Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2024.v29i3.115-125

Soil Characteristics and Management of Ultisols Derived from Claystones of Sumatra

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Received 03 October 2023, Revised 02 November 2023; Accepted 06 December 2023

ABSTRACT

Ultisols are one of the soil types that develop from claystone parent materials and are widely distributed in Indonesia, making them suitable for agricultural land use. Naturally, Ultisols have low soil fertility, such as acidic soil reactions and low base content; without proper management, they can lead to suboptimal agricultural yields. Therefore, this study aims to determine the physical, chemical, and mineralogical characteristics of Ultisols to formulate appropriate land management practices. Soil samples were collected from Ultisols with claystone parent materials from various regions in Sumatra, Indonesia. Soil profile creation was conducted to observe soil morphology in the field, followed by physical, chemical, and mineralogical analysis in the laboratory. The results showed that the Ultisols studied have a deep solum (90-120 cm), clay texture, and sticky and plastic consistencies. These soils generally have an acidic reaction, low organic C content, low potential P and K contents, low cation exchange capacity, low base saturation, and high Al saturation. The contents of easily weathered minerals, such as orthoclase, biotite, augite, hypersthene, tourmaline, and andalusite, which are essential nutrient reserves, are also generally low. Thus, the Ultisols studied are classified as low fertility soils, requiring specific management practices such as adding lime, organic materials, and soil amendments in a balanced and appropriate manner to achieve optimal yields.

Keywords: Claystone, land management, nutrient reserves, ultisols

INTRODUCTION

Ultisols come from the Latin word "Ultimus," which means last; it is a soil that has undergone extensive weathering and is mainly characterized by the presence of an argillic or Candice horizon, which is a horizon formed from the illuviation of clay from the horizon above it (Bockheim and Hartemink, 2013). Ultisols generally develop from old parent materials. Ultisols have a relatively advanced level of development, characterized by a deep soil profile, an increase in clay fraction with depth, acidic soil reaction, and low base saturation (Adiningsih and Mulyadi, 1993).

Ultisols have an extensive distribution, covering almost 25% of Indonesia's total land area (Subagyo et al., 2004). The widest distribution is found in Kalimantan (21,938,000 ha), followed by Sumatra (9,469,000 ha), Maluku and Papua (8,859,000 ha), Sulawesi (4,303,000 ha), Java (1,172,000 ha), and Nusa Tenggara (53,000 ha). The diversity of the wide distribution of Ultisols will affect the development of its characteristics. The variation in climate, parent material, relief, organisms, and time found in Indonesia is a combination of pedogenic mechanisms that determine the diversity of the development of Ultisols characteristics.

In Indonesia, Ultisols are derived from various types of parent material. Ultisols derived from acidic tuffs in Lampung (Buurman and Dai, 1976), acid metamorphics and sedimentary rock in South East

Sulawesi (Dai et al., 1980), granodiorite in West Kalimantan (Buurman and Subagjo, 1980; Suharta and Prasetyo, 1986), claystone and sandstones in Riau (Suhardjo and Prasetyo, 1989), claystone and sandstones in East Kalimantan (Prasetyo et al., 2001), acid sedimentary rock in East Kalimantan (Sulaeman and Prasetyo, 2001), andesitic volcanic (Prasetyo et al., 2005), basaltic andesite (Purwanto et al., 2020), and andesite lava and tuff dacite in Banten (Arifin et al., 2021). In Indonesia, ultisols are commonly found in areas with claystones as parent materials. However, studies on Ultisols derived from claystones are still rare in Indonesia.

The main problem with Ultisols is their acidic pH and low soil fertility (Purwanto, Gani, and Suryani, 2020; Purwanto et al., 2020). Previous research shows that Ultisols formed from sandstone and claystone have a very acidic soil reaction, low organic matter and CEC, and high Al saturation. It is also similar to the characteristics of Ultisols formed from acidic plutonic rocks and acidic tuffs found in Riau (Prasetyo et al., 2001). In addition, Ultisols are deficient in essential nutrients such as nitrogen, phosphorus, and potassium, which are crucial for plant growth and development. Therefore, appropriate management is needed to improve the fertility and productivity of Ultisols. However, only some studies have discussed soil characteristics based on parent material specifications, especially claystone. Thus, data on the characteristics of Ultisols developed from claystone are needed to determine the proper management steps, considering that many Ultisols in Indonesia are derived from claystone.

This research aims to determine the characteristics of Ultisols derived from claystone parent materials based on different landforms and locations in Sumatra. Specifically, this study examines several morphological and physical properties, chemical properties, and sand mineral composition related to soil nutrient reserves and soil classification based on the described properties. Furthermore, it can provide an overview of land management practices on Ultisols for sustainable agricultural land use.

MATERIALS AND METHODS

Soil samples were collected from a soil mapping survey conducted in Sumatra in 2016. The materials used in the study were five representative soil pedons taken from different locations with the same claystone parent material. The pedon locations belong to the tectonic landform group, including the peneplain, tectonic plain, and tectonic hills. The research site has varying slopes ranging from 4-20%, with undulating, rolling, and hillocky relief. The land use in the research location includes oil palm plantations and rubber. The procedure for soil description adheres to the recommendations outlined by Sukarman et al. (2017). The locations of the studied Ultisol pedons, along with their landforms, relief, slope, and land use, are presented in Table 1.

A total of 24 soil samples were taken from each horizon of the five pedons, and their soil morphology was described. The soil samples were then subjected to physical, chemical, and mineralogical analyses. The soil analysis followed the protocol Soil Survey Staff (2014) outlined, except where otherwise specified. The soil texture was determined using the pipette method. Soil pH was measured by making a soil and water solution with a ratio of 1:5, which was shaken using a shaker machine for 30 minutes. Organic C was determined using the Walkley & Black method. Potential P and K were determined using 25% HCl extraction. The available P was measured using the Bray 1 method. The exchangeable cations (Ca, Mg, K, Na) were determined using 1N NH_4-Acetate extraction at pH 7. The determination of Al^{3+} and H^+ was done using 1 M KCl extraction. The mineral composition of the sand fraction was determined using the line counting method, which involves counting up to 100 mineral grains using a polarizing microscope (Carter and Gregorich, 2007).

RESULTS AND DISCUSSION

Soil Morphological and Physical Characteristics

All the soils have a deep solum, ranging from 90 to 120 cm (Table 2). Pedons P1 to P5 have a deeper solum (90-120 cm) located on the plain to tectonic hill landform. Pedon P5 has a B horizon depth of up to 90 cm because it is a hard layer with many iron concretions at depths greater than 90 cm. The thickness of the A horizon varies between 8 and 25 cm, and the B horizon is between 56 and 103 cm.

The Ap horizon in P1 to P5 indicates disturbance at the surface layer due to land use for oil palm and rubber plantations. Meanwhile, the clay content is identified with the Bt and Bto symbols in the B horizon of the five observed soil profiles. The laboratory analysis results of clay content indicate an increase in clay with the depth of the soil in the Bto, Bt1, and Bto1 horizons (Figure 1). The clay content in the subsoil is obtained through clay

Table 1. Location and observed pedon information

Pedon	Parent Material	Landform	Location	Coordinate		Slope (%)	Relief	Landuse
P1	Claystone	Tectonic hills	Bukit Makmur Village, Muara Sahung Subdistrict, Kaur Regency, Bengkulu	4°33' 55.361" S	103°20' 29.486" E	20	Hillocky	Palm oil
P2	Claystone	Tectonic plains	Cinto Mandi Village, Pinoraya Subdistrict, South Bengkulu Regency, Bengkulu	4°19' 35.400" S	102°52' 59.038" E	10	Rolling	Palm oil
P3	Claystone	Tectonic plains	Padang Bindu Village, Benakat Subdistrict, Muara Enim Regency, South Sumatera	3° 25' 59.974"S	103° 47' 43.008" E	10	Rolling	Rubber
P4	Claystone	Tectonic plains	Kayu Ara Village, Rambang Kuang Subdistrict, Ogan Ilir Regency, South Sumatera	3° 34' 18.818"S	104° 22' 11.298" E	5	Undulating	Rubber
P5	Claystone	Peneplain	Kertayu Village, Sungai Keruh Subdistrict, Musi Banyuasin Regency, South Sumatera	3° 6' 0.720" S	103° 44' 49.841" E	4	Undulating	Rubber

illuviation and indicates the presence of clay silicate in the soil. This clay silicate in the soil is formed through illuviation (Soil Survey Staff, 2022). It is defined as an argillic horizon, one of the characteristics of Ultisols (Subardja et al., 2016). It is consistent with the research findings of Aditya et al. (2021) on Ultisols in the Malaysian Peninsula, which showed clay silicate content identified with the Bt symbol as a characteristic of the argillic horizon, and (Raziah et al., 2019) on Ultisols in Aceh Besar Regency, with the characteristic horizon of clay silicate higher in the Bt horizon and having a fine-textured soil due to clay accumulation.

The particle size distribution analysis results define the soil texture shown in Table 2. The soil texture of all the pedons is dominated by clay (C)

Table 2. Morphological and physical properties of Ultisols.

Pedon	Horizon	Depth (cm)	Color	Particle Size			Texture*	Consistency*
				Sand	Silt	Clay		
				%				
P1	Ap	0-10	7.5YR 4/6	34	16	50	C	s, p
	Bt1	10-39	7.5YR 5/6	18	18	64	C	s, p
	Bt2	39-54	5YR 5/8	8	22	70	C	s, p
	Bt3	54-79	5YR 5/8	9	24	67	C	s, p
	BC	79-120	5YR 5/8	6	29	65	C	s, p
P2	Ap	0-17	7.5YR 3/1	33	28	39	CL	ss, sp
	Bt1	17-48	7.5Y 4/6	17	34	49	C	s, p
	Bt2	48-71	7.5YR 5/6	15	32	53	C	s, p
	Bt3	71-120	7.5YR 5/6; 2.5YR 4/8	15	32	53	C	s, p
P3	Ap	0-8	10YR 3/3	41	21	38	CL	ss, sp
	Bt1	8-34	7.5YR 4/4	31	13	56	C	s, p
	Bt2	34-70	7.5YR /6; 2.5Y 56/4; 2.5YR 3/6	41	2	57	C	s, p
	BC	70-120	5YR 4/6; 2.5Y 7/3	12	4	84	C	s, p
P4	Ap	0-15	10YR 3/3	53	18	29	SCL	ss, sp
	Bto1	15-34	7.5YR 5/6	45	19	36	CL	s, p
	Bto2	34-71	7.5YR 5/8	29	19	52	C	s, p
	BC	71-120	7.5YR 5/8; 10YR 5/6	20	19	61	C	s, p
P5	Ap	0-25	7.5YR ¾	20	32	48	C	ss, sp
	AB	25-56	5YR 4/6	13	35	52	C	s, p
	Bto	56-90	5YR 5/6	10	27	63	C	s, p
	BC	≥ 90	-	-	-	-	-	-

Note: *) CL= clay loam, C= clay, SCL= sandy clay loam; s= sticky, p= plastic, ss= slightly sticky, sp= slightly plastic

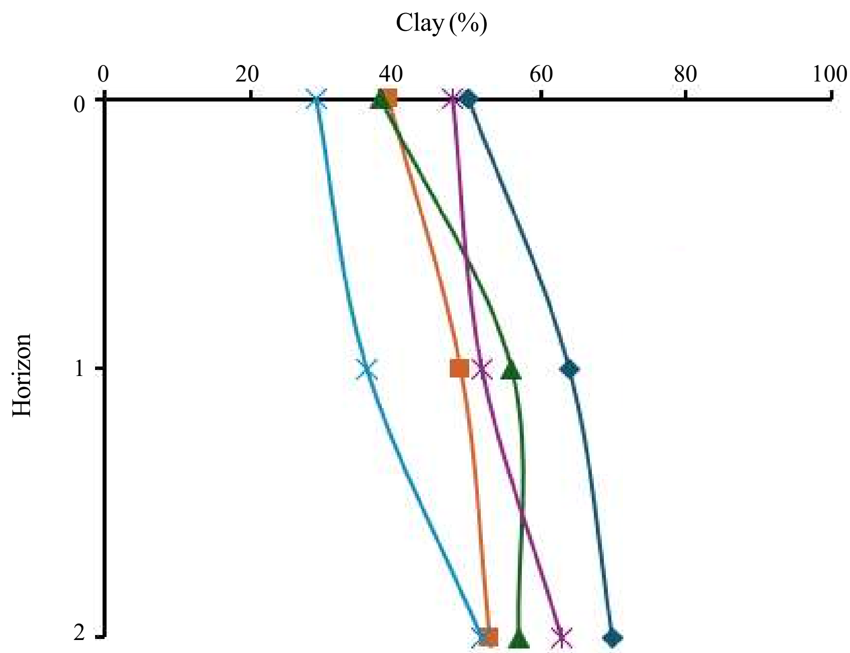

Figure 1. Clay content in five pedons. P1: , P2: , P3: , P4: , P5: .

due to the claystone origin of the soil, which has a clay content ranging from 48% to 84%. In contrast, the percentage of silt and sand is lower, with an average of <30%, especially in the lower layers. In the upper layer, texture differences exist in P2, P3, and P4. Pedons P2 and P3 have a clay loam (CL) texture because the clay content is <40%. In the top layer of all pedons, the clay content is lower the top layer than the bottom layer due to clay leaching into the bottom layer. However, in P2 and P3, the leaching is more intense, resulting in a clay loam texture supported by rolling relief. The top layer of P4 has a sandy clay loam (SCL) texture due to the intensive leaching of clay into the bottom layer (third layer). It may also be influenced by weathering of the surrounding sandstone so that the percentage of sand is relatively high (45-53%).

The color of the upper layer of the soil is generally dominated by dark brown (7.5 YR 3/4; 10 YR 3/3), brown solid (7.5 YR 4/6), and very dark gray (7.5 YR 3/1), while the lower layer averages brown (7.5 YR 4/4) to intense brown (7.5 YR 5/6), and reddish-yellow (5 YR 5/8; 5 YR 4/6). The change in Ultisols to red is caused by a higher content of hematite (Prasetyo and Suriadikarta, 2006). In addition, the soil at the research location has a sticky and plastic consistency. Consistency refers to the level of adhesion/cohesion of the soil mass, which is determined by pressing, squeezing, kneading, or pinching with hands (Sukarman et al., 2017).

Soil Chemical Properties

The analysis of soil reaction (pH H_2O) in Ultisols showed various values with different criteria (Table 3). A strongly acidic soil reaction (pH <4.5) was found in pedon P5 at a depth of 0-15 cm, while a slightly acidic soil reaction (pH 5.5-6.5) was found in pedon P2 at a depth of 0-17 cm. When compared between pedons, P3 and P5 generally had lower pH values than other pedons. However, most of the pH values in Ultisols were dominated by acidic criteria (pH 4.5-5.5), which could be found in all pedons at varying depths. The acidic soil reaction can be caused by several factors, including high rainfall intensity leading to nutrient leaching, acidic parent material, decomposition of organic matter, and agricultural harvesting bringing nutrients into the soil (Arnall, 2024).

The organic carbon content of Ultisols in all pedons is generally very low (<1%), especially in the lower layers. Conversely, the organic carbon content in the topsoil varies from low criteria (1-2%), medium (2-3%), to high (3-5%). Thus, the organic carbon content decreases with increasing soil depth. The highest organic carbon content was in pedons P3 (3.25%) and P5 (3.45%). Both were found in tectonic plains with rubber land use. Judging from the vegetation above, soils with rubber land use (P3, P4, P5) have higher organic carbon content than oil palm (P1, P2). The research results by Guillaume et al. (2016) showed that soils under oil palm had significantly lower organic C content than those in rubber plantations. Similarly, Junedi (2010) found that organic matter content was higher in rubber (4.7%) than in oil palm (1.51%) because oil palm plantations generally do not have ground-covering plants. In contrast, rubber plantations have more litter from rubber leaves and surface plants. Thus, litter in rubber plantations tends to be more abundant than in oil palm plantations.

The soil organic carbon (organic C) content can affect the amount of cations that can be absorbed or exchanged in the soil. It is because the weathering of organic matter produces humus, which acts as a soil colloid. A low content of C-organic causes the soil not to receive little charge addition from organic colloids. Therefore, the Ultisols in this study have low to medium Cation Exchange Capacity (CEC) criteria. It is in line with the research conducted by Syahputra et al. (2015), which found a low content of soil organic carbon and cation exchange capacity (CEC) in Ultisols in several regions in North Sumatra. In addition, Darlita et al. (2017) showed that soil organic matter and clay mineral content play an important role in improving CEC and soil aggregation.

The potential P content (HCl 25%) in this study is generally deficient (<15 mg 100 g^{-1}), except for pedon P2 (having moderate to high criteria) and the topsoil layer of pedon P5 with moderate criteria. Pedon P2 is ideal for showing the relationship between potential P content and Al^{3+}. In line with the potential P content (HCl 25%), the available P content is also generally shallow (<10 ppm), except for the topsoil layer of pedon P2 with moderate criteria and P5 with low criteria. The P content can reflect P availability in the soil, so the higher Al solubility can cause P to be unavailable for plants. Prasetyo and Suriadikarta (2006) stated that the low P content in Ultisols is not only caused by the low P content in the parent material but also influenced by the high content of Al and Fe in the soil.

This study's potential K content (HCl 25%) is generally shallow, less than 10 mg 100 g^{-1}, except in the topsoil of pedon P3 with a low criterion (16 mg 100 g^{-1}). The potential K content can affect the exchangeable K value, which CEC and the organic matter content in the soil influence. Nursyamsi

(2006) stated that there is a correlation between the potential K content and exchangeable K value, where organic C and CEC of the soil are the main factors affecting K availability in Ultisols. Organic matter promotes K availability in the soil. Research by Bader et al. (2021) shows that the concentration

Table 3. Chemical analysis results of Ultisols

Pedon	Depth (cm)	pH (H_2O)	Organic carbon	HCl 25%		Bray 1	Cation Exchangeable (NH_4-Acetat 1N, pH7)				CEC			KCl 1N		Saturation	
				P_2O_5	K_2O	P_2O_5	Ca	Mg	K	Na	Soil	Clay	Effective	Al^{3+}	H^+	Base	Al
			%	mg 100 g^{-1}		ppm	$cmol_c\,kg^{-1}$				$cmol_c\,kg^{-1}$			$cmol_c\,kg^{-1}$		%	
P1	0-10	5.1	1.77	12	3	1.95	2.45	1.32	0.06	0.08	16.11	32.22	6.07	2.16	0.30	24.27	35.59
	10-39	5.1	1.26	13	3	2.04	2.56	1.36	0.04	0.07	17.62	27.53	8.25	4.22	0.59	22.87	51.15
	39-54	5.1	0.84	10	2	1.84	2.65	1.62	0.04	0.07	18.95	27.07	10.00	5.62	0.44	23.11	56.21
	54-79	4.8	0.75	11	3	1.43	1.59	1.00	0.05	0.16	17.63	26.31	10.57	7.77	0.74	15.88	73.51
	79-120	4.8	0.29	4	3	1.63	1.25	0.89	0.06	0.04	15.34	23.60	15.09	12.85	1.49	14.60	85.15
P2	0-17	5.7	1.75	41	5	16.00	6.31	0.84	0.04	0.11	17.07	43.77	7.34	0.04	0.16	42.77	0.56
	17-48	5.2	0.84	26	6	3.53	3.05	1.12	0.09	0.70	16.21	33.08	9.88	4.92	0.40	30.60	49.82
	48-71	5.0	0.70	23	3	2.53	2.58	1.27	0.04	0.05	16.92	31.92	10.14	6.20	0.57	23.29	61.13
	71-120	5.0	0.49	24	3	1.95	2.34	1.33	0.04	0.04	16.38	30.91	10.47	6.72	0.51	22.89	64.17
P3	0-8	4.8	3.25	10	16	9.33	2.63	1.34	0.31	0.11	14.28	37.58	7.35	2.96	0.34	30.74	40.29
	8-34	4.7	0.70	5	2	2.98	0.39	0.33	0.04	0.08	11.99	21.41	9.26	8.42	0.74	7.01	90.93
	34-70	4.7	0.52	6	3	3.80	0.37	0.25	0.06	0.09	10.82	18.98	7.43	6.66	0.58	7.12	89.64
	70-120	4.5	0.35	4	6	2.20	0.44	0.30	0.12	0.11	14.97	17.82	19.59	18.62	1.60	6.48	95.05
P4	0-15	4.8	2.35	8	5	4.31	0.42	0.37	0.10	0.12	7.31	25.21	3.68	2.67	0.62	13.82	72.58
	15-34	5.0	0.55	6	2	2.15	0.43	0.25	0.02	0.09	5.99	16.64	4.63	3.84	0.73	13.19	82.93
	34-71	5.2	0.49	5	3	1.19	0.41	0.23	0.03	0.09	6.28	12.08	6.52	5.76	0.50	12.10	88.34
	71-120	5.1	0.36	5	5	0.98	0.40	0.20	0.06	0.14	7.36	12.07	9.57	8.77	0.70	10.87	91.64
P5	0-25	4.4	3.45	22	6	13.30	0.81	0.27	0.11	0.06	13.86	28.88	5.94	4.69	0.69	9.02	78.96
	25-56	4.6	0.83	8	2	4.44	0.58	0.26	0.04	0.04	8.96	17.23	5.30	4.38	0.44	10.27	82.65
	56-90	4.6	0.38	7	2	1.71	0.67	0.21	0.04	0.06	9.46	15.02	3.61	2.63	0.26	10.36	72.83

Note: CEC = Cation Exchange Capacity

of available potassium in the soil is influenced by organic matter. It is because organic acids (humic and fulvic) dissolve some potassium-bearing soil minerals, releasing them into the soil solution. Meanwhile, soil CEC is essential because it absorbs K in the soil. A high soil CEC increases soil uptake of potassium, thereby increasing its availability.

The exchangeable base (Ca, Mg, K, Na) is generally low to moderate (Table 3). The Ca content is generally very low (<2 $cmol_c\ kg^{-1}$) in P3, P4, and P5, and low (2-4 $cmol_c\ kg^{-1}$) in P1 and P2. The Mg content is generally shallow (<0.3 $cmol_c\ kg^{-1}$) in P4 and P5, low (0.3-1.0 $cmol_c\ kg^{-1}$) in P3, and moderate (1.1-2.0 $cmol_c\ kg^{-1}$) in P1 and P2. The K content is generally shallow (<0.1 $cmol_c\ kg^{-1}$), except in P3. The Na content is generally very low (<0.1 $cmol_c\ kg^{-1}$) in P1, P3, and P5, and low (0.1-0.3 $cmol_c\ kg^{-1}$) in P2 and P4. The low base status of Ultisols can occur due to the leaching of the parent material, in addition to the low content of base minerals in the weathered parent material. Miller (1983) stated that the low nutrient status of Ultisols is due to intensive leaching of base-rich parent material or the low content of base minerals in the weathered parent material.

Soil cation exchange capacity (CEC) represents the soil's ability to adsorb cations, including plant essential nutrients. The value of soil CEC is influenced by the type of clay minerals and the organic matter content in the soil. The CEC values of Ultisol in all topsoil layers were low (7.3-16.1 $cmol_c\ kg^{-1}$), except for P2, which had a moderate CEC value (17.1 $cmol_c\ kg^{-1}$). Meanwhile, the CEC values in all subsoil layers tended to be low to moderate (5.99-18.95 $cmol_c\ kg^{-1}$). The low CEC values of the soil may be caused by the dominance of kaolinite or 1:1 type of clay minerals with low charge density. Prasetyo's (2001) research showed that kaolinite minerals dominate Ultisols formed from claystone. Ultisols are often formed on old geomorphic surfaces with advanced weathering intensity and high leaching, which results in a high H activity (Allen and Fanning, 1983). In addition, as discussed earlier, the low organic matter content in the soil results in no additional charge coming from humus.

All the studied Ultisols have a very high saturation value of Al (>40%). In the upper layers, the highest value of Al saturation was found in P5 (78.96%), while the lowest was found in the upper layer of P2 (0.56%). In the lower layers, Al saturation values were generally higher than in the upper layers and increased with soil depth. The highest values were found in the lower layers of P3 (95.05%) and P4 (91.64%). Al saturation values tended to have a close relationship with pH. Based on Table 3, the average analysis results showed that the higher the soil pH value, the lower the Al^{3+} value. In addition to being influenced by the type of parent material, a high soil pH value can also reduce the solubility of Al hydroxides, which can benefit plant growth (Prasetyo and Suriadikarta, 2006; Hikmatullah, 2010).

Meanwhile, soil pH is closely related to base saturation. Low soil pH values generally correspond to low base saturation as well. In addition, one of the requirements for Ultisols is to have a base saturation of less than 35% (Prasetyo and Suriadikarta, 2006). Pedon P2 has a base saturation value of 42.77%, suggesting the application of lime in the tillage layer, indicated by the soil reaction and higher values of Ca, as well as lower values of Al^{3+} and H^+ compared to other pedons. Low base saturation values are a characteristic of Ultisols according to Soil Taxonomy (Soil Survey Staff, 2022) and national soil classifications Subardja et al. (2016).

Sand Minerals Composition

The mineral composition of soil depends on the parent material and weathering processes. The parent material of the Ultisols studied is a sedimentary rock, specifically claystone. The soil pedons' sand fraction is dominated by resistant minerals such as opaque minerals and quartz (Table 4). Opaque minerals dominate pedons 1 and 2, while pedons 3, 4, and 5 are dominated by quartz. Opaque minerals are iron oxide minerals whose type cannot be distinguished by polarization microscopy. Meanwhile, quartz is a mineral that originates from acidic igneous rocks such as granite, rich in SiO_2 and crystallized at relatively low temperatures, making it more resistant to weathering (Prasetyo et al., 2005).

The dominance of resistant minerals indicates that the Ultisols studied have undergone extensive weathering. In contrast, easily weathered minerals such as hornblende, augite, sanidine, hypersthene, and others are scarce. Quickly weathered minerals can release nutrient elements that are available to plants. Hornblende and augite contain macronutrients that plants need, such as Ca and Mg, as well as micronutrients, such as Fe and Na. Meanwhile, sanidine is rich in the macronutrient K and the micronutrient Na (Churchman and Lowe, 2012). Although their amount is small, the presence of easily weathered minerals can be a valuable nutrient reserve for plants.

Weatherable minerals have the potential to serve as nutrient reserves for plant growth. Calculation of mineral reserves (MR) (Table 4), the sum of weatherable minerals, shows that the pedons

Table 4. Csompositions of sand fraction mineral of Ultisols.

Pedon	Depth (cm)	Sand Fraction Mineral (%)																											MR (%)	MR Status
		Resistant Mineral					Weatherable Mineral																							
		Op	Zi	Tq	Cq	Ic	Li	Ze	Hi	Wm	Rf	Vg	Al	Ol	An	Lb	Or	Sa	Mu	Gh	Au	Hs	Ov	Ep	Tu	Ad	Sm	RA		
P1	0 - 10	46	8	8	26	-	sp	-	Sp	sp	4	-	sp	sp	-	-	-	2	-	sp	4	2	sp	-	sp	-	-	-	12	M
	39 - 54	43	9	6	25	-	1	-	Sp	1	3	-	sp	sp	-	-	-	3	-	1	5	3	-	-	sp	-	-	-	17	M
	79 - 120	29	1	9	47	sp	5	-		7	2	-	-	-	-	-	-	sp	-	sp	sp	sp	-	-	-	-	-	-	14	M
P2	0 - 17	50	2	13	22	1	sp	sp	Sp	6	sp	-	-	sp	sp	sp	sp	5	-	sp	1	sp	-	sp	-	-	-	-	12	M
	48 - 71	46	5	10	20	sp	sp	1	2	5	sp	sp	-	-	-	-	-	11	-	sp	-	-	-	-	-	-	-	-	19	M
P3	8 - 34	21	7	36	28	2	1	-	-	3	sp	-	-	-	-	-	-	2	-	-	-	-	-	-	sp	sp	-	-	6	L
	34 - 70	18	3	45	30	sp	sp	-	-	3	sp	-	-	-	-	-	-	1	-	-	-	-	-	-	-	sp	-	-	4	VL
P4	15 - 34	10	3	65	15	sp	sp	-	-	3	-	-	-	-	-	-	-	-	-	-	sp	sp	-	-	4	sp	-	sp	7	L
	71 - 120	10	3	69	11	-	1	-	-	4	sp	-	-	-	-	-	-	-	-	-	sp	-	-	-	1	1	-	-	7	L
P5	0 - 25	15	2	39	24	1	sp	-	-	17	sp	-	-	-	-	-	-	sp	1	-	-	-	-	-	1	-	sp	-	19	M
	56 - 90	21	1	45	23	sp	-	-	-	10	-	-	-	-	-	-	-	sp	sp	-	-	-	-	-	sp	-	sp	-	10	L

Remarks: Op=Opaque, Zi=Zircon, Tq=Turbid quartz, Cq=Clear quartz, Ic=Iron concretion, Li=Limonit, Ze=Zeolit, Hi=Hidragillite, Wm=Weathered mineral, Rf=Rock fragment, Vg=Volcanic glass, Al=Albit, Ol=Oligoklas, An=Andesine, Lb=labradorite, Or=Orthoclase, Sa=Sanidine, Mu=Muskovite, Gh=Green horblende, Au=Augite, Hs=Hypersthene, Ov=Olivine, Ep=Epidote, Tu=Tourmaline, Ad=Andalusite, Sm=Sillimanite, RA=Rutile and Anatase, sp=sporadic, MR=Mineral Reserves, H=High, M=Moderate, L=Low, VL=Very Low, - = no data.

have MR values ranging from very low to medium. The percentage of MR in P1 and P2 shows a higher trend in the subsoil than in the topsoil. This indicates that intensive soil management activities in the topsoil accelerate the process of mineral weathering. Prasetyo et al. (2005) show that weatherable mineral content such as orthoclase, biotite, epidote, volcanic glass, olivine, sanidine, augite, and hypersthene in

Ultisols is generally low or even absent. Pedons P3 and P4 have the lowest MR status compared to the other three pedons. This may be due to differences in soil formation processes (age, climate) and land management practices. Several studies have shown that land management practices can affect the amount of organic and mineral materials (Wilcke and Lilienfein, 2004; Li et al., 2014; Kundu et al., 2017; Amanuel et al., 2018). The overall MR values of the five Ultisols pedons indicate that the soils are poor in the nutrients required for plant growth.

Mineral clay analysis was not conducted in this study. However, Prasetyo's (2009) research showed that red soils such as Ultisols are dominated by kaolinite clay minerals, which have a low negative charge and, thus, low cation exchange capacity (CEC). The dominance of kaolinite also indicates a high level of weathering and leaching of bases in the soil environment, resulting in generally acidic soil reactions.

Soil Classification

The soil classification is based on the soil's morphological, physical, and chemical properties. The soil classification in this research is presented in Table 5. The upper horizon characteristics (epipedon) of the studied soil are classified into Ochric. The soils in this study are categorized as Ochric because they exhibit bright soil color (value and chroma) of > 3 (P1 and P5) and a depth of < 18 cm (P2, P3, and P4), which does not meet the criteria for an umbric epipedon. The lower horizon characteristics of the soil are classified as Argillic (P1, P2, and P3) and Kandic (P4 and P5) horizons. This is characterized by an increase (illuviation) in clay content from the A horizon to the B horizon in all pedons (Figure 1). Therefore, all pedons are classified into the Ultisols order. All pedons are placed in the Udults suborder at the suborder level due to the udic moisture regime. Pedons 1, 2, and 3 are categorized as Hapludults at the great group level because they have a moderate to deep (d" 120 cm) soil thickness with relatively good drainage conditions. In comparison, pedons 4 and 5 are classified as Kanhapludults because they have a moderate to deep (90-120 cm) soil thickness with relatively good drainage conditions, and CEC clay of 16 $cmol_c\ kg^{-1}$ or less and effective CEC of 12 $cmol_c\ kg^{-1}$ or less. Meanwhile, at the subgroup level, all pedons P1 to P5 are placed in the Typic subgroup because the pedon characteristics do not meet the criteria for other subgroup classes (Soil Survey Staff, 2022).

Land Management

The development of agriculture on Ultisols faces several challenges related to high acidity, high aluminum saturation, and low nutrient and organic matter content (Prasetyo and Suriadikarta, 2006), likewise, with Ultisols, which comes from the claystone parent material. These soils have a pH range of 4.4-5.7 (acidic to slightly acidic). The overall aluminum saturation values are very high, except in the top layers of P1 and P2. The top layer of P1 has a high aluminum saturation value, while P2 has a low aluminum saturation value. The total organic C, P, and K contents are deficient, except for P3 and P5, which have high organic C contents in the top layer. The base saturation and cation exchange capacity values are generally low to moderate.

Table 5. Soil classification using Soil Taxonomy Keys (Soil Survey Staff, 2022).

Classification	P1	P2	P3	P4	P5
Epipedon	Ochric	Ochric	Ochric	Ochric	Ochric
Subsurface Horizon	Argillic	Argillic	Argillic	Kandic	Kandic
Soil moisture regime	Udic	Udic	Udic	Udic	Udic
Soil temperature regime	Isohyperthermic				
Order	Ultisols				
Suborder	Udults	Udults	Udults	Udults	Udults
Great Group	Hapludults	Hapludults	Hapludults	Kanhapludults	Kanhapludults
Subgroup	Typic	Typic	Typic	Typic	Typic

The fertility of Ultisols from the claystone parent material in the research location, according to the criteria for soil analysis (Eviati and Sulaeman, 2012), is classified as very low to moderate. Based on these criteria, Ultisols in the research location require liming, organic matter management as a soil conditioner, and increased P and K fertilizers. The utilization of Ultisols as agricultural land is suitable for perennial or estate crops, such as oil palm, rubber, pepper, coffee, cocoa, and industrial plantations, especially in Sumatra and Kalimantan (Prasetyo et al., 2001; Prasetyo and Suriadikarta 2006; Andalusia et al., 2016).

CONCLUSIONS

Ultisols derived from claystone parent material at Sumatra generally exhibit deep soil profiles and high clay content. These soils are categorized as having low to moderate fertility. The chemical properties of these soils include an acidic to slightly acidic soil pH, generally low organic carbon content, low to moderate Cation Exchange Capacity (CEC), low available phosphorus content, and low potential potassium content, as well as low to moderate potential phosphorus content. The prevalence of resistant minerals (opaque and quartz minerals) and the low levels of easily weathered minerals in these claystone-derived Ultisols contribute to their low essential nutrient content for plant growth. Various challenges in claystone-derived Ultisols can be addressed through appropriate management practices, such as adding lime, organic matter management, balanced fertilization, and implementing suitable technologies.

ACKNOWLEDGMENTS

This study data was supported by the Indonesian Center for Agricultural Land Resources Standardization (ICALRS). We are thankful to our survey team, who helped with technical and fieldwork. All authors are the main contributors to this paper, contributed to collecting and analyzing the data, and wrote the manuscript.

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