Acta Solum 4, Number 2 (March 2026), 138–147. DOI: 10.20527/actasolum.v4i1.3579
http://jtam.ulm.ac.id/index.php/actasolum e-ISSN: 2987-514

Comparison of Morphology and Physico-Chemical Properties of Inceptisols in Two Different Landscapes of the Special Region of Yogyakarta

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Article Information

Received December 01st 2025
Accepted April 08th 2026
Published April 20th 2026
Online April 20th 2026

Keywords:
Landform differentiation; Pedogenesis; Soil horizon; Soil morphology; Soil variability

Abstract

Inceptisols are widely distributed soils with significant agricultural potential; however, their characteristics are strongly influenced by landscape and parent material. Understanding these variations is essential for explaining soil-forming processes and supporting appropriate land management. This study aims to compare the morphological and physico-chemical properties of Inceptisols developed under karst and volcanic landscapes in the Special Region of Yogyakarta, Indonesia. A comparative field study was conducted on two representative pedons located in Bedoyo Kulon and Berbah. Soil profile descriptions followed standard soil survey guidelines and were supported by field and laboratory analyses of selected properties, including texture, structure, pH, carbonate content, and organic matter. The results show that Bedoyo Kulon soils are characterized by Ap–Bw1–Bw2 horizons, clay texture, dark reddish-brown color, moderately acidic pH (5–6), and the presence of carbonates in subsurface horizons. In contrast, Berbah soils exhibit Ap–A1–Bw horizons, a sandy loam texture, very dark gray to gray color, a slightly acidic pH (5–5.5), and the absence of carbonates. These differences indicate that parent material and topography play a dominant role in soil development and horizon differentiation. The findings provide insights into pedogenesis in contrasting landscapes and highlight the need for site-specific soil management strategies to improve soil fertility and sustainability.

1. Introduction

Inceptisols are among the most widely distributed soil orders globally and play a crucial role in supporting agricultural systems, particularly in tropical and subtropical regions (IUSS Working Group WRB, 2015). These soils are generally characterized by weak horizon development and relatively young pedogenic stages, reflecting limited profile differentiation (Soil Survey Staff, 2022). Despite their relatively simple profile development, Inceptisols exhibit considerable variability in morphological, physical, and chemical properties, which is strongly influenced by environmental factors such as climate, parent material, and topography (Buol et al., 2011; Schaetzl and Anderson, 2015). This variability has important implications for soil fertility, land suitability, and sustainable land management, particularly in tropical regions where soil-forming processes are highly dynamic (Minasny et al., 2017).

Soil formation is governed by the interaction of climate, organisms, relief (topography), parent material, and time, as conceptualized in the soil-forming factors model proposed by Jenny (1941). Among these factors, parent material and landscape position play a dominant role in determining soil development pathways. Lithological variation has been shown to strongly influence soil texture differentiation, horizon development, and chemical characteristics, even under similar climatic conditions (Pereira et al., 2024). In humid tropical environments, the interaction between parent material and topography regulates weathering intensity and material translocation, resulting in distinct soil profiles across landscapes (Tsai et al., 2016).

Pedogenic processes further control soil development by modifying soil morphology and chemical

composition. Processes such as melanization, brunification, and decalcification are associated with the accumulation of organic matter, iron oxidation, and carbonate leaching, respectively, and are particularly active in humid tropical climates (Schaetzl and Anderson, 2015; Bonar et al., 2023). These processes influence horizon differentiation, mineral transformation, and soil color development, and are often closely related to variations in parent material and topographic position. Previous studies have demonstrated that pedogenic pathways in Inceptisols are strongly controlled by these factors, resulting in diverse soil characteristics across different geomorphic settings (Herdiansyah et al., 2022).

The Special Region of Yogyakarta provides a representative setting for investigating these interactions, given its contrasting geomorphological landscapes. Karst regions in Gunungkidul, dominated by limestone parent material, differ markedly from volcanic landscapes in Sleman, which are influenced by pyroclastic deposits from Mount Merapi. These contrasting lithologies are known to produce significantly different soil characteristics and development pathways, particularly in tropical environments where weathering processes are highly active (Skorupa et al., 2017; Aini and Hanudin, 2025; Muslim et al., 2025). In karst systems, geomorphic processes and carbonate dynamics further regulate pedogenesis and soil distribution patterns (Solleiro-Rebolledo et al., 2023). Local-scale studies have also reported variations in mineral composition and soil properties associated with limestone and volcanic materials, indicating the strong influence of parent material on soil formation processes (Atmoko et al., 2016).

Although numerous studies have examined the morphology and physicochemical properties of Inceptisols across different environments, most have focused on single landscape types or specific factors, such as land use and elevation (Nurdin, 2012; Ermawati et al., 2024). Comparative studies explicitly addressing pedogenesis of Inceptisols across contrasting parent materials, particularly between karst and volcanic environments under humid tropical conditions, remain limited (Pereira et al., 2024). This lack of integrated analysis constrains a comprehensive understanding of how lithology and landscape position jointly control soil development processes.

Therefore, this study aims to compare the morphological and physicochemical properties of Inceptisols developed on karst and volcanic landscapes in Yogyakarta and to elucidate the pedogenic processes that control their formation. The findings are expected to enhance understanding of soil genesis across contrasting environments and provide a scientific basis for site-specific, sustainable land management strategies.

2. Research Methods

The research was conducted at 2 locations (Figure 1): Bedoyo Kulon, Karangasem Village, Ponjong District, Gunung Kidul Regency (440 m above sea level; 8.009430° S, 110.742838° E) and Sekarsuli, Sendangtirto Village, Berbah District, Sleman Regency (110 m above sea level; 7.818282° S, 110.426139° E). These contrasting pedon locations were selected to represent different landscape conditions and to provide a clearer understanding of the morphological characteristics of Inceptisols in the Special Region of Yogyakarta. Field observations of soil morphological properties were conducted following the guidelines of the Soil Survey Manual (Soil Survey Staff, 1993), while soil classification was carried out according to the Keys to Soil Taxonomy (Soil Survey Staff, 2022).

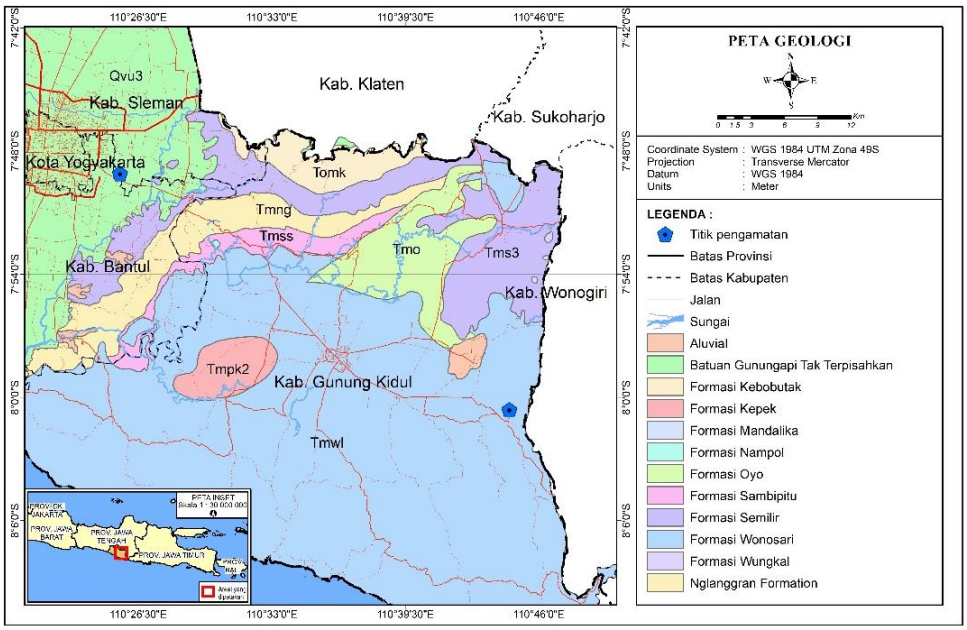

Figure 1. Map of research location points

Field observations describe the physiography and morphology of the land by determining the location coordinates, altitude, land use, and description of the outcrop or profile created. The morphology of the soil outcrop is described by determining the boundaries of the soil horizons, taking soil samples at each horizon, and conducting a rapid investigation and analysis of various physical and chemical soil parameters. Testing of each layer/horizon is carried out in the field and in the laboratory. Tests that can be carried out include physical properties of the soil, such as soil depth, layer depth, color, texture (feeling method), structure, consistency, and rooting, as well as chemical properties, such as organic matter content and pH (H_2O). The tools used include the Munsell Soil Color Chart, hoe, meter, clinometer, dagger, soil drill, drill list, GPS, penetrometer, and pH stick. The materials used include Aquades, plastic clips, 3% H_2O_2, 10% H_2O_2, 10% HCl, and α-α dipyridyl. Soil properties were analyzed using standard laboratory and field research procedures, including color assessment using a Munsell chart, pH measurement using a pH meter, and organic material analysis using a 10% H_2O_2 extract.

3. Results and Discussion

3.1. General Conditions of the Site

Observation point location 1, namely Bedoyo Kulon, Karangasem Village, Ponjong District, Gunung Kidul Regency, at an altitude of 440 meters above sea level and coordinates 8.009430 S, 110.742838 E, has a hilly macro-relief on Bedoyo Kulon Hill. The average rainfall of the last three years from the Meteorology, Climatology, and Geophysics Agency of the Special Region of Yogyakarta, namely 2019 - 2021, is included in the medium - high category because rainfall in one month reaches > 100 mm, it is called a wet month, if rainfall is 60-100 mm, it is called a humid month, while if rainfall <60 mm in one month is called a dry month. The fieldwork area experiences moderate to high rainfall (Schmidt and Ferguson, 1951). The observation location is approximately 750 m from the highway at 440 meters above sea level and on sloping land. The local slope position (field observations) is downslope, with a 30% slope angle, which is considered steep. The vegetation around the soil outcrop consists of *Nassella*, *Setaria sphacelata*, *Imperata cylindrica*, and *Crotalaria juncea.* Near the research location, the area has been used for community cultivation, as it is part of an agricultural area.

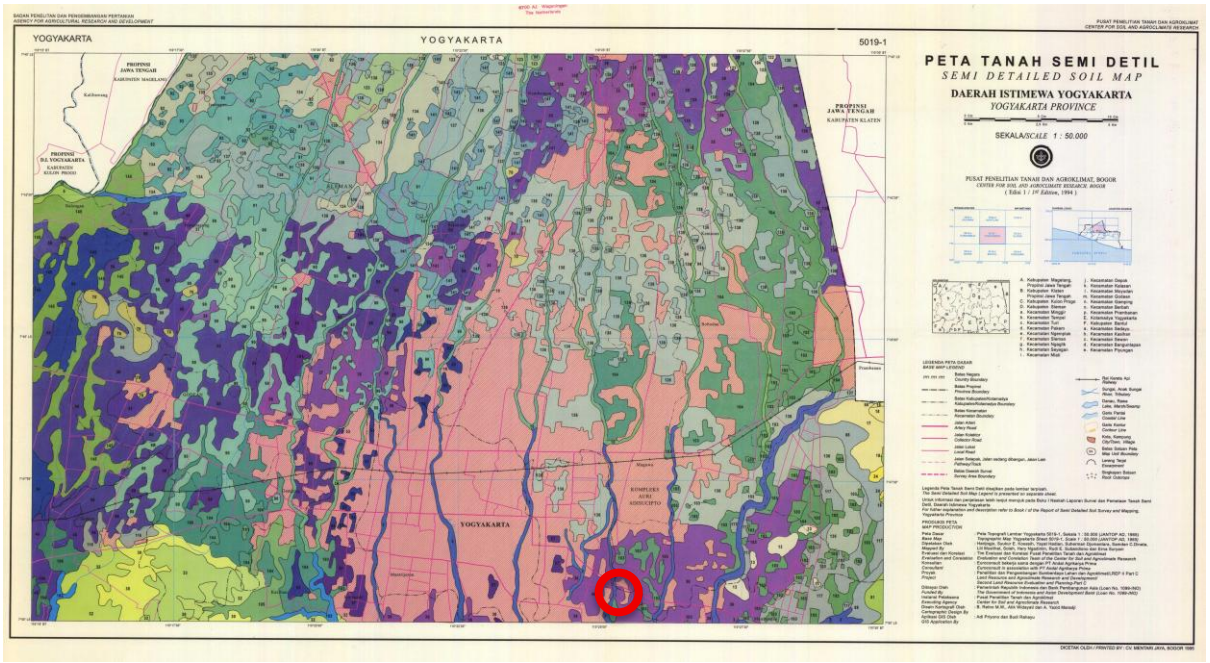

Figure 2. Semi-detailed land map of the Special Region of Yogyakarta, scale 1:50,000 (Muslihat et al., 1995)

Observation point location 2 is in Sekarsuli, Sendangtirto Village, Berbah District, Sleman Regency, at 110 meters above sea level, with coordinates -7.818282 S, 110.426139 E, and flat relief. Berbah rainfall data in the observation year, according to Berbah rainfall data, Sleman, Yogyakarta. NASA POWER Data Access Viewer (https://power.larc.nasa.gov) is included in the moderate category according to Schmidt and Ferguson (1951). The vegetation around the land outcrop consists of *Imperata cylindrica* and *Nassella*. The land is used for rice paddies, secondary crops, and nuts. A semi-detailed soil map of the Special Region of Yogyakarta at a scale of 1:50,000 from 1994 (Figure 2) shows that the research location (red circle) has Inceptisol soil. It is consistent with direct soil profile observations at the research location, which showed similar soil characteristics. Agricultural activities, particularly periodic flooding in paddy fields, can enhance processes such as reduction-

oxidation, soil mixing, and nutrient enrichment. These factors contribute to the modification of natural pedogenic processes, but also support the formation of weakly developed horizons.

3.2. Soil Morphological Characteristics

Soil morphology can indicate soil conditions that can be analyzed in the field, describing soil characteristics and appearance. Soil formation and development are closely related to geomorphological conditions. Soil morphology reflects the conditions and dynamics of soil development and is crucial in identifying land capabilities. Soil morphological characteristics are soil properties directly observed in the field, such as color, texture, structure, and consistency.

The results of observations of soil outcrops on Inceptisols at Point 1, Bukit Bedoyo Kulon, Gunung Kidul, Special Region of Yogyakarta, based on Table 2, show that the soil horizon consists of the Ap layer at a soil depth of 0-11 cm. Switching to the Bw1 horizon at a depth of 11-51 cm indicates a new B horizon with changes in soil color and consistency. Horizon boundaries in soil outcrops depend on the level of weathering of the parent material and soil organic matter. It is seen in the Ap horizon, which has more organic matter than other horizons.

Moist consistency is when the soil water content is between the permanent wilting point and field capacity. Moist consistency is determined by squeezing the soil mass with the thumb and index finger. The soil consistency of Inceptisols in the Ap horizon is a soil mass that is crushed under moderate pressure, also called firm. At the same time, Bw1 and Bw2 have a soil mass consistency that is crushed under intense pressure between the thumb and index finger in a moist state (very firm) according to Sukarman et al. (2017).

Table 1. Several morphological characteristics of the Bedoyo Hill outcrop, west, and changed

Horizon	Depth	Matrix Color	Morphology
Morphology of the Bedoyo Kulon Hill Outcrop (Point 1)			
Ap	0 - 11	5YR 2.5/2 (dark reddish brown)	The boundary of the diffuse horizon is wavy; clay texture; blocky structure, rounded, smooth, weak; firm consistency, not sticky, slightly plastic; lots of micro roots, few meso, no macro
Bw1	11 - 51	7.5YR 3/3 (dark reddish brown)	The boundary of the diffuse horizon is wavy; clayey clay texture; blocky structure, rounded, smooth, weak; firm, slightly tacky, slightly plastic consistency; medium micro roots, little meso, very little macro
Bw2	51 - 60	7.5YR 3/3 (dark reddish brown)	The boundary of the diffuse horizon is wavy; clayey clay texture; blocky structure, rounded, smooth, weak; consistency is very firm, somewhat tacky, slightly plastic; medium micro roots, little meso, very little macro
Morphology of Berbah Land Outcrop (Point 2)			
Ap	0 - 34	7,5 YR 3/1 (very dark gray)	The horizon boundary is mixed-wave; sandy loam texture; granular, fine, weak structure; loose, non-adhesive, non- plastic consistency; many micro roots, moderate meso, no macro roots
A1	34 - 48	7,5YR 2,5/2 (very dark brown)	Limit clear-wave horizon; sandy loam texture; granular, medium, weak structure; loose, non-adhesive, non-plastic consistency; moderate micro-rooting, few meso-rooting, no macro-rooting
Bw	48 - 70	7,5 YR 5/1 (gray)	Wave-diffuse horizon boundary; dusty texture; angular blocky structure, medium, somewhat firm; loose consistency, slightly sticky, not plastic; little micro rooting, very little meso, no macro

The soil profiles observed across different land-use types have slightly different colors. The easiest soil characteristic to determine in the field is soil color. Determination of soil color by referring to the Munsell Soil Color Chart at Point 1 has an Ap horizon at a soil depth of 0 – 11 cm, namely 5YR 2.5 / 2 (dark reddish brown) and switches to the Bw1 horizon at a depth of 11 – 51 cm, there is no degradation with the color in the next layer Bw2 7.5YR 3 / 3 (dark reddish brown) the difference in color in the soil is caused by various factors, one of which is the content of organic matter (Iyanti et al., 2023) the content of organic matter in the Ap layer or the first horizon is due to the incomplete decomposition of organic matter (still fresh) compared to the Bw horizon.

Soil classification depends on the formation process and the factors that influence it. Morphological characteristics of soil include horizon boundaries, color, texture, structure, and consistency (Mursyid et al., 2023). Soil morphology describes the appearance of soil in the field based on observable properties and characteristics (Gunawan et al., 2020). One method for identifying soil morphology is to examine soil outcrops. Soil outcrop is the visible part of a vertical section that reveals the structure of soil horizons.

The results of observations at Point 1 Bukit Bedoyo Kulon, Gunung Kidul, Special Region of Yogyakarta, include the Udik soil moisture regime, Ochric epipedon, Cambic endopedon, Inceptisols order, Udepts sub order, great group Eutrudepts, sub group Typic Eutrudepts, while the soil outcrop at the Berbah location, Sleman, Special Region of Yogyakarta, namely at the research location has a very dark gray color characteristic (7.5 YR 3/1) up to the horizon surface, with a relatively thick base of 0-34 cm, which means it meets the requirements value color, moist, 3 or less, and 5 or less. With these characteristics, the epipedon is included in the Umbric epipedon. The subsurface horizon shows differences in color and degree of structural development but does not yet exhibit eluviation or illuviation processes, so it is grouped with the Cambic horizon.

The real difference can be seen in the use of the land, which, of course, affects the characteristics of the Bedoyo Kulon and Berbah soils. The differences between these two locations show that Bedoyo is more influenced by calcification processes and soil structure development, while Berbah is dominated by leaching and melanization, which makes the soil looser (Retzer et al., 1952). Based on the data morphology, the soils are tentatively classified as Typic Eutrudepts (Bedoyo) and Typic Humudepts (Berbah), reflecting differences in base status and organic matter dynamics.

Observations of soil outcrops at the research site, located in Sekarsuli Hamlet, Sendangtirto Village, Berbah District, Sleman Regency, Yogyakarta Special Region, indicate 3 horizons (Figure 2b). The soil color at the research site is dominated by very dark gray (1-34 cm) in the Ap horizon and very dark brown (34-48 cm) in the A1 horizon, darker than the Ap layer, indicating a higher organic matter content. The Bw horizon is dominated by gray, indicating that the soil has experienced flooding, and yellowish-brown rust was also found. According to Prasetyo and Setyorini (2008), the continuous Fe oxidation and reduction process results in the soil in layer B containing rust and glei. The glei color appears. After all, a part of the soil in layer B is deficient in Fe, because during the reduction process, much of the Fe^{2+} from layer B is transported by water.

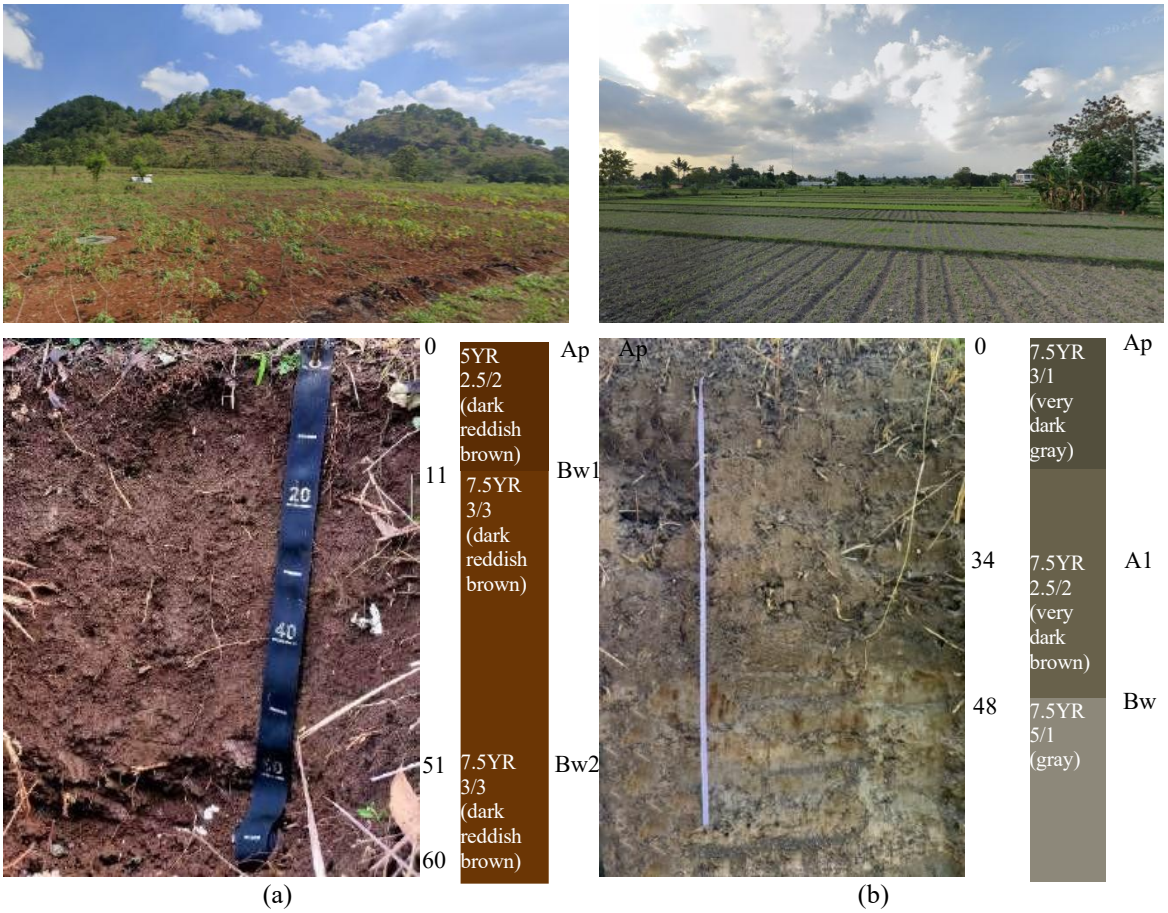

Figure 2. Landscape and profile of pedon (a) Bedoyo Kulon, Karangasem Village, Ponjong District, Gunung Kidul Regency, and (b) Sekarsuli, Sendangtirto Village, Berbah District, Sleman Regency

The parent material of the Inceptisol soil at Point 2, originating from the eruption of Mount Merapi, together with the characteristics of the epipedon and endopedon, comprises the soil at the research location, which is classified as an Inceptisol (Soil Survey Staff, 2017). The climate character in which soil moisture has no dry period

for 90 cumulative days in normal years is included in the Inceptisol regime, humidity Udik. Soil must be classified in the Udepts suborder. The soil at the research site has an Umbric epipedon, which is classified in the Humudepts group. This soil is classified as Udepts grouped in the Typic Humudepts subgroup without any other characteristics identified during the research.

The equivalent name of the soil at this site, according to the characteristics of acid volcanic soil, with Umbric epipedon and Cambic endopedon, and there are hydromorphic characteristics at 50-100 cm from the surface, is grouped as Cambisol Gleik/Bg soil (Hardjowigeno, 2016). Based on the World Reference Base for Soil Resources 2014 (WRB) guidebook, the soil at the research location is classified as Cambisol.

3.3. Physical and Chemical Properties of Soil

The physical and chemical properties of the soil are essential parameters for direct field soil testing or for rapid investigations, including soil structure, pH, carbonate (HCl), and organic matter (H_2O_2 10%), as shown in Table 2. These parameters provide an initial indication of soil development and fertility.

Table 2. Physical and chemical properties of Bedoyo Kulon Soil, Gunung Kidul.

Horizon	Depth	pH	Carbonate (HCl 10%)	Organic Materials (H_2O_2 10%)	Structure	Classification
Morphology of the Bedoyo Kulon Hill Outcrop						
Ap	0 - 11	5	0	+++	lumps round, smooth, weak	
Bw1	11 - 51	6	2	+++	lumps round, smooth, weak	Typic Eutrudepts
Bw2	51 - 60	6	2	+++	lumps round, smooth, weak	
Morphology of Berbah Land Outcrop						
Ap	0 - 34	5	0	++	granular, fine, weak;	
A1	34 - 48	5.5	0	+	granular, medium, weak;	Typic Humudepts
Bw	48 - 70	5	0	-	Angular lumpy, medium, somewhat firm	

Note: Many (+++); moderate (++); few (+); none (0); weak (2)

Soil pH is measured in the field using a pH stick and a pH meter to indicate the soil's acidity and alkalinity. Soil pH in the field is higher than that in the laboratory (Rukmana et al., 2019). The concentration of H^+ ions in the soil indicates the soil pH. The higher the H^+ concentration, the lower the soil pH (Hardjowigeno, 2016). This demonstrates that dry pH conditions in the laboratory under oxidative conditions differ from wet pH conditions in the field under reductive conditions. The pH value is generally lower in the lower horizon than in the upper horizon (Suryani et al., 2022), namely the pH in the Inceptisols Bukit Bedoyo Kulon soil Ap horizon, pH 5, and horizons Bw1 and Bw2, pH 6, as a result of downward leaching of the solum and nutrient uptake by plants. In the Inceptisols Berbah soil pH ranges from 5 to 5.5. Factors contributing to high soil pH are the presence of $CaCO_3$ and high base content, especially calcium and magnesium. Organic matter, base saturation, colloidal properties, and types of adsorbed cations influence pH. The presence of $CaCO_3$, a buffering agent that reduces soil acidity and increases pH, is associated with higher pH in Bedoyo Kulon than in Berbah. Additionally, soils with higher carbonate content commonly show neutral to alkaline pH ranges, further confirming the role of carbonate in controlling soil reaction (Azis et al., 2022)

Soil texture and structure are important factors that influence soil's physical, chemical, and biological properties. Qi et al. (2018) stated that particle size distribution is one of the main physical components that influence soil's physical, chemical, and biological properties. To determine soil texture class in the field, qualitative methods are used to quickly assess soil texture. In Bukit Bedoyo Kulon, the soil structure of each horizon is the same, namely the type of slightly rounded clumps with a fine size and a weak degree. The soil has a clumped structure with small (fine) aggregates and low stability (weak). This structure indicates that the soil has many pores and is easily disturbed, which can affect the movement of water and air within it, whereas in Berbah, each horizon has a different texture and structure. Namely, in the Ap horizon, the texture is sandy loam; the structure is sandy loam, granular, fine, weak, horizon A1 sandy loam texture; structure granular, medium, weak and horizon Bw dusty loam texture, angular blocky structure, medium, somewhat firm.

Testing the carbonate content on the soil outcrop in Bukit Bedoyo Kulon to test the carbonate content in the soil using 10% HCl. The results of the carbonate distribution are influenced by the amount of foam seen during the inspection. Shows that the soil horizon consists of a layer of Ap at a soil depth of 0-11 cm, which does not have carbonate. Switching to the Bw1 horizon at a depth of 11-51 cm, namely the B horizon, there are signs or symptoms of the transfer or addition of carbonate compounds (Sukarman et al., 2017), where only carbonate with foam

appears weak. Meanwhile, in the outcrop in the Berbah area, there are no visible bubbles on each horizon, meaning there is no carbonate content. Increased exchangeable bases are caused by the presence of carbonate, which increases base saturation and helps to classify Eutrudepts (Hu et al., 2021).

The differences in carbonate distribution in the two regions can be attributed to topographic conditions, parent material, and groundwater dynamics. The soil in Bukit Bedoyo Kulon, located in a hilly area, has the potential to accumulate carbonates in the underlying horizon due to leaching from the overlying horizon. The pedogenic characteristics observed in Bedoyo are consistent with calcification processes commonly found in calcareous soils, which are typically associated with high base saturation and carbonate accumulation. The $CaCO_3$ content of Bedoyo Kulon and Berbah soils differs, indicating a dominant pedogenic process. Bedoyo Kulon soil contains $CaCO_3$ in the lower horizon as a result of calcification ($CaCO_3$ accumulation), while Berbah soil contains no $CaCO_3$ due to intensive leaching. This differentiation aligns with the way soil classification is carried out (Soil Survey Staff, 2022).

To find out the organic matter content of soil in the field, you can react it with H_2O_2. High organic matter content is found in soil horizons because organic matter originates from plants and animals that remain on the soil surface and produce organic acids during decomposition. These chemical compounds, or organic acids, can accelerate the weathering of minerals. Water as a carrier agent can cause the formed materials to translocate to the lower part of the profile, creating new horizons. Living organisms such as worms, termites, and ants that burrow in the soil also influence soil formation and help maintain soil fertility, particularly through nutrient cycling (Susilawati et al., 2013). High organic carbon levels are related to climate conditions and soil drainage. The cool climate in well-drained soils is conducive to the rapid decomposition of organic matter by anaerobic microorganisms. Meanwhile, in Berbah, the organic matter content of 3.1% is considered moderate, but the organic matter content is organic which in at a depth of 48-70 Bw horizon, there is no organic material content due to the dusty loam structure, in accordance with research by Ghosh et al. (2019) which states that carbon in macro aggregates tends to be more protected and difficult to decompose, while in micro aggregates, carbon is more easily decomposed. Organic material is material in or on the surface of the soil from plant, animal, and human remains, whether they have undergone advanced decomposition or are undergoing decomposition.

Berbah is classified as a Typic Humudept due to the abundance of organic matter in its surface horizons. Brunification, another possible process, is the development of a brown color due to iron oxidation under relatively well-drained conditions. Geochemical conditions and microbial activity that accelerate decomposition in calcareous soils decrease organic carbon content in Bedoyo Kulon. This is consistent with the findings of Yang et al. (2021).

3.4. Land Use

The same soil type can be produced if one factor changes while others remain constant (Skorupa et al., 2017). Here, we observe the opposite trend, where two soils are similar despite having many of the same formation factors. Land use results from the interaction between human and land factors. Humans are the agents that influence or carry out activities on land to meet their needs (Widiatmika et al., 2015). Land use across different topographies certainly varies. The land's ability to support agricultural activities, plantations, and residential development is greatly influenced by slope gradient, as in the studied areas, Berbah Sleman and Bedoyo Kulon Gunung Kidul.

The Berbah area of Sleman Regency is dominated by agricultural paddy fields and residential areas (Figure 2b). The rice paddy management system in this area is generally intensive, resulting in low soil organic matter content in the Berbah area. According to Acín-Carrera et al., (2013), intensive agricultural soils have lower organic matter content than forest land or land managed conservatively because the input of organic matter is not balanced with decomposition rates. Meanwhile, land in hilly landscapes, such as the Bedoyo Kulon area (Figure 2a), is usually dry, with fields, mixed gardens, and shrubland, and features thatch and perennial crops such as acacia. Land in this area is more susceptible to erosion due to its undulating, steep topography, especially on land not under a conservation system. The slope factor significantly influences erosion hazard (Pasaribu, 2022). Different soil types and topography must be considered when selecting plant species and their specific purposes (Hairiah et al., 2025).

4. Conclusion

The soil at the Bedoyo Kulon hill location point has Ap, Bw1, and Bw2 horizons with a soil matrix color dominated by dark reddish brown, pH values ranging from 5 to 6, and has a low carbon content due to the presence of limestone, clay texture, slightly rounded lump structure, and fine size, with a young development level. Meanwhile, the Berbah location point has Ap, A1, and Bw horizons, with a soil matrix color dominated by very dark gray, a sandy clay texture, a granular structure, pH values ranging from 5 to 5.5, and does not contain carbon. Different land uses and physiographic conditions influence the soil's morphological characteristics and physical-chemical properties at both locations. Differences in location altitude also indirectly affect soil morphology, especially regarding horizon development. Pedogenic processes, such as calcification in calcareous Bedoyo and melanization

in non-calcareous Berbah, drive the soil differences between Bedoyo Kulon and Berbah. These processes support their classification as Typic Eutrudepts and Typic Humudepts, but more supporting data is needed.

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