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 subdivided 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.](image-url)
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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 $\alpha = 0.05$ 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 toposquence 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; Paramananthan, 1977; Ashton, 1995; Majit et al., 2014).

| Location of Pedons (m) | Elevation (m) | Peninsular Malaysia | Sabah/Sarawak | Climatic zones | Soil moisture |
|------------------------|--------------|---------------------|---------------|----------------|--------------|
|                        |              | Formation Type      | Floristic Zones | Soil Temperature Regime | Regime       |
|                        |              | Vegetation Types    | Floristic Zones |                |              |
| P1 (1932)              | 2000         | Upper Montane       | Montane        | Isomesic       |              |
|                        |              | Forest              | Ericaceous     |                |              |
|                        |              | Upper Montane       | (Mossy Forest) |                |              |
|                        |              | Forest              | Elfin Woodland |                |              |
| P2 (1727)              | 1800         | Oak-Laurel          | Lower Montane  | Isothermic     |              |
|                        |              | Forest              | Forest         |                |              |
|                        |              | Oak-Laurel          | Forest         |                |              |
| P3 (1556)              | 1600         | Lower Montane       | Upper          | Isohyperthermic | Udic         |
|                        |              | Dipterocarp Forest  | Dipterocarp    |                |              |
|                        |              | Forest              | Mixed          |                |              |
| P4 (1317)              | 1400         |                     | Upper          |                |              |
|                        |              | Dipterocarp Forest  | Dipterocarp    |                |              |
|                        |              | Forest              | Mixed          |                |              |
| P5 (1173)              | 1200         | Hill Dipterocarp    | Hill Dipterocarp |                |              |
|                        |              | Forest              | Forest         |                |              |
| P6 (921)               | 1000         | Lowland Dipterocarp | Lowland        |                |              |
|                        |              | Forest              | Dipterocarp    |                |              |
|                        | 800          |                     |                | Isohyperthermic |              |
|                        | 600          |                     |                |                |              |
|                        | 400          |                     |                |                |              |
|                        | 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 | Texture | Structure | Consistence | Other properties |
|---------|------------|-------|---------|-----------|-------------|------------------|
| Pedon P1 |            |       |         |           |             |                  |
| Om      | 0-10       | 10YR2/1 | 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) |
| 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. |
| Bw1     | 5-40       | 5YR4/4  | SCL     | We, Mc, Sa | Fr          |                  |
| Bw2     | 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 | 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. |
| Bt1     | 5-80       | 5YR5/6  | FSCL    | We, Fm, Sa | Fr          |                  |
| Bt2     | 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. |
| Bt1     | 15-45      | 10YR5/6 | FSCL    | We, Fm, Sa | Vfr         |                  |
| Bt2     | 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, Mc, Sa | Fr          | Few fine roots and ants nest within 15 cm depth; common clay skins presented on 15-110 cm depth. |
| Bt1     | 15-38      | 7.5YR6/8| FSC-C   | Mo, Mc, Sa | Sfi         |                  |
| Bt2     | 38-110     | 5YR6/8  | FSC-C   | St, Mc, Sa | Vfi         |                  |
| R       | 110-130    | 2.5YR5/8|         |           |             |                  |

*Texture: SL = sandy loam; C = clay; CL = clay loam; SCL = sandy clay loam; FSC = Fine sandy clay; FSCL = Fine sandy clay loam
*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
*Consistence: Vfi = very firm; Fi = firm; Sfi = slightly firm; Vfr = very friable; Fr = friable; Sfr = slightly friable
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 cmol\(\text{kg}^{-1}\))
to high (>24 cmol c 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.

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 Acrisols (Dystric, clayic) | Lithic Hapludrepts | Humic, lithic, fine clayey, argillic, isomesic, red-yellow, Hapludrepts |
| P2        | Shoulder | 1727          | Lower montane forest | Crocker (moderately deep/ reddish brown) | Rhodic Hapludrepts | Lithic Rhodic Cambisol (Dystric) | Lithic, fine loamy, siliceous, isothermic, red-yellow, Rhodic Hapludrepts |
| P3        | Backslope| 1556          | Lower montane forest | Crocker (moderately deep) | Typic Hapludrepts | Lithic Cambisol (Dystric) | Lithic, fine loamy, siliceous, isothermic, red-yellow, Typic Hapludrepts |
| 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 Paleudult |
| P6        | Toeslope | 921           | Mix dipterocarp forest | Mujan | Typic Paleudult | Dystric Nitosols | Fine clayey, mixed, isothermic, red-yellow, Typic Paleudult |

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.
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**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      | ++     | ±         | +      | -        | -                                 | ±           |
| Bt₁     | ++     | ±         | -      | -        | -                                 | +           |
| Bt₂     | +      | ±         | ++     | -        | -                                 | -           |
| **Profile P4** | | | | | | |
| Ah      | +      | ±         | -      | +        | ±                                 | -           |
| Bt₁     | +      | ±         | -      | -        | +                                 | -           |
| Bt₂     | +      | ±         | -      | +        | -                                 | -           |
| **Profile P5** | | | | | | |
| Ah      | ++     | +         | +      | -        | +                                 | -           |
| Bt₁     | ++     | +         | +      | -        | +                                 | -           |
| Bt₂     | ++     | +         | +      | -        | +                                 | -           |
| **Profile P6** | | | | | | |
| Ah      | ++     | ++        | ++     | -        | -                                 | -           |
| Bt₁     | ++     | ++        | ++     | -        | -                                 | -           |
| Bt₂     | ++     | ++        | ++     | -        | -                                 | -           |

* 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.

| Profile  | Horizon | Depth (cm) | pH | OC (%) | TN (%) | C : N ratio | Pavai (mg kg⁻¹) | ExCa (cmolc kg⁻¹) | ExMg (cmolc kg⁻¹) | ExK (cmolc kg⁻¹) | ExAl (cmolc kg⁻¹) | CEC soil (cmolc kg⁻¹) | CEC clay (cmolc kg⁻¹) | BS (%) |
|----------|---------|------------|----|--------|--------|------------|-----------------|------------------|------------------|-----------------|------------------|---------------------|---------------------|--------|
| P1       | Om      | 0-10       | 3.7 | a      | 13.37 | a          | 0.70            | 18.8             | 29.33            | 315.33          | 2.07             | 1.17                | 0.36                | 0.28               |
|          | Bw      | 10-45      | 4.3 | ab     | 1.44  | b          | 0.10            | 14.0             | 2.00             | 170.33          | 1.85             | 0.97                | 0.21                | 1.00               |
|          |         | 45-120     | 4.9 | b      | 0.42  | b          | 0.06            | 7.4              | 1.00             | 294.33          | 2.74             | 1.34                | 0.22                | 1.32               |
| P2       | Ah      | 0-5        | 4.3 | a      | 11.22 | a          | 0.64            | 17.3             | 64.33            | 376.33          | 2.05             | 1.78                | 0.29                | 0.25               |
|          | Bw      | 5-40       | 4.5 | a      | 1.16  | a          | 0.10            | 12.4             | 3.00             | 169.00          | 1.79             | 2.07                | 0.34                | 0.77               |
|          |         | 40-80      | 4.8 | b      | 0.35  | a          | 0.09            | 7.2              | 1.00             | 183.67          | 1.67             | 1.99                | 0.24                | 0.81               |
| P3       | Ah      | 0-5        | 4.1 | a      | 11.60 | a          | 0.68            | 16.5             | 51.00            | 542.33          | 2.42             | 1.65                | 0.34                | 0.43               |
|          | Bw      | 5-70       | 4.8 | b      | 1.52  | a          | 0.12            | 12.6             | 2.00             | 197.67          | 1.76             | 2.39                | 0.13                | 1.13               |
|          |         | 70-150     | 4.9 | b      | 0.91  | a          | 0.10            | 9.9              | 1.00             | 242.00          | 2.00             | 2.07                | 0.22                | 1.28               |
| P4       | Ah      | 0-5        | 4.4 | a      | 5.16  | a          | 0.29            | 17.7             | 4.00             | 180.00          | 1.81             | 0.47                | 0.28                | 0.55               |
|          | Bt      | 5-80       | 5.3 | b      | 1.28  | b          | 0.08            | 15.1             | 1.00             | 146.33          | 0.92             | 0.11                | 0.15                | 0.94               |
|          |         | 80-130     | 5.1 | b      | 0.65  | b          | 0.04            | 14.7             | 1.33             | 124.67          | 1.03             | 0.77                | 0.14                | 1.02               |
| P5       | Ah      | 0-15       | 4.4 | a      | 3.89  | a          | 0.24            | 16.0             | 9.33             | 164.33          | 2.17             | 0.89                | 0.36                | 0.75               |
|          | Bt      | 15-45      | 4.6 | a      | 1.32  | b          | 0.10            | 12.6             | 1.67             | 119.00          | 1.46             | 2.16                | 0.30                | 0.92               |
|          |         | 45-110     | 4.7 | a      | 0.39  | b          | 0.04            | 8.7              | 1.00             | 90.67           | 1.73             | 1.41                | 0.21                | 1.01               |
| P6       | Ap      | 0-15       | 4.9 | a      | 2.01  | a          | 0.16            | 12.7             | 58.67           | 290.33          | 2.32             | 2.04                | 0.28                | 0.83               |
|          | Bt      | 15-38      | 4.5 | a      | 0.56  | b          | 0.06            | 9.4              | 2.33             | 118.00          | 1.58             | 3.70                | 0.22                | 1.01               |
|          |         | 38-110     | 4.8 | a      | 0.35  | b          | 0.05            | 7.6              | 1.33             | 113.67          | 1.31             | 0.67                | 0.19                | 1.03               |

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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