	H ₂ O	KCl							K	Ca	Mg	Na	
Point 1													
Hor. 1	6.63	4.00	1.35	0.13	19	27	60	27.01	1.05	28.84	5.97	0.53	134.73
Point 2													
Hor. 1	6.49	4.20	1.49	0.22	6	8	62	20.74	1.26	8.05	4.24	0.67	68.56
Hor. 2	6.84	4.40	2.00	0.15	7	12	65	24.86	3.40	8.38	2.88	1.12	63.48
Hor. 3	6.61	4.50	3.07	0.09	1	8	41	30.47	0.68	11.97	6.22	0.82	64.42
Point													
Hor. 1	5.19	4.30	0.79	0.12	5	6	52	30.37	0.57	3.66	0.97	0.51	18.80
Hor. 2	5.09	4.10	1.01	0.25	11	14	61	20.06	1.38	5.60	1.93	0.50	46.91
Hor. 3	5.63	3.60	1.71	0.16	8	19	37	22.35	1.11	10.54	3.32	0.83	70.69

Total potassium (Total-K) ranges from 37 to 65 mg/100 g, with the highest values observed in sites with higher base saturation. Although the soil contains sufficient potassium, areas with faster permeability are at a higher risk of leaching potassium, making potassium fertilization an essential strategy for maintaining soil productivity. Soils serve as a significant reservoir of potassium, primarily stored in K-bearing aluminosilicate minerals, such as feldspar, mica, biotite, muscovite, and nepheline, which gradually release potassium through slow weathering processes (Rawat et al., 2016).

Cation Exchange Capacity (CEC) and base saturation are crucial indicators of soil fertility and buffering capacity (Ma et al., 2024), as they determine the soil's ability to retain and supply essential nutrients. The observed CEC values range from 20.06 to 30.47 cmol/kg, indicating a moderate nutrient holding capacity, influenced by soil texture, clay minerals, and organic matter content. Soils with high cation exchange capacity (CEC) can retain more nutrients and are more effective at maintaining stable nutrient levels in the soil solution by replenishing them as they are used up, preventing sudden fluctuations (Hodges, 2010). Higher CEC values suggest better nutrient retention, while lower values may lead to increased nutrient leaching. Cation exchange capacity (CEC) in vertisols typically ranges from 20 to 45 cmol/kg, which is primarily influenced by the organic carbon content, the amount of clay, and the specific types of clay minerals present in the soil (Coulombe et al., 1996). Base saturation varies widely, from 18.805% (low) to 134.73% (very high), reflecting differences in soil fertility status. Soils with low base saturation are more acidic and prone to nutrient deficiencies, whereas high base saturation indicates an abundance of base cations that enhance soil productivity. Low base saturation in soils can lead to very acidic conditions, which may cause the release of potentially harmful cations, such as aluminum (Al) and manganese (Mn), into the soil environment (Hodges, 2010; Tiecher et al., 2023).

3.5. Soil Description

This study was conducted at three locations in Dalisodo Village to classify soils based on their morphological properties, soil formation processes, and classification according to the soil taxonomy system (Soil Survey Staff, 2014). Each site exhibits distinct characteristics, indicating variations in fertility, base saturation, and soil development stages.

Based on observations at Point 1 (Figure 3), the soil surface exhibits a dark yellowish-brown color (10YR 3/4, moist) with a clay texture, a massive structure, and a sticky-plastic consistency. Cracks and fissures are visible on the surface, reflecting the typical shrink-swell behavior of clay-rich soils. The organic carbon content is moderate (1.35%), which does not meet the criteria for mollic and umbric epipedons. Therefore, the surface horizon is classified as an ochric epipedon. Based on its morphological and chemical properties, the soil belongs to the order Vertisols, which reflects a high clay content, shrink-swell behavior, and a high nutrient retention potential under a udic moisture regime. Since the A horizon is present, the soil exhibits weak horizon development but maintains characteristic Vertisol features, such as high clay content and plasticity. It is classified as Suborder Uderts, Great Group Hapluderts, and Subgroup Typic Hapluderts, representing a typical Vertisol with a udic moisture regime and no intergrading or extra-grade features observed.

At Point 2, the soil profile (Figure 4) exhibits an Ochric epipedon, indicated by its dark reddish gray (10R4/1), clay texture, slightly plastic and slightly sticky consistency in a depth of 28 cm. the horizon contains few fine roots, very fine pores, and show no effervescence upon application of 10% HCl, indicating the absence of free carbonates. Beneath the surface, the Bw₁ horizon (29-37 cm) is clay loam, loose to slightly hard, slightly plastic, with very fine pores and few fine roots, while the Bw₂ horizon (38-58 cm) is sandy clay, firm to hard, slightly plastic, with small pores and no effervescence. The subsurface horizons show no significant clay accumulation, cutans, or other features indicative of an argic horizon. Therefore, the diagnostic subsurface horizon is identified as a cambic horizon, reflecting early soil development without substantial clay illuviation.

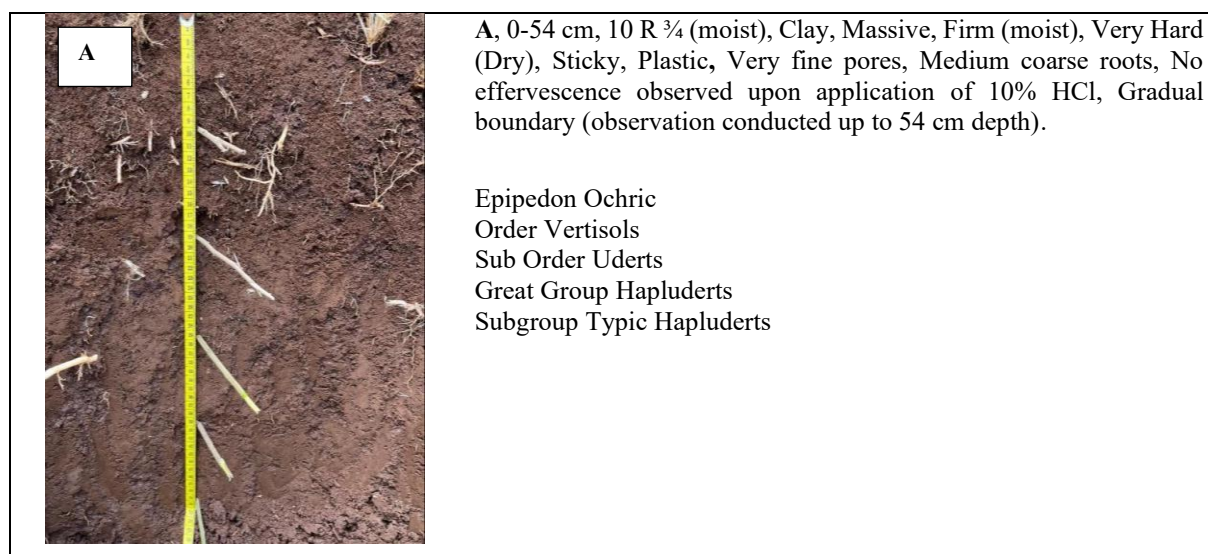


Figure 3. Photo and description of the soil profile cross-section at point 1

The soil order is Inceptisols, characterized by the presence of a cambic horizon and some profile development, although it is not yet fully developed. Considering the soil moisture and base saturation, it belongs to the Udepts suborder, which includes Inceptisols in humid regions. The great group is Eutrudepts, reflecting relatively high base saturation. The absence of free carbonates, lithic contact, or aquic conditions excludes other subgroup features. Consequently, the soil is classified under the Dystric Eutrudepts subgroup, indicating that it is moderately fertile with high base saturation but lacking free carbonates.

Meanwhile, at Point 3, the soil profile (Figure 5) exhibits an ochric epipedon, characterized by a reddish-brown color (2.5 YR 4/4), a clay texture, an angular blocky structure, and a sticky and plastic consistency to a depth of 16 cm. The surface exhibits small cracks, a typical feature of clayey soils that expand and contract in response to changes in moisture. The horizon contains abundant very fine pores and shows no effervescence upon application of 10% HCl, indicating the absence of free carbonates.

Beneath the surface, the Bss₁ horizon (16-50 cm) is a clay loam with an angular blocky structure, friable to slightly sticky, and plastic, characterized by abundant very fine pores. The Bss₂ horizon (50-65 cm) is a clay, formed into a hard, sticky, and plastic material, also showing abundant very fine pores and no effervescence. Both subsurface horizons display slickensides, indicative of shrink-swell clay activity, which is characteristic of Vertisols. Based on these diagnostic horizons, the soil is classified as a Vertisol, representing soils with significant clay activity and self-mixing behavior. Considering the humid soil moisture regime, it belongs to the Udepts suborder, the Greatgroup Hapluderts, indicating vertisols with moderate fertility and well-developed slickensides. The soil is further classified into the Chromic Hapluderts subgroup, because within the top 30 cm of the mineral soil, one or more horizons exhibit reddish coloration meeting the chroma and value criteria: either (1) moist color value ≥ 4 , (2) dry color value ≥ 6 , or (3) chroma ≥ 3 (Soil Survey Staff, 2014). In this profile, the A horizon (2,5 YR 4/4) satisfies these criteria, justifying the designation as Chromic Hapluderts.

Hence, this study demonstrates that soil at the three observed sites in Dalisodo Village, Wagir Sub-District, exhibits variations in morphological properties, horizon development, and chemical characteristics, which collectively influence soil fertility and agricultural management. These differences are further influenced by variation in land use and slope, which affect soil structure, organic matter accumulation, and nutrient retention. Management of vertisols is a challenging task due to certain physical constraints, such as a narrow soil moisture range, unique consistency that is sticky when wet and very hard or cracks when dry (Somasundaram et al., 2018). Typic Hapluderts at Point 1 under monoculture napier grassland are located on a gentle slope, which promotes rapid drainage but may enhance nutrient loss under continuous monoculture.

The soil's high clay content, massive structure, and surface cracks limit infiltration and aeration, making it suitable for Napier grass cultivation. To optimize soil use and maintain productivity, practical management practices are recommended, including periodic mowing, the application of organic amendments to improve soil structure and fertility, and minimal tillage to reduce compaction and prevent the widening of surface cracks. These measures help maintain water retention, support the sustainable growth of Napier grass, and lay the groundwork for the potential introduction of other tolerant crops in the future. This recommendation is supported by Zulhaedar et al., (2023), which indicates that minimal soil disturbance helps maintain optimal physical and chemical soil properties on Vertisols, ensuring sustainable growth even in clay-rich soils with slow drainage.

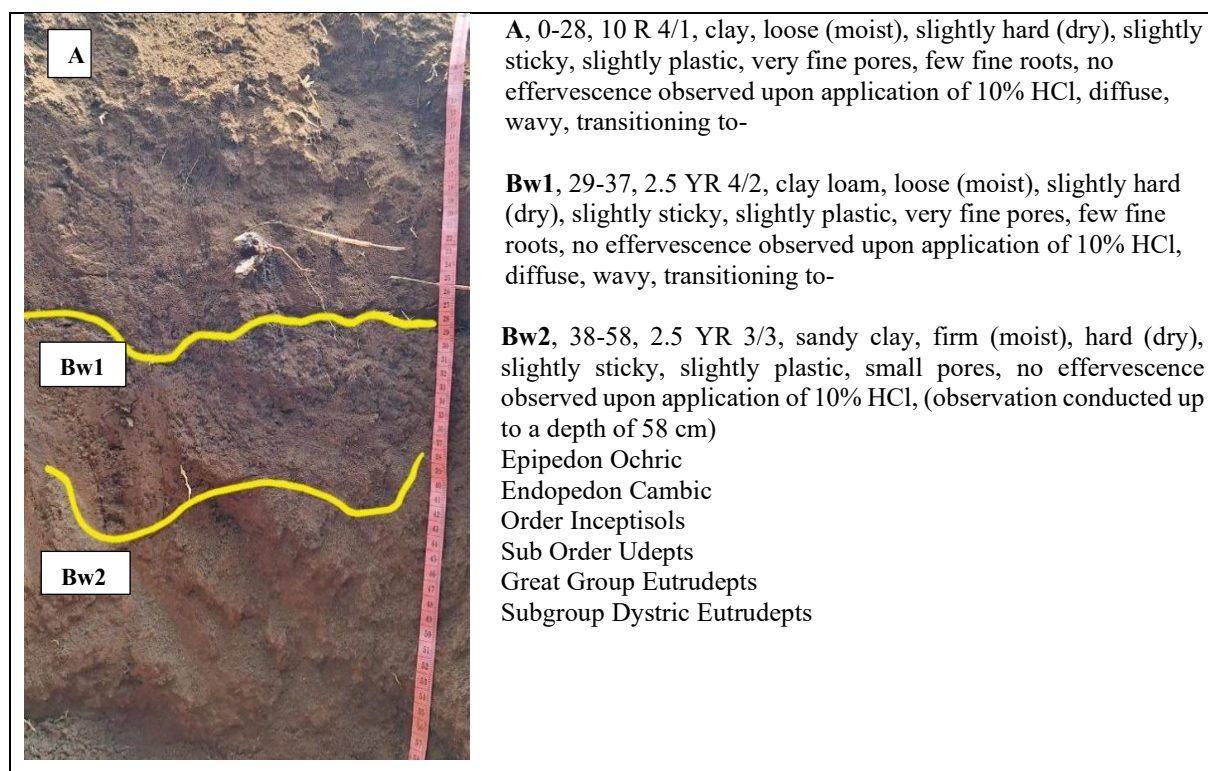


Figure 4. Photo and description of the soil profile cross-section at Point 2

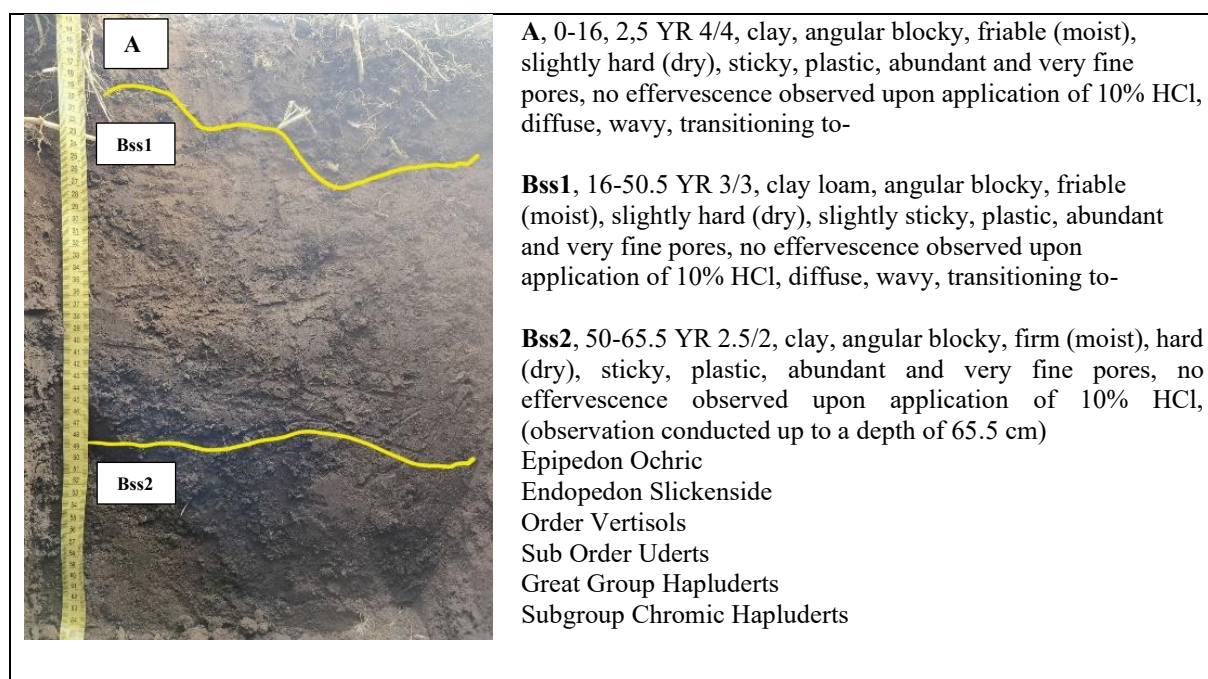


Figure 5. Photo and description of the soil profile cross-section at Point 3

Chromic Hapluderts under open grassland at Point 3 exhibit a horizon with reddish-colored soils of firm to hard consistency, angular blocky structure, abundant very fine pores, and high clay content, displaying shrink-swell behavior. These soils have moderate to high base saturation and moderate fertility, and are generally less prone to erosion due to their clay-rich texture and sparse grass cover; however, surface cracks may form during dry periods. To maintain productivity, conservative tillage, the addition of organic amendments, and the establishment of cover crops or legumes are recommended to improve soil structure and moisture retention. The roots of legumes enhance soil organic matter and carbon sequestration by producing biomass and exudates that stimulate microbial activity, improve soil structure, and promote the formation of stable aggregates (De Deyn et

al., 2008; Duarte et al., 2024). Sofyan (2014) stated that the application of bokashi made from water hyacinth (*Eichhornia crassipes*) significantly increased available phosphorus, organic-C, and sulfate levels in Chromic Hapluderts soils.

Inceptisols are soils of humid/subhumid regions with altered horizons, some weatherable minerals, but lacking illuvial clay or aluminum-organic carbon enrichment (Soil Survey Staff, 2014). Disturbed Eutrudepts under coffee agroforestry exhibit horizons with a clay texture, sticky and plastic consistency, and a weakly developed subsoil with an angular blocky structure. These features indicate moderate weathering and base saturation, typical of humid upland inceptisols. The loose surface layer, with its fine pores, supports infiltration, while the firmer subsoil limits root penetration and water retention during dry conditions. Similar to Dystric Eutrudepts reported in the upper Brahmaputra valley (Phillips et al., 2020), these soils exhibit a slightly acidic pH, moderate nutrient status, and good drainage, making them suitable for perennial crops such as coffee when managed appropriately.

Management strategies for sustaining inceptisols quality under coffee agroforestry include the incorporation of organic amendments (compost, manure, or biochar) to improve soil structure and nutrient retention, the use of mulch or leaf litter to conserve moisture (Sánchez-Reinoso et al., 2023), and maintaining diverse shade trees to reduce erosion and enhance biological activity (Blanco-Sepúlveda et al., 2024). Such practices align with Mulutega & Mabrate (2017) stated that trees and shrubs constantly add organic matter to the soil and help protect it from erosion and nutrient leaching.

4. Conclusion

The soils in Dalisodo Village, Wagir Sub-District, exhibit diverse morphological, physical, and chemical characteristics influenced by topography, land use, and climate. The soil temperature regime is isohyperthermic, and the moisture regime is ustic, indicating a tropical environment with seasonal variation. Soil texture ranged from clay to sandy loam. Chemically, the soils ranged from acidic to slightly acidic, with low to moderate C-Organic content, low Available-P, low to moderate Total-P, and varying CEC and base saturation levels, suggesting a moderate level of weathering and development. The soils in the study area belong to the Inceptisols order, specifically under the Udepts suborder, and to the Vertisols order under the Uderts suborder. Three soil profiles were classified as Typic Hapluderts (Point 1), Dystric Eutrudepts (Point 2), and Chromic Hapluderts (Point 3). These soil characteristics have direct implications for agricultural management in the area. Vertisols (Typic and Chromic Hapluderts) require careful moisture and tillage management to prevent compaction and cracking, while Inceptisols (Dystric Eutrudepts) benefit from organic matter addition to improve nutrient retention and soil structure. Understanding these site-specific constraints and potentials enables the application of appropriate soil conservation and fertility management practices to support sustainable land use.

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