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Toposequent Effect on Soil Morphology and Classification of Ultisol Soil in the Ayer Hitam Forest Reserve, Peninsular Malaysia

Haidar Fari Aditya[1], Seca Gandaseca[2,3,*], Mochtar Lutfi Rayes[4], Daljit Singh Karam[5]

[1] Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Jatim. Jl. Raya Rungkut Madya, Gunung Anyar, Surabaya, 60294, East Java, Indonesia
[2] Faculty of Forestry and Environment, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia
[3] Institut Ekosoins Borneo, Universiti Putra Malaysia Bintulu Sarawak Campus. 97008 Bintulu, Sarawak, Malaysia
[4] Faculty of Agriculture, Brawijaya University. Jalan Veteran, Malang, East Java, Indonesia
[5] Faculty of Agriculture, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia
[*] Corresponding Author. E-mail address: seca@upm.edu.my

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ABSTRACT

Morphology in forest soils has developed over a long time due to the non-intensive management of forest soils. Damage to forest soil occurs when there is logging activity, fire, or land use change. Some forest was used as productive land for example agroforestry and forest production. As with land use in agriculture, intensive management of forests can also reduce soil productivity. Inaccuracy forest land use would cause environmental or economic damage, so basic soil management data in forest areas is needed. However, the soil morphology of the Ayer Hitam Forest Reserve (AHFR) in Malaysia has never been observed. The objective of this study is to assess the soil characteristic and soil morphological properties of the AHFR. Studying the characteristics of soil morphology in toposequent conditions is necessary to find out the differences in soil from different heights and the effects of erosion, transportation, and deposition on the soil. This study was conducted in the AHFR, Puchong, Selangor Darul Ehsan, Peninsular Malaysia. Mapping of the area under investigation was carried out by conventional soil survey techniques with a physiographic approach using maps with a scale of 1:30,000. The results showed that AHFR has some different soil morphological characteristics and classification in subgroup among five different slope positions with similar soil order, which is a Ultisol soil. The soil in the AHFR is formed from highly weathered soil due to high rainfall in this location. The results of this study are important for soil development, identification management, and land use priority such as erosion control on steep-slope forest areas, regeneration and reforestation, and it can also be used for forest education, practice, research, and training activities.

1. Introduction

Soil is one of the natural resources that has a vital role in the ecosystem, including for plant growth, habitat for animals living in the soil, recycling systems for nutrients, water supply, and filtering or purifying systems. Peninsular Malaysia is dominated by Ultisol and Oxisol soils as the most common soil order found in tropical forests and agricultural land (Anda et al. 2008).

Generally, soils in Peninsular Malaysia are classified as Ultisol soils. These soils are highly weathered and have low nutrients; hence, they are not sufficient for farming (Fatai et al. 2017).

In the study of soil development, the topographic factor is the most important thing in assessing and determining soil properties; slope position also affects the weathering process, development, and leaching (Khomo et al. 2011, 2013; Molina et al. 2019). According to (Grealish and Fitzpatrick 2014). Toposequence is a concept of soil development by considering topography as a soil-forming factor that plays an active role in pedogenesis. Jimoh et al. (2020) stated that topography plays an active role in influencing soil properties, especially in sequential units (toposequent), where toposequency is a conceptual approach to changing soil properties due to differences in elevation.

Ultisol soils have limited physical and chemical properties, which can be a problem in building a stand (Riniarti and Setiawan 2014; Shamshuddin and Fauziah 2010; Taisa et al. 2019; Yuwono 2009). However, naturally, the tropical forest in Ayer Hitam can thrive on it, given the wide distribution of Ultisol soils. So, this soil has unique characteristics in morphological properties. Ayer Hitam Forest Reserve (AHFR) is a tropical forest with rich biodiversity dominated by dipterocarp trees (Aditya et al. 2020). Studying the characteristics of soil morphology in toposequent conditions is necessary because we can find out the differences in soil from different heights and the effects of erosion, transportation, and deposition on the soil in this location.

Knowing soil characteristics and classification in the forest would also be helpful to identify management and land use priorities. Morphology in forest soils has developed over a long time due to the non-intensive management of forest soils. Damage to forest soil occurs when there is logging activity, fire, or land use change. Some forest was used as productive land for example agroforestry and forest production. As with land use in agriculture, intensive forest management can also reduce soil productivity (Binkley and Fisher 2019). Inaccuracy forest land use would cause environmental or economic damage, so basic soil management data in forest areas is needed. However, the soil at AHFR has never been observed. So, the objective of this study was to assess the soil characteristic and soil morphological properties. This study was conducted in the AHFR Puchong, Selangor Darul Ehsan, Peninsular Malaysia.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Ayer Hitam Forest Reserve (AHFR), located in the fast-growing area of Puchong, Selangor Darul Ehsan. The AHFR has soil series of Serdang-Kedah and Durian. Generally, the soil of AHFR was a combination of alluvium-colluvium, derived from metamorphic stones and dominated by loam clay texture (Lepun 2007). This forest has an annual temperature of 22.7°C with a maximum temperature of 32.1°C and a minimum temperature of 24.6°C (Lepun 2007; Saari et al. 2014). The AHFR forest has high rainfall of 3,301.4 mm (Lepun 2007). According to Azim and Okada (2014), the AHFR is classified as a tropical rainforest with a short dry period of 1-2 months, from June to July. The vegetation composition in the AHFR is dominated by dipterocarp trees with subtype 'Kelat-Kedondong'-Mix dipterocarp, and this forest is dominated by a high density of small and medium-size trees (Aditya et al. 2020; Ibrahim 1999; Lepun 2007).

2.2. Soil Sampling

Mapping of the area under investigation was carried out by soil survey techniques with a physiographic approach using maps with a scale of 1:30,000 (**Fig. 1**). Soil pits with a breadth of 1 m x 1 m and 180-200 cm profile depth were excavated. Soil color, particle-size distribution, consistency, and structure (hand-feel method) were determined in the field. Soil samples from all horizons were determined by physical analysis in the laboratory at Universiti Putra Malaysia, Serdang.

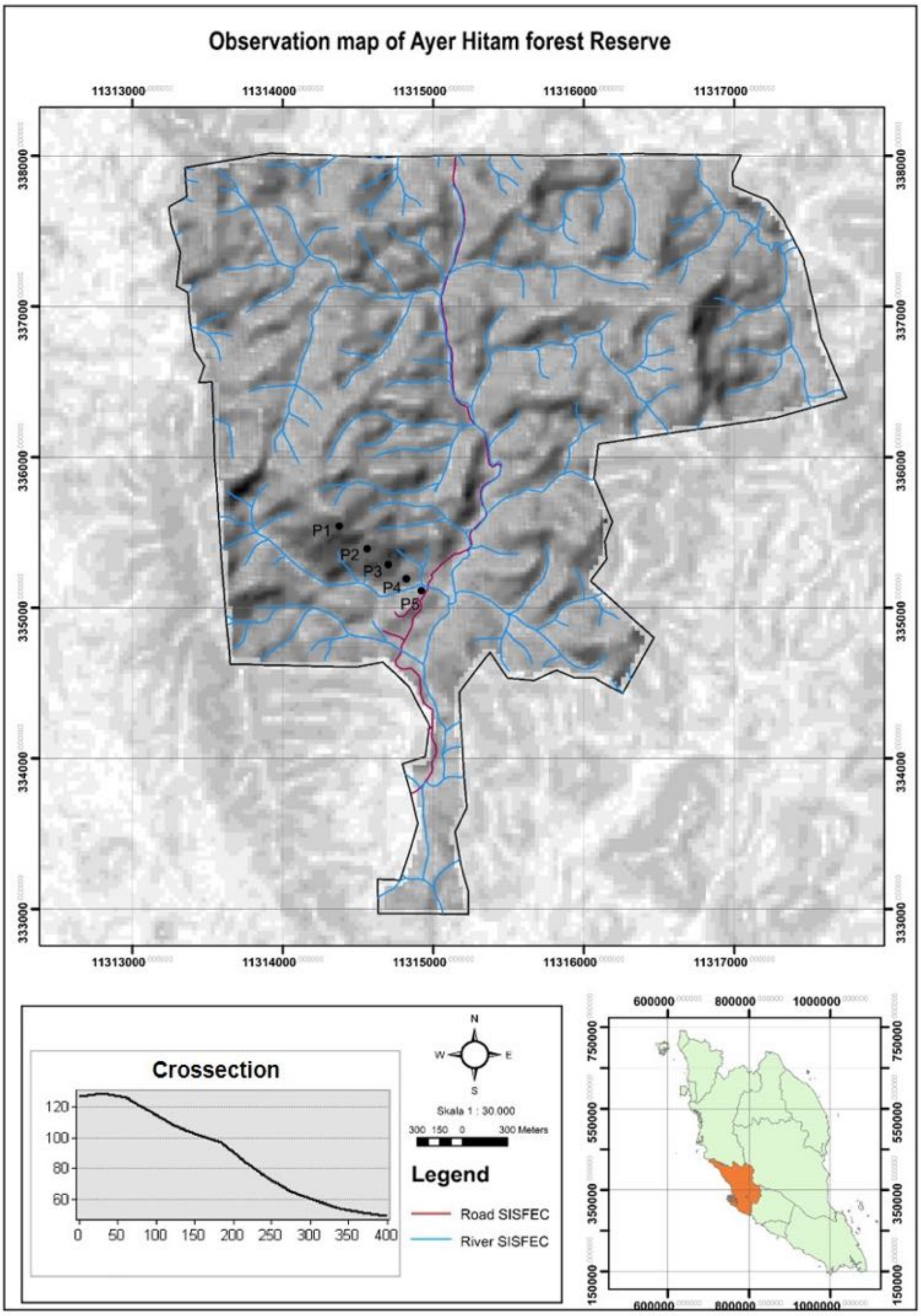

Fig. 1. Research location at P1 (ridge), P2 (middle slope), P3 (middle slope), P4 (lower slope), and P5 (flatland) in Ayer Hitam Forest Reserve, Selangor Darul Ehsan, Malaysia.

The pedogenesis of horizon in the soil profile must be identified in the field and then described using the rules of soil classification, followed by soil sampling in accordance with the identified genetic horizon. Rayes (2017) suggested to observe the soil profile according to horizon boundary, horizon thickness, texture, structure, consistency, effective depth, type and number of pores, and other characteristics. On the other hand, physiographic criteria observed were relief, slope, drainage, permeability, erosion rate and flooding, rocks, surface, irrigation system, natural vegetation, and other environmental conditions. In this research, five observation points were determined based on topographic components such as slope and elevation. Based on the slope component, AHFR was grouped into seven slope classes: 0–3%, > 3–8%, > 8–15%, > 15–25%, > 25–40%, > 40–60%, and > 60%. Land elevation ranged between 50 to 233 masl and divided into three landforms: hill, medium, and low.

3. Results and Discussion

3.1. Soil Morphological Characteristic in Ayer Hitam Forest Reserve

Fig. 2 shows the soil profile classification identified using keys to soil taxonomy (Soil Survey Staff 2014) for each type of topography (P1, P2, P3, P4, and P5). It showed differences between the 5 different topographies. The soil in the AHFR is formed from highly weathered soil due to high rainfall at this location. From the five soil profiles, clay content was identified by the *Bt* symbol. Clay content in the subsoil is obtained through the clay illuviation process. Symbol *t* indicates the presence of silicate clay in the soil. Silicate clay soil formed due to the process of illuviation (Soil Survey Staff 2014) and is defined as Argilic horizon. The illuvial horizon is presented in all sites. Generally, soil in the AHFR is formed from granite metamorphic rock, characterized by high sand content in the horizon A (A1 and A2) from each horizon at soil profile P1 until P5. This was because the forest vegetation produced a high amount of organic litter on horizon A. From the illuviation process, clay on the surface will move and accumulate to horizon B, which is influenced by high rainfall (Shamshuddin and Fauziah 2010; Tessens and Shamsuddin 1983). Criteria of the argillic horizon and its illuviation process presented the major criteria of Ultisol order.

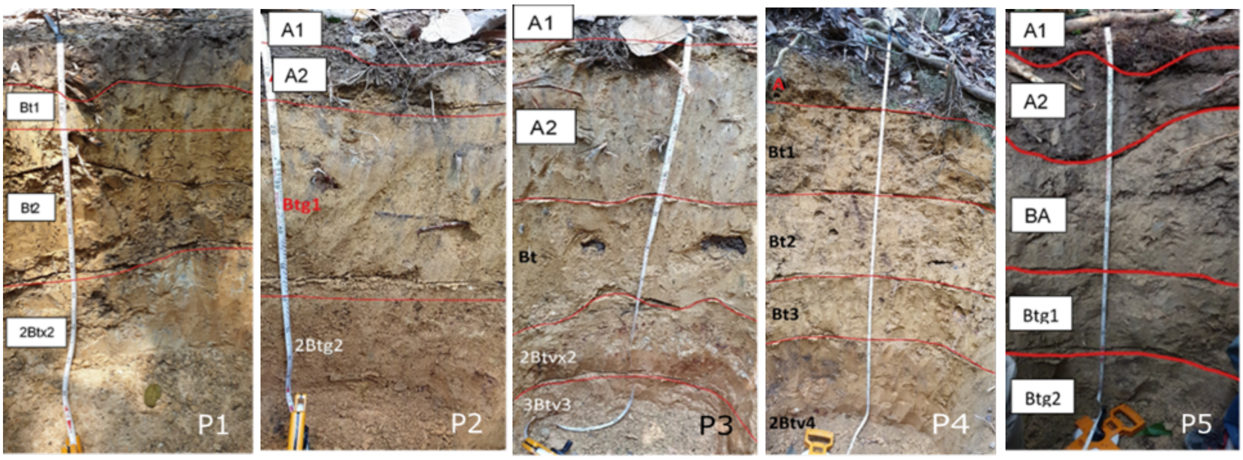

Fig. 2. Soil profile from each topography (P1, P2, P3, P4, and P5).

Table 1 shows that the soil's morphological characteristics (color, texture, structure, and consistency) at the 5 study sites at AHFR have almost similar characteristics. According to the soil survey, the soil structure has developed soil color occurs braunification (yellowish-brown to red-brownish). Fatai et al. (2017) stated that the color of Ultisol soil in the topsoil has a yellowish-brown color and will get reddish with the increase of depth.

Table 1. Morphological characteristics of the soil at each profile and horizon in Ayer Hitam Forest Reserve

Profile	Hori-zon	Symbol	Depth	Color		Texture	Structure	Consistency			Distinctness	Topography
				Moist	Dry			Moist	Wet	Dry		
P1	1	*A*	0-10	10 YR 3/3	10 YR 6/2	Sandy Clay Loam	Subangular Blocky, md, mr	FR	NPL/NST	HA	Clear	Wavy
	2	*Bt1*	10-15	10 YR 8/4	10 YR 8/2	Sandy Clay	Subangular Blocky, md, mr	FI	NPL/NST	VHA	Clear	Wavy
	3	*Bt2*	15-50	7,5 YR 7/6	10 YR 8/3	Clay	Angular Blocky, md, st	VFI	SST/SPL	VHA	Diffuse	Smooth
	4	*2Btx2*	50-110	7,5 YR 6/5	10 YR 8/2	Clay	Angular Blocky, cr, st	EFI	SST/SPL	EHA	Diffuse	Smooth
P2	1	*A1*	0-5	10 YR 5/2	10 YR 6/3	Silty Clay Loam	Single Grain, fn, wk	FR	NPL/NST	LO	Clear	Smooth
	2	*A2*	5-15	10 YR 6/6	10 YR 8/4	Silty Loam	Angular Blocky, md, mr	FR	NPL/NST	SHA	Gradual	Smooth
	3	*Btg1*	15-60	7,8 YR 7/8	10 YR 7/6	Clay Loam	Angular Blocky, md, st	FI	SST/SPL	SHA	Diffuse	Smooth
	4	*2Bt2*	60-150	7,5 YR 4/6	10 YR 7/6	Clay Loam	Subangular Blocky, md, st	FI	ST/SPL	VHA	Diffuse	Smooth
P3	1	*A1*	0-5	10 YR 5/4	10 YR 6/3	Silty Clay Loam	Single Grain, cr, wk	VFR	NPL/NST	LO	Clear	Smooth
	2	*A2*	5-35	10 YR 6/8	10 YR 6/2	Silty Loam	Angular Blocky, md, mr	FR	SST/SPL	SHA	Gradual	Smooth
	3	*Bt1*	35-70	10 YR 8/6	10 YR 8/4	Clay	Subangular Blocky, md, st	FR	ST/PL	HA	Diffuse	Smooth
	4	*2Btvx2*	70-100	7,5 YR 5/8	10 YR 8/6	Clay	Angular Blocky, cr, st	FI	ST/SPL	VHA	Diffuse	Wavy
	5	*3Btv3*	100-150	5 YR 5/6	10 YR 8/6	Clay	Angular Blocky, cr, st	FI	ST/PL	VHA	Diffuse	Wavy
P4	1	*A*	0-27	10 YR 5/4	10 YR 6/8	Clay Loam	Subangular Blocky, fn, wk	FR	NPL/NST	SO	Gradual	Wavy
	2	*Bt1*	27-60	10 YR 6/6	10 YR 7/6	Sandy Clay	Subangular Blocky, fn, wk	FR	SST/SPL	HA	Diffuse	Smooth
	3	*Bt2*	60-95	10 YR 6/6	10 YR 8/6	Sandy Clay	Angular Blocky, md, mr	FI	SST/SPL	HA	Diffuse	Smooth
	4	*Bt3*	95-125	10 YR 6/8	10 YR 8/6	Sandy Clay	Angular Blocky, md, st	FI	SST/SPL	HA	Diffuse	Smooth
	5	*2Btv4*	125-170	7,5 YR 4/6	10 YR 8/6	Clay	Angular Blocky, fn, st	VFI	ST/PL	HA	Diffuse	Wavy
P5	1	*A1*	0-10	10 YR 3/1	10 YR 6/2	Sandy Loam	Single Grain, cr, wk	VFR	NPL/NST	LO	Gradual	Smooth
	2	*A2*	10-30	10 YR 3/2	10 YR 7/3	Sandy Loam	Angular Blocky, md, wk	FR	NPL/NST	SO	Diffuse	Smooth
	3	*BA*	30-70	10 YR 3/3	10 YR 8/3	Clay Loam	Angular Blocky, md, st	FI	SST/SSL	SHA	Diffuse	Smooth
	4	*Bt1*	70-100	10 YR 7/6	10 YR 8/2	Silty Clay Loam	Angular Blocky, md, st	VFI	SST/SSL	HA	Diffuse	Smooth
	5	*Bt2*	100-130	10 YR 8/8	10 YR 8/2	Clay	Subangular Blocky , md, st	VFI	ST/PL	HA	Diffuse	Smooth

Note: FR=friable; FI=firm; VFI=very firm; EFI=extremely firm; NPL=non plastic; SPL=slighty plasctic; PL=plastic; NST=non sticky; SST=slighty sticky; ST=sticky; HA=hard; VHA=very hard; EHA=extremely hard; SHA=slighty hard; LO=loose; SO=soft; md=medium; cr=coarse; fn=fine; wk=weak; mr=moderate; st=strong

Generally, the color change in the Ultisol soil to the yellowish-brown was due to the higher content of goethite, while the redder color in Ultisol soil was caused by higher hematite content (Prasetyo and Suriadikarta 2006). According to Tessens and Shamsuddin (1983), the yellowish color in Ultisol soil contains the mineral Kaolinite. Fatai et al. (2017) conducted RXD analysis and stated that soils in Peninsular Malaysia are dominated by hematite minerals, one of the widespread minerals found in very weathered soils in Malaysia, especially Ultisol soil. Previous studies (Fauzi et al. 2004; Prasetyo et al. 2006) stated that Ultisol soils generally have a strongly developed soil structure that is medium to strong with angular blocky. The morphology characteristics with high soil consistency align with a previous study in Central Pahang (Tan et al. 2014), showing key characteristics of Ultisol soil. Based on color, texture, structure, and consistency (**Table 1**), it can be determined that the AHFR has one soil order, which is Ultisol.

On the other hand, each site has different characteristics depending on the slope. At the soil profiles P3 and P4, plinthite was found at 100 cm in depth (horizon B). In **Table 1**, it is marked by the suffix *v,* which means plinthite. At P5, there were concretions of redox morphic feature (RMF) at 50 cm to the lower depth. According to Soil Survey Staff (2014), the suffix *g* in naming the genetic horizon was added after *B* symbols. Concretions can occur in Podzolic soils with alternating dry and moist periods, favoring oxidation-reduction processes, hydration, and dehydration (Sanborn et al. 2011). Those unique characteristics were showing major key criteria of Ultisols. As noted above, the efficient depth of these sites ranged up to 150 cm and suitable for forest reserve land use regionally.

3.2. Soils Classification in Ayer Hitam Forest Reserve

The AHFR has similar soil characteristics with different subgroups of soil classification (**Table 2**). If we look at the climate data in the AHFR, it is categorized in the Udic soil moisture regime (rainfall exceeds 90 days in a year). The soil temperature regime is categorized into isohyperthermic (> 22ºC with differences in summer and cold soils <5ºC). Almost all soil temperature regime in Malaysia is classified to isohyperthermic. Based on chemical and physical data analysis from Aditya et al. (2020), field research shows that soil profile at P1 until P5 in all depths of 60-150 cm indicated an accumulation of clay textures. The results also showed a base saturation value of less than 50% on the entire horizon at P1 and P5. Thus, it strengthens the notion that Epipedon is categorized into the Umbric horizon at all observation points.

Fragipan properties were found at the Endopedon (P1 and P3), marked by the suffix *Bx*. One of the properties of fragipan is that it is hard when pressed but easily crumbles when exposed to water. West et al. (1998) stated that fragipan is a subsurface horizon with white color, high clay texture, low organic matter content, and high bulk density. Raimondo et al. (2019) stated that fragipan is a soil horizon with hard properties and easily brittle when moist. Fragipan has a high bulk density ranging from 2 to 3 g/cm^3 and low porosity (Raimondo et al. 2019). However, at the P3 observation point, the plinthite horizon properties (colored red at depth > 100 cm) were found. Martins et al. (2018) stated that plinthite could be found in flat or slightly sloping areas, has high Fe, and is often exposed to seasonal groundwater levels. Plintithe is formed from the accumulation of iron hydroxide, quartz, and kaolinite. If quartz hardened, it will form petroplinthite.

The presence of iron in the plintithe is due to anaerobic water conditions. The iron ion content is transported, and precipitation occurs, forming soft clayey iron oxide, which hardens after drying (Martins et al. 2018). Almost all soil profiles (P1 to P5) at a depth of more than 100 cm showed evidence of clay eluviation due to the lessivage process. This lessivage process is formed because the AHFR area has high rainfall, causing clay particles to leach into the subsoil and formed an argillic horizon. Calabrese et al. (2018) stated that the transport of clay particles mainly occurs vertically during percolation events but can be more complex, depending on water flow dynamics. Bacon et al. (2012) stated that the content of clay particles could be found more at depths between 150-200 cm characterized by an acid and very weathered area, namely Ultisols. The phenomenon of finding clay illuviation in the AHFR forest is expected due to the high rainfall in Malaysia (Shamshuddin and Fauziah 2010).

Table 2. Soil classification in Ayer Hitam Forest Reserve based on keys to soil taxonomy (Soil Survey Staff 2014)

Pedon	P1	P2	P3	P4	P5
Epipedon	Umbric	Umbric	Umbric	Umbric	Umbric
Endopedon	Argilic and Fragipan	Argilic	Fragipan and Plintite	Argilic	Argilic
Orders	Ultisols	Ultisols	Ultisols	Ultisols	Ultisols
Suborders	Udults	Udults	Udults	Udults	Udults
Groups	Hapludults	Hapludults	Fragiudults	Hapludults	Hapludults
Subgroups	Typic Fragiudults	Typic Hapludults	Plintic Fragiudults	Typic Hapludults	Typic Hapludults

Plinthite is generally characterized by a high Fe content (in the form of goethite, hematite, and poorly crystallized oxide compounds) and aluminium with other components (Eze et al. 2014; Lal and Stewart 2005). The irreversible massive plinthite generally can be referred to as "Petro plinthite" which is also known as "ironstone" (Beinroth et al. 1996; Eze et al. 2014). The characteristics of mineral in Ultisol soils is dominated by secondary minerals such as kaolinite and oxides of Fe and Al, which have a broad impact on soil fertility (Fatai et al. 2017). From the results of determining the soil classification in AHFR according to the USDA book (Soil Survey Staff 2014), The five soil profiles met the requirements of the Ultisol order characteristics. Soil profile at the P1 is classified as Typic Fragiudults as indicated by the presence of fragipan properties. Soil profiles P2, P4, and P5 are classified as Typic Hapludults. On the other hand, soil profile P3 is classified as Plintic Fragiudults as indicated by the presence of fragipan and plintitthe properties on the horizon.

3.3. *Toposequence Influence Soil Morphology and Classification*

The topography is a factor that influences the development of soil morphology. Topography has several components, including elevation, slope, and relief. Based on the results, the topography influences AHFR to soil taxonomy. **Fig. 3** shows the cross-section of pedon location along toposequent, starting from the top point, namely P1 (top) to P5 (foot slope). The level of soil development can be seen from the thickness of the horizon, soil color, structure, and consistency to soil texture.

The soil in P1 has a Typic Fragiudults soil taxonomy. This soil is located at the top of the AHFR. Having a shallow solum and fragipan at 110 cm of depth, vegetation in this location is a forest with distributing trees. The high rainfall in this site can make a clay fraction illuviation process due to the direct drop of rainwater on the surface, forming fragipan below (> 100 cm). Breemen and Buurman (1998) stated that many fragipans have oriented clay. Illuviation of clay on grain contacts and pores is a possible cause of higher bulk density and binding of particles by sedimented (or crystallized amorphous) material. Arrangement of silt-size material in spaces between much coarser grains, caused by water percolation, increases density. Locations P2, P4, and P5 have the same soil taxa, Typic Hapludults. Points P2 to P5 have deep soil solum > 120 cm. The depth of the soil solum at this point is caused by erosion so that the soil in position P1 is eroded due to high rainfall in the location.

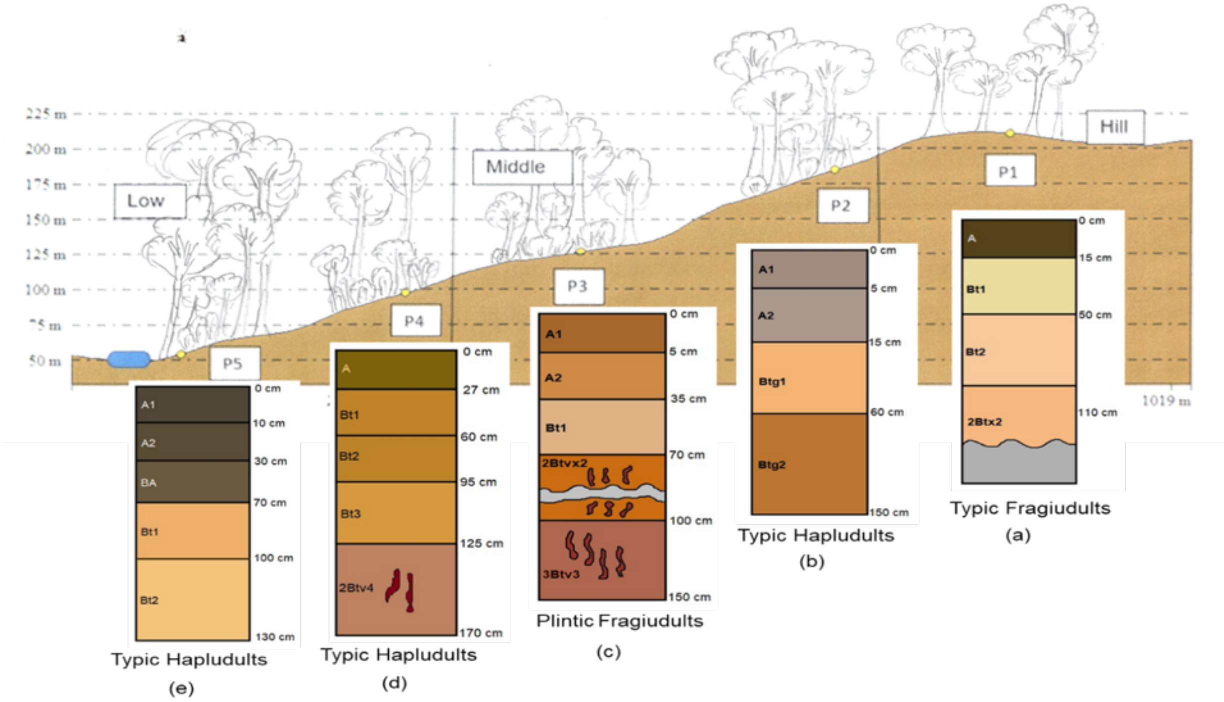

Fig. 3. Crossection of pedon location along toposequence: (a) top (b) upper middle slope (c) lower middle slope (d) lower slope (e) foot slope.

According to Yulina (2015), the steeper slope could have higher soil erodibility so that the soil is less resistant to erosion and transports material to a lower place. High rainfall at the study site can also provide intense leaching. According to Fatai et al. (2017), Malaysia has high rainfall, so that it is under highly leaching in the subsoil. Therefore, soil particles and nutrients are leached and lost to the subsoil (B horizon) during the rainy season. However, the P3 has different soil taxa compared to others. We found a fragipan and plinthite so that it is classified as the Plinthic Fragiudults soil taxa. Previous studies (Collins and Foster 2016; Hook and Burke 2000) stated that soil variations on the slopes generally reflect long-term geomorphic processes (such as erosion and deposition) that can distribute soil particles to more places in the soil. The slope of the AHFR can also contribute to the transfer of soil material and soil properties. Steeper slopes can contribute to more significant runoff and greater translocation of slope surface material through the process of surface erosion and soil mass movement (Tsui et al. 2004).

This finding result is essential as the soil database of the AHFR as a university forest education for soil development, identification management, and land use priority such as erosion control on steep slope forest areas, regeneration and reforestation. This finding may provide a clue to help develop sustainable and eco-friendly systems for forest management in AHFR. So, these findings can also be used for forest education, practice, research, and training activities.

4. Conclusions

Different soil morphological characteristics and classification at the AHFR in each soil profile were found at the five different slope positions. High clay content was found in all sub-soils due to the illuviation process. According to the color, texture, structure, and consistency of soil in the study area, it can be concluded that the area under investigation at the AHFR has only one soil type as an Ultisol soil. This finding result is important for soil development, identification management, and land use priority such as erosion control on steep slope forest areas, regeneration, and reforestation. It can also be used for forest education, practice, research, and training activities.

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