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Characterization and genesis of soils derived from sedimentary rocks in the Crocker Formation, Sabah, Malaysia

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Abstract: Soil properties in three rain forest types and six different elevations (921, 1173, 1317, 1556, 1727 and 1932 m above sea level) were studied at Mount Alab, Sabah. The chosen study site consisted of soils derived from sedimentary rocks of the Crocker Formation aged from Late Eocene to Early Miocene. Results of this study showed that soils with difference in elevation demonstrated considerable variations in term of morphological and physicochemical properties depending on the nature of the parent materials. At the highest elevation, the soil profile presented with a thin surface organic layer. On the other hand, the soils changed from Inceptisols to Ultisols with decreasing elevation. All soils were moderately acidic with an abundance of sand in these soil profiles due to the dominance of sandstones in their parent materials. Clay fraction of these soil profiles was dominated by clay-sized quartz while illite, kaolinite, interstratified illite-vermiculite, gibbsite and vermiculite were present in low or minor amounts. The chemical properties of the soils were significantly affected by topographical positions. The highest value of total organic carbon and total nitrogen were obtained at the summit, whereas, toeslope had relatively more exchangeable calcium and aluminium. Therefore, soil quality was better at higher topographical positions in this study.

Keywords: Soil physicochemical properties, sedimentary rocks, topographical positions

INTRODUCTION

The genesis and transformation of rocks into soils depends greatly on five soil forming factors, namely climate, organisms, topography, parent materials and time (Jenny, 1941). Malaysia is located near the equator, exhibiting tropical climate with high precipitation and temperature throughout the year. Consequently, soil formation underwent higher intensity of weathering when compared with temperate and arid regions. This was due to stronger and more intensive weathering processes that occurs continuously throughout the year (Verheye, 2008) and hence promoting a rapid leaching of nutrients (Radulovich & Sollins, 1991). Consequently, it is estimated that about 72% of Malaysia is dominated by Ultisols and Oxisols (Shamshuddin & Noordin, 2011). In addition, tropical soils are often characterized by their high acidity, low cation exchange capacity and poor base saturation in which the mineralogy of Oxisols is predominantly in quartz, kaolinite, oxides of iron, manganese and aluminum (Osman, 2013a).

Sedimentary rock formations consisting of sandstone, shale, claystone and limestone are widespread in Sabah, East Malaysia (Gopinathan *et al*., 1977; Hutchison, 2005). Due to historical reasons, Peninsular Malaysia, Sabah and Sarawak used different criteria to define soil families and soil series. Reconnaissance and semi-detailed soil surveys classify the soils of Sabah state mainly in Acrisols, Fluvisols, Gleysols, Cambisols, Luvisols, Ferralsols, Lithosols, Podzols and Histosols with a limited extent of Rankers, Arenosols and Rendizinas (Gopinathan *et al*., 1977). Specifically, the Crocker association comprised mostly of Cambisols and Lithosols which is the most extensive association in Sabah that stretched almost continuously from Kudat and Bengkoka Peninsulas in the north-east to the Kalimantan boundary in the south (Acres *et al*., 1975).

Stauffer (1967) studied the typical flysch-type sequences that are present in the rhythmic sequences of interbedded sandstones and mudstones within the Crocker Formation. The sandstone beds are generally 10-80 centimeters thick, but vary from a few centimeters to several meters and are interbedded with mudstones and shales which are dark gray in colour and mostly 5-50 centimeters thick but vary from 1 centimeters to 2 meters in thickness. Major tectonic activities during Late Oligocene to Middle Miocene deposited the sandstones by turbidity current (Tongkul, 1990). More recently, Azfar *et al*. (2015) have described new outcrops exposed in the West Crocker Formation and identified eight sedimentary facies which can be divided into three main groups namely sand dominated facies, poorly-sorted unit of mixed sand and mud-dominated facies as well as mud-dominated facies. This interpretation corroborates with earlier finding by Abdullah *et al*. (2013) who sub-divided seven facies types into three facies which were sand-dominated facies, debris flow-dominated facies and mudstone-dominated facies.

This study was carried out in Borneo Island, which resembled other mountainous landscape in Asia particularly in term of climate and land use. Therefore, more information which reflects soil health status under the natural ecosystem is indispensable for agriculture or conservation policy recommendations. The objective of the present study was to examine soil genesis and physicochemical properties of Mount Alab that is situated on a natural protected forest in the Crocker Formation in Sabah, Malaysia.

MATERIALS AND METHODS

Site description and field study

Mount Alab (1964 m a.s.l.) is situated within the Crocker Range Park (CRP) that covered an area of 139,919 hectares (Suleiman *et al*., 2002). It is considered to be the largest terrestrial park in Sabah (Suleiman *et al*., 2002). The present-day climate of that region is humid tropical type with a mean annual temperature of 17.9°C and a mean annual precipitation of 4,257 mm (unpublished CRP station records, 2008–2014). Relative humidity is estimated at 91 % with only 1°C difference between dry bulb and wet bulb temperatures.

The six described soil pedons (Paramananthan, 2010a; Paramananthan, 2010b; Soil survey staff, 2014; IUSS Working Group WRB, 2015) were sampled along the topographic sequence with approximately 200 m differences in altitude from the summit to the toeslope of Mount Alab (Figure 1). Such a landscape is well suited to an analysis of local spatial changes in soil properties and vegetation (upper montane forest, lower montane forest and dipterocarp forest). Location of soil pedons were assisted by the 1:125,000 scale reconnaissance scale soil maps, geological

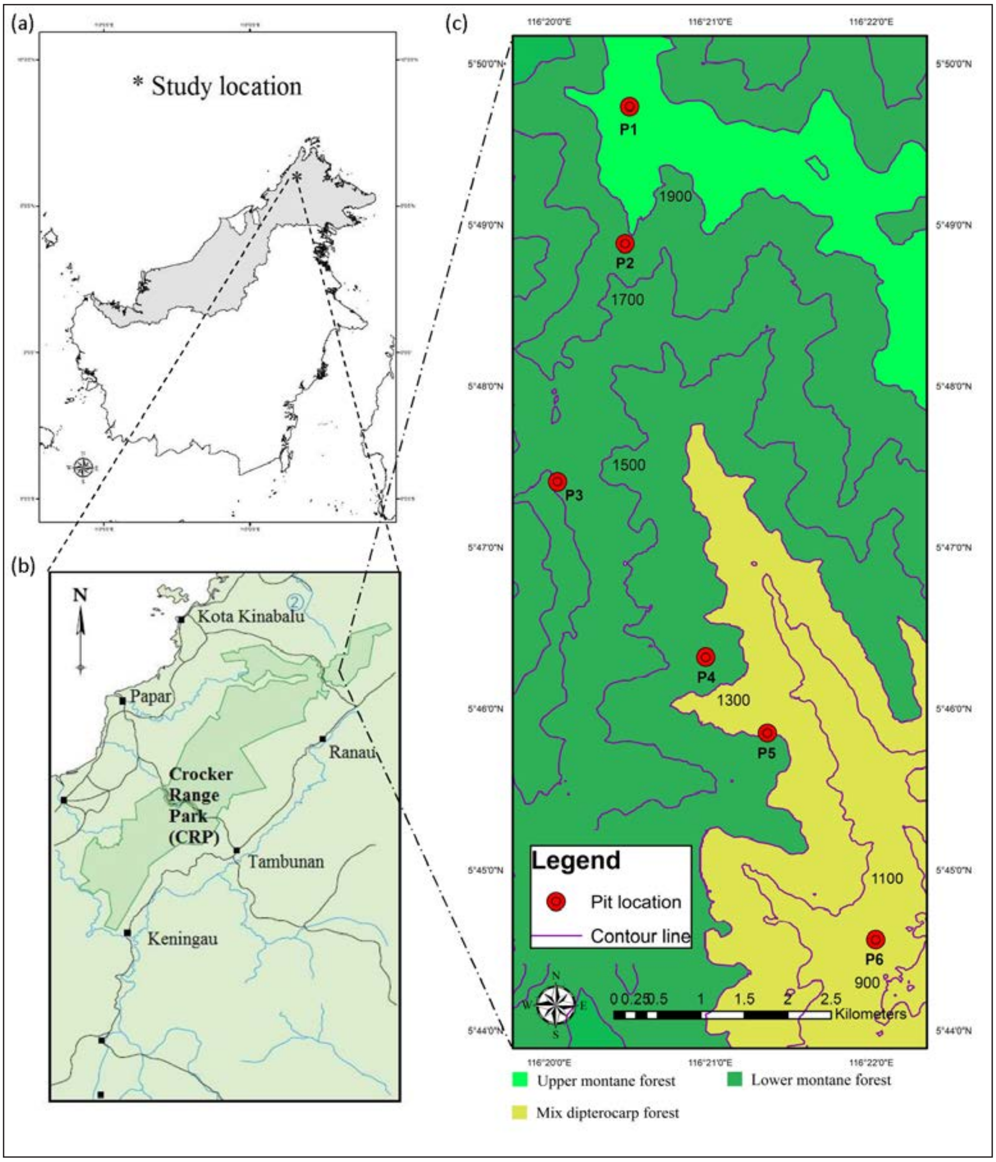

Figure 1: Map showing the location of the study area:
(a) Sabah, Borneo Island;
(b) boundary of Crocker Range Park (CRP);
(c) distribution of soil pedons and vegetation types along the Mount Alab, Sabah.

and vegetation maps. Pedon 1 to 5 (P1 - P5) were located within the protected virgin forest class VI while pedon 6 (P6) was located at a sub-rural settlement where the human impact on the vegetation were minimal.

Laboratory and statistical analysis

Soil samples were air-dried and gently crushed and then sieved to pass through a 2 mm sieve. Soil particle size distribution was determined by the pipette method (Pansu & Gautheyrou, 2006). Soil pH was measured in a suspension of soil:water in 1:2.5 ratio using pH meter (Cyberscan model 1500). Total organic carbon was analysed using the potassium dichromate oxidation method (Walkley & Black, 1934). Total nitrogen (TN) was determined by indophenol blue colorimetric method after digestion with sulfuric acid (Bremner 1982). Available phosphorus was quantified following the Bray-2 method (Kuo, 1996). Total phosphorus was determined through extraction by sulfuric acid:perchloric acid in 1:1 ratio followed by colorimetric measurement using molybdenum blue method (Murphy & Riley, 1962). Exchangeable base cations (Ca, Mg and K) were measured by the atomic absorption spectrophotometry (Perkin Elmer, AAnalyst 100). Exchangeable aluminium was determined by aluminon colorimetric method (Barnhisel & Bertsch, 1982). The soil cation exchange capacity (CEC) was determined by leaching the soil with 1 M ammonium acetate (pH 7) (Anonymous, 1980). Clay minerals of soil were determined by conducting powder X-ray diffraction by using PANalytical Empyrean X-ray Diffractometer. Sample preparation and identification of clay minerals following the procedures by U.S. Geological Survey (Poppe *et al*., 2002) with the aid of the software PANalytical Highscore version 3.

Data from the soil samples were analyzed using SPSS software, version 20 (SPSS Incorporate, 2011). Analysis of variance (ANOVA) was utilized to determine significant differences between soil horizons and Tukey HSD test with α = 0.05 was used for mean comparison between groups.

RESULTS AND DISCUSSION

Soil morphology and profile description

Of the six soil pedons (P1-P6) located along the toposequence on Mount Alab, one soil pedon (P1) is located at an elevation of 1932 m on the upper montane mossy forest (Table 1). Three soil pedons P2, P3 and P4 are located at elevations of 1727 m, 1556 m and 1317 m respectively.

Figure 1: Vegetation and soil climatic zones in Malaysia (Sources: Burgess, 1969[1]; Paramananthan, 1977[4]; Ashton, 1995[2]; Majit *et al.*, 2014[3]).

		Vegetation Zones				Soil[4]	
Location of Pedons (m)	Elevation (m)	Peninsular Malaysia[1]		Sabah/Sarawak[2,3]		Climatic zones Soil Temperature Regime	Soil moisture Regime
		Formation Type	Floristic Zones	Vegetation Types	Floristic Zones		
P1 (1932)	2000	Upper Montane	Montane Ericaceous Forest	Upper Montane (Mossy Forest)	Montane Elfin Woodland	Isomesic	Perudic
P2 (1727)	1800		Oak-Laurel Forest	Lower Montane Forest	Oak-Laurel Forest	Isothermic	
P3 (1556)	1600	Lower Montane	Upper Dipterocarp Forest				
P4 (1317)	1400			Upper Dipterocarp Forest	Mixed Dipterocarp Forest		
P5 (1173)	1200						
P6 (921)	1000						
	800		Hill Dipterocarp Forest	Hill Dipterocarp Forest		Isohyperthermic	Udic
	600						
	400	Lowland	Lowland Dipterocarp Forest	Lowland Dipterocarp Forest			
	200						
	0						

These three soil pedons are located on the lower montane forest. Pedons P5 and P6 are located on the mix diterocarp forest at elevations of 1173 m and 921 m. The soil depth changed from shallow (<50 cm) at the summit to moderately deep (50-100 cm) at the upper slopes, and eventually to deep (>100 cm) at the lower slopes (Table 2). The depth of soils was mainly due to sandstone fragments or parent materials forming at the BC to C of soil horizons. Majority of pedons surface layers exhibited dark brown colours due to the presence of litter and humus layers at the surface–as reflected by the higher total organic carbon contents at the surface due to decomposition of the surface litter (Figure 2). Likewise, the subsurface soil horizons colours varied from brownish yellow to reddish yellow or reddish brown depending on the presence of intermediate tuffs or red iron-rich shales. The presence of moss organic soil material in

Table 2: Morphological and physical characteristics of the soils of the Mount Alab.

Horizon	Depth (cm)	Color (dry)	Texture[a] (field)	Structure[b]	Consistence[c]	Other properties
Pedon P1						
Om	0-10	10YR2/1 10YR3/2	C	We, Fi, Sa	Vfr	Black moss organic soil material existed at soil surface; many fine and medium roots at the surface; rock fragments presented in BC (R) horizon.
Bw	10-45	10YR6/6	CL-FSCL	We, Fm, Sa	Sfr	
BC(R)	45-120	10YR6/8	CL-FSCL		Sfi	
Pedon P2						
Ah	0-5	10YR3/1	SCL	We, Fi, Sa	Vfr	Many fine and few coarse roots up to 40 cm depth; rock fragment layer presented at 80-130 cm depth.
Bw_1	5-40	5YR4/4	SCL	We, Mc, Sa	Fr	
Bw_2	40-80	5YR5/4	SCL	We, Mc, Sa	Sfi	
C(R)	80-130	5YR3/3				
Pedon P3						
Ah	0-5	10YR3/2	CL	We, Fi, Sa	Fr	Many fine and medium and a few coarse roots up to 60 cm depth; weathered rock mottles presented at 70-150 cm depth.
Bw	5-70	10YR6/8	SCL	Fm, Sa	Fr	
C(R)	70-150	10YR5/4 5YR5/4 2.5YR6/3	SL	Fm, Sa	Fi	
Pedon P4						
Ah	0-5	10YR4/4	CL	We, Fi, Sa	Vfr	Common fine and medium as well as few coarse roots at the surface.
Bt_1	5-80	5YR5/6	FSCL	We, Fm, Sa	Fr	
Bt_2	80-130	7.5YR6/8	FSCL	We, Fm, Sa	Sfi	
Pedon P5						
Ah	0-15	10YR4/4	SCL	We, Fm, Sa	Vfr	Many fine and medium roots up to 45 cm; thin patchy clay skins; partly weathered pinkish gray sandstone presented on 110 cm and below.
Bt_1	15-45	10YR5/6	FSCL	We, Fm, Sa	Vfr	
Bt_2	45-110	7.5YR5/8	FSCL	Mo, Me, Sa	Sfi	
C(R)	110-140	2.5YR7/2				
Pedon P6						
Ap	0-15	10YR4/3	CL	Wm, Me, Sa	Fr	Few fine roots and ants nest within 15 cm depth; common clay skins presented on 15-110 cm depth.
Bt_1	15-38	7.5YR6/8	FSC-C	Mo, Mc, Sa	Sfi	
Bt_2	38-110	5 YR6/8	FSC-C	St, Mc, Sa	Vfi	
R	110-130	2.5YR5/8				

[a] Texture: SL = sandy loam; C = clay; CL = clay loam; SCL = sandy clay laom; FSC = Fine sandy clay; FSCL = Fine sandy clay loam

[b] Structure: We = weak; Mo = moderate; St = strong; Wm = weak to moderate; Fi = fine; Me = medium; Fm = fine to medium; Mc = medium to coarse; Sa = subangular block

[c] Consistence: Vfi = very firm; Fi = firm; Sfi = slightly firm; Vfr = very friable; Fr = friable; Sfr = slightly friable

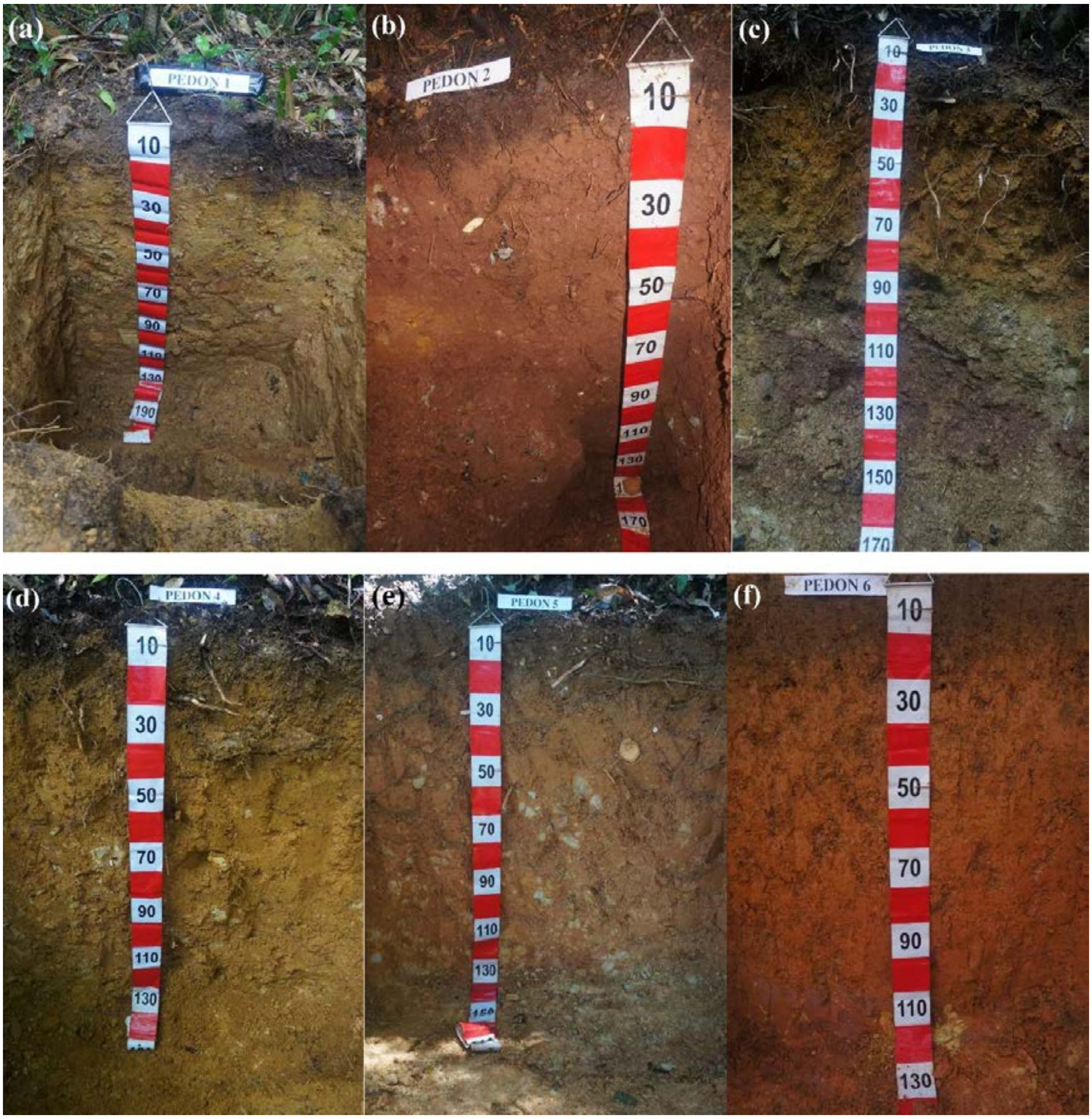

Figure 2: Soil pedons in this study: (a) P1-Gunung Alab (shallow/organic phase) series; (b) P2-Crocker (moderately deep/reddish brown) series; (c) P3-Crocker (moderately deep) series; (d) P4-Kiau (deep/red) series; (e) P5-Kiau (deep) series; (f) P6-Mujan series.

pedon P1 near the summit was due to lower temperature that resulted in slower decomposition (Marian *et al*., 2017).

The names of the soil series (Paramananthan, 2010b) for pedons P1-6 and the approximate classifications in the Keys to the Soil Taxonomy – 12th Edition (Soil Survey Staff, 2014), World Reference Base for Soil Resources 2015 (IUSS Working Group WRB, 2015) and the Malaysian Soil Taxonomy-Revised Second Edition (Paramananthan, 2010a) provided in Table 3. The clay mineralogy of the six pedons is presented in Table 4. As expected, clay-sized quartz, kaolinite and illite dominate the clay fraction. Pedon 1 and 4 have low amounts of gibbsite while illite-vermiculite and vermiculite are present in pedon 1, 3, 4 and 5. These distribution patterns could be explained by the interbedded parent materials which comprise of sandstone and shale that were found in the study site.

Soil chemical properties

The acidity of the soils ranging from strongly to moderately acidic with a pH range of 3.7–5.3, which is common for tropical soils (Table 5). The highest acidity of 3.7 was located in the mossy organic soil layer (Om) of pedon P1. One possible explanation was vegetation was known to play an important role in soil acidification. Changes in vegetation from upper montane forest to lower montane forest and finally to dipterocarp forest, triggered the effect of different tree species on soil pH where the most significant changes appeared in the few centimeters of the topsoil (Osman, 2013b).

The CEC soil values extending from low to very low, mainly due to high proportion of sand fraction. However, calculated CEC clay values were moderate (16-24 $\mathrm{cmol_c\,kg^{-1}}$)

Table 3: Soil classification of the Mount Alab.

Pedon no.	Position	Elevation (m)	Vegetation type	Soil series (Paramanathan, 2010b)	Key to Soil Taxonomy 12th Edition (Soil Survey Staff, 2014)	World Reference Base (IUSS Working Group WRB, 2015)	Malaysian Soil Taxonomy- Revised Second Edition (Paramanathan, 2010a)
P1	Summit	1932	Upper montane forest	Gunung Alab (shallow/ organic phase)	Humic Hapludepts	Lithic Acrisols (Dystric, clayic)	Humic, lithic, fine clayey, argillic, isomesic, red-yellow, Hapludepts
P2	Shoulder	1727	Lower montane forest	Crocker (moderately deep/ reddish brown)	Rhodic Hapludepts	Lithic Rhodic Cambisol (Dystric)	Lithic, fine loamy, siliceous, isothermic, red-yellow, Rhodic Hapludepts
P3	Backslope	1556	Lower montane forest	Crocker (moderately deep)	Typic Hapludepts	Lithic Cambisol (Dystric)	Lithic, fine loamy, siliceous, isothermic, red- yellow, Typic Hapludepts
P4	Backslope	1317	Lower montane forest	Kiau (deep/red)	Rhodic Paleudult	Rhodic Nitosols	Fine loamy, siliceous, isothermic, red, Rhodic Paleudult
P5	Backslope	1173	Mix dipterocarp forest	Kiau (deep)	Typic Hapludult	Dystric Acrisols	Fine loamy, siliceous, isothermic, red-yellow, Typic Hapludult
P6	Toeslope	921	Mix dipterocarp forest	Mujan	Typic Paleudult	Dystric Nitosols	Fine clayey, mixed, isothermic, red-yellow, Typic Paleudult

to high (>24 $\text{cmol}_c\ \text{kg}^{-1}$) for all the pedons. These high calculated CEC clay values were partly attributed to the loamy textures of the subsoils. The sandy clay loam textures and high porosity of these soils coupled with the high intensive rainfall results in intensive weathering, causing the soils to have low CEC and base saturation (Binkley & Fisher, 2013). Besides that, these moderate values were also dependent on the nature and the quantity of silicate clays, organic matter content and pH of the soils (Bache, 1976).

The soil organic carbon of the surface horizons in this study showed a clear decreasing trend with decreasing elevation and vegetation type. Total organic carbon was 13.38 % (P1) at summit with mossy organic soil materials. It was then reduced to 11.22 % (P2); 11.60 % (P3); 5.16 % (P4); 3.89 % (P5) and finally 2.01 % (P6) at the toeslope. There was a distinct correlation of total organic carbon content along the slopes on various topographical positions. Decrease in elevation leads to increase of temperature and therefore increased breakdown of surface litter and leaching. This clearly indicates that the total organic carbon in the surface layer is strongly dependent on the elevation and the vegetation types.

Total nitrogen in soil was low. Furthermore, it had a decreasing trend with depth and altitude–identical trend as total organic carbon. Total nitrogen of surface soil decreased from 0.70 % (P1) at the summit to 0.64 % (P2), 0.68 % (P3), 0.29 % (P4), 0.24 % (P5) and 0.16 % (P6) along the topographical positions. This trend was consistent with the trend in other tropical mountains (Kitayama & Aiba, 2002; Weintraub *et al*., 2015). However, total nitrogen decreased sharply in all soil profiles from the surface to subsurface in agreement with Lee *et al*. (2015) and Schrumpf *et al*. (2014). C/N ratio of the topsoils decreased from 18.8 to 12.7 from the summit to the toeslope. Forest litter is known to have a high C/N ratio which decreases with an increase in its decomposition (Osman, 2013a).

The available phosphorus decreased with decreasing topographical positions except for P6. Likewise, total phosphorus values show a reducing but irregular trend with elevation. Furthermore, total and available phosphorus recorded in this study were in line with the results obtained by Kitayama & Aiba (2002) that revealed the differences of phosphorus were more prominent at higher elevation

Table 4: Clay fraction composition for soil horizon from the soil profiles.

Horizon	Quartz	Kaolinite	Illite	Gibbsite	Interstratified Illite-Vermiculite	Vermiculite
Profile P1						
Om	++	±	-	+	+	-
Bw	+	±	-	+	-	+
BC(R)	+	+	+	-	-	-
Profile P2						
Ah	++	±	-	-	++	-
Bw	++	+	++	-	-	-
BC(R)	++	+	++	-	-	-
Profile P3						
Ah	++	±	+	-	-	±
Bt$_1$	++	±	-	-	-	+
Bt$_2$	+	±	++	-	-	-
Profile P4						
Ah	+	±	-	+	±	-
Bt$_1$	+	±	-	+	-	+
Bt$_2$	+	±	-	+	-	+
Profile P5						
Ah	++	+	+	-	+	-
Bt$_1$	++	+	+	-	+	-
Bt$_2$	++	+	+	-	+	-
Profile P6						
Ah	++	++	++	-	-	-
Bt$_1$	++	++	++	-	-	-
Bt$_2$	++	++	++	-	-	-

* Note: - = absent; ± = present in trace amount; + = present in low/minor amount; ++ = present in moderate amount

(2,700 m and 3,100 m) as compared with lower elevation (700 m and 1,700 m).

Among the exchangeable cations (Ca, Mg and K), both Ca and Mg appeared to be abundance in the soil. In addition, these exchangeable cations of middle elevations were lower than either higher or lower elevations. Therefore, no trend was observed for these exchangeable cations. However, exchangeable Al increased with soil depth and also increased along with decreasing topographical positions. This may explained by the destruction of clays by microorganisms led to the released of chelating organic acids (e.g. citric acid) which enhanced the leaching of Al and Fe from upper soil horizon before accumulating in the subsoils (Fujii *et al*., 2018).

CONCLUSION

Tropical montane forest soils have a distinctive morphological and physicochemical characteristics when compared with lowland tropical rain forest and agricultural soils. At higher elevations with lower temperature, lower light availability and higher precipitation encouraged soil formations to accumulate soil organic carbon on surface horizons. Low-level disturbance such as soil movement on steep slopes did not adequately affect the physicochemistry of soils at the lower topographical positions (e.g. shoulder and backslope) as compared to anthropogenic disturbance at lowest topographical position (e.g. toeslope). Therefore, conservation of these soils should be prioritized to preserve biodiversity and carbon stock, rather than converting these high conservation value land for agricultural activities that maybe less appropriate due to steep slopes.

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Table 5: Chemical properties of the soils of the Mount Alab.

Horizon	Depth (cm)	pH H_2O	OC (%)	TN (%)	C : N ratio	Pavai mg kg^{-1}	TP mg kg^{-1}	ExCa cmol$_c$ kg^{-1}	ExMg cmol$_c$ kg^{-1}	ExK cmol$_c$ kg^{-1}	ExAl cmol$_c$ kg^{-1}	CEC soil cmol$_c$ kg^{-1}	CEC clay cmol$_c$ kg^{-1}	BS (%)
Profile P1														
Om	0-10	3.7 a	13.38 a	0.70 a	18.8 a	29.33 a	315.33 a	2.07 ab	1.17 a	0.36 a	0.28 a	9.94 ab	25.9 a	35.9 a
Bw	10-45	4.3 ab	1.44 b	0.10 b	14.0 b	2.00 b	170.33 a	1.85 b	0.97 a	0.21 a	1.00 b	8.01 a	30.2 a	40.3 a
BC(R)	45-120	4.9 b	0.42 b	0.06 b	7.4 c	1.00 b	294.33 a	2.74 a	1.34 a	0.22 a	1.32 c	10.62 b	49.1 a	41.0 a
Profile P2														
Ah	0-5	4.3 a	11.22 a	0.64 a	17.3 a	64.33 a	376.33 a	2.05 a	1.78 a	0.29 a	0.25 a	5.81 a	18.6 a	75.4 a
Bw_1	5-40	4.5 a	1.16 a	0.10 a	12.4 a	3.00 b	169.00 a	1.79 a	2.07 a	0.34 a	0.77 b	12.19a	47.0 a	38.6 a
Bw_2	40-80	4.8 a	0.35 a	0.09 a	7.2 a	1.00 b	183.67 a	1.67 a	1.99 a	0.24 a	0.81 b	8.37 a	34.0 a	60.0 a
Profile P3														
Ah	0-5	4.1 a	11.60 a	0.68 a	16.5 a	51.00 a	542.33 a	2.42 a	1.65 a	0.34 a	0.43 a	8.21 a	22.5 a	57.6 a
Bw	5-70	4.8 b	1.52 a	0.12 a	12.6 a	2.00 a	197.67 a	1.76 a	2.39 a	0.13 b	1.13 b	5.38 a	24.6 a	80.8 a
C(R)	70-150	4.9 b	0.91 a	0.10 a	9.9 a	1.00 a	242.00 a	2.00 a	2.07 a	0.22 ab	1.28 b	8.43 a	51.0 a	54.5 a
Profile P4														
Ah	0-5	4.4 a	5.16 a	0.29 a	17.7 a	4.00 a	180.00 a	1.81 a	0.47 a	0.28 a	0.55 a	4.76 a	13.3 a	54.8 a
Bt_1	5-80	5.3 b	1.28 b	0.08 b	15.1 a	1.00 b	146.33 a	0.92 b	0.11 a	0.15 b	0.94 b	3.83 a	22.7 a	30.7 b
Bt_2	80-130	5.1 b	0.65 b	0.04 b	14.7 a	1.33 b	124.67 a	1.03 b	0.77 a	0.14 b	1.02 b	4.94 a	18.8 a	37.7 b
Profile P5														
Ah	0-15	4.4 a	3.89 a	0.24 a	16.0 a	9.33 a	164.33 a	2.17 a	0.89 a	0.36 a	0.75 a	7.71 a	22.1 a	45.9 a
Bt_1	15-45	4.6 a	1.32 b	0.10 b	12.6 ab	1.67 b	119.00 b	1.46 a	1.34 a	0.30 b	0.92 ab	5.72 a	24.2 a	54.3 a
Bt_2	45-110	4.7 a	0.39 b	0.04 b	8.7 b	1.00 b	90.67 c	1.73 a	1.41 a	0.21 c	1.11 b	7.69 a	29.6 a	44.7 a
Profile P6														
Ap	0-15	4.9 a	2.01 a	0.16 a	12.7 a	58.67a	290.33 a	2.32 a	2.04 a	0.28 a	0.83 a	6.53 a	20.8 a	71.5 a
Bt_1	15-38	4.5 a	0.56 b	0.06 b	9.4 ab	2.33 a	118.00 a	1.58 ab	2.16 a	0.22 a	1.01 b	7.49 a	18.4 a	53.5 ab
Bt_2	38-110	4.8 a	0.35 b	0.05 b	7.6 b	1.33 a	113.67 a	1.31 b	2.15 a	0.19 a	1.03 b	8.31 a	17.9 a	44.5 b

Mean with the same letter within a row are not significantly different at $p < 0.05$.

reviewers as they significantly improved the quality of the final manuscript.

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