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# Characterization and Distribution of Soils at Lambir Hills National Park in Sarawak, Malaysia, with Special Reference to Soil Hardness and Soil Texture

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**ABSTRACT** For the rehabilitation of the degraded and abandoned land in the tropical area, it needs to define the various characteristics of remaining natural forests. This work was done to find out a physical hazard for root elongation of plant at Lambir Hills National Park, Miri, Sarawak, Malaysia, with special reference to soil hardness and soil texture. Furthermore, soil moisture and soil temperature were monitored at the hill ridge and at the valley to show their annual fluctuation. Soil physico-chemical properties at the hill ridge and the valley were also investigated.

At the hill ridge, well-developed soils with a deep solum were found. Organic matter content was high only at the surface horizon (0-5 cm) where a root mat develops. Although soil moisture content fluctuated significantly, the soil was dry throughout the monitoring period. On the other hand, at the valley, soil moisture content was relatively stable even after the frequent rainfall. The small particles and nutrients at the valley have been brought by the continuous water and eroded particles supply from surroundings.

Based on the topographical investigation, the study area was roughly divided into 3 categories:

1) Steep slope area : Soil and vegetation status may be often affected and modified by the land slide or soil erosion. Soil texture was sandy loam, loamy sand, or loam. Gravelly materials often appeared in the subsurface layer at the depth of 20-40 cm, which are hard for root to penetrate into. This layer can be regarded as the one with physical hazard against root penetration.
2) Gentle slope area : Soil and vegetation status are relatively stable for a long time. Soil texture was light clay or heavy clay. Transported clayey materials were accumulated to a depth below 20 cm, and/or the in-situ weathering in the deeper part could have occurred because of the relatively stable topography.
3) Ridge area : Although soil and vegetation status looks stable in view of topography, moisture condition much fluctuated. Soil texture was clay loam or sandy clay loam, which was the middle range between that of a steep slope area and a gentle slope area. The physical hazard in the soil might not be found, but the rates of root elongation and plant growth may be slow since the soil is prone to be dry.

**Key words:** soil hardness / soil texture / soil physico-chemical properties / soil moisture / topography


**Fig. 1. Location of study site of Lambir Hills, Sarawak, Malaysia.**

The various tropical rain forests are the most structurally complex and diverse land ecosystems that have ever existed on the earth (Whitmore, 1990). The mixed dipterocarp forest in Sarawak is certainly one of the richest tropical rain forests in the world with quite high species diversity of trees (Inoue *et al.*, 1994). The rain forests in tropical Asia have been degraded rapidly. For the proper conservation and management of the forest, an accumulation of knowledge on soils is of prime importance. Ultisols are the most abundant soils in Southeast Asia (Sanchez, 1976). Ohta and Effendi (1992a) reported that the soil texture was the primary factor controlling the morphological and physical properties of Ultisols, the major soils of the "Lowland Dipterocarp Forest" in East Kalimantan. The total C, N, and P contents decreased abruptly within the top 15-20 cm layer. The contents were directly correlated with the clay content in each horizon group (Ohta and Effendi, 1992b). Therefore, it is worthy of notice on the soil physical properties for evaluation of soil fertility in the tropical area.

In order to evaluate the influence of soil physical properties on root elongation and plant growth, it is necessary to establish an appropriate way of diagnosis for the soils in the field in view of vertical distribution. Especially for the research in the tropical countries, we need a simple but a valuable technique which can be easily conducted by the cooperative researchers and/or workers routinely. Soil hardness of each depth has been measured at the soil pit using a push cone type penetrometer. However, this method may not applicable when it is not possible to prepare a big soil pit without disturbing the pedo-ecology and without spending much time to dig one.

To know the vertical distribution of the soil hardness, we better use a cone penetrometer equipped with a metal cone on top and a weight to push and make the cone penetrating into soils (Hasegawa Type, H-60). We just fall the 2 kg of weight at a given distance (50 cm), and recorded the penetrating depth by an attached scale. Sakurai *et al.* (1995) found that the soil hardness measurement could provide various information on soils at hand in the field. In this paper, we will try to make some maps of distribution of soils in 8 ha plot whether it is possible to grasp characteristics of soils in terms of physical hazard to plant roots.

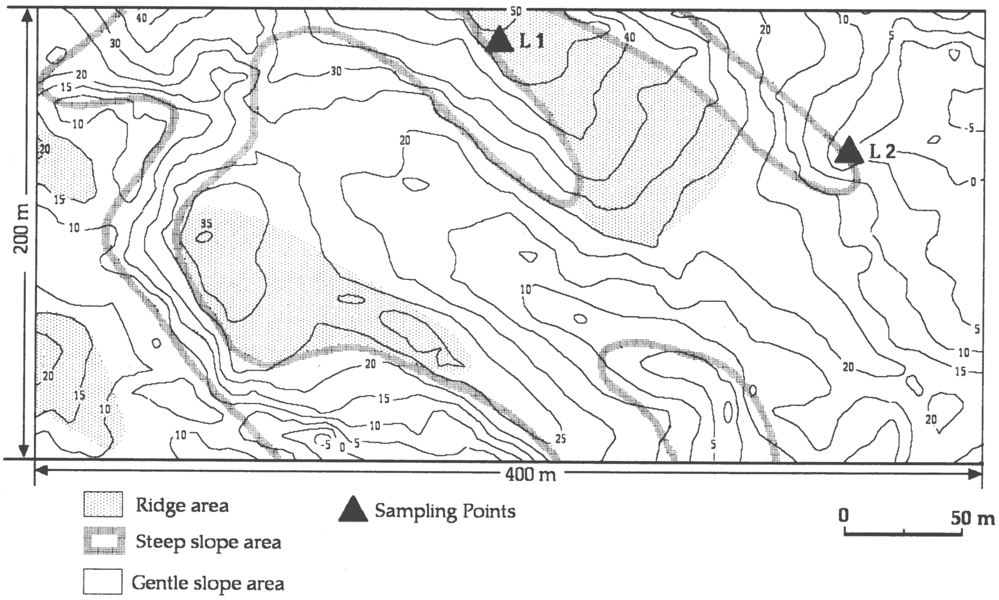


**Fig. 2. Topography of 8 ha plot in Lambir Hills National Park.**

# MATERIALS AND METHODS

## Study site

Lambir Hills National Park (4°12'N, 114°00'E) is located about 30 km south of Miri downtown, in Miri Division, Sarawak, Malaysia (Fig. 1). It covers an area of 6,949 hectares at the central portion of the Lambir Hills with a maximum altitude of 465 m. Vegetation is mainly composed of mixed dipterocarp forests. Parent materials are tertiary period sedimentary rock (sandstone and/or shale). In Miri city, the mean annual temperature and precipitation are 27.2℃ and 2,927 mm, respectively (Watson, 1985). A research project of Long Term Ecological Research of Tropical Rain Forest in Sarawak (LTER) was cooperatively initiated in 1991 between Forest Department Sarawak, Japan and United States Universities. An 8 ha research plot (200×400 m) lies in the Lambir Hills National Park (Fig. 2). The plot is divided into 800 quadrates 10×10 m in size, by setting land marks at all corners of quadrates.

Two sites were selected within the plot to carry out the monitoring of soil temperature and moisture; one site was located on a ridge of undulating hills, and the other was in a valley along with a steep cliff made by a small landslide. At these sites, soil profiles were prepared and described in terms of texture, soil color, soil structure, consistency, gravels, and roots (Table 1). Soil samples were collected for further analyses.

## Analytical methods

### Field experiment

The evaluation of the soil hardness and soil texture was done at the corner of 400 quadrates 10×20 m. Soil hardness was measured using fall-corn-type soil penetrometer (Hasegawa Type H-60) until the

**Table 1.** Morphological properties of the soils.

| Soil | Hori-zon | Depth (cm) | Soil color (moisture[a]) | Tex-ture | Structure[b] | Roots/ stone | Boundary[c] |
|---|---|---|---|---|---|---|---|
| L 1 | A | 0 - 5 | 7.5YR3/4 (m) | CL | 1 vfg | many / none | cs |
| | BA1 | 5 - 50 | 10YR5/8 (dm) | CL | 2msbk | common / none | gs |
| | BA2 | 50 - 75 | 10YR6/8 (dm) | LiC | 2csbk | few / none | gs |
| | BA3 | 75 - 100 | 10YR6/8 (dm) | LiC | 2csbk | few / none | gs |
| | Bw1 | 100 - 150 | 7.5YR6/8 (dm) | LiC | 2cabk | common* / none | gs |
| | Bw2 | 150 - 200+ | 7.5YR6/8 (dm) | CL | 2cabk | none / none | |
| L2 | A | 0 - 8/10 | 10YR4/4 (dm) | SL | lmsbk | many / none | cw |
| | Bw | 8/10 - 27/30 | 10YR5/6 (dm) | SCL | lmsbk | common / none | cw |
| | CB | 27/30 - 45/60 | 10YR6/4<br>10YR5/4<br>7.5YR5/8 (dm) | SL | no structure | common / none | gi |
| | Cl | 45/60 - 77/85 | 10YR6/3, 7/3 (dm) | SL | no structure | none / few | gi |
| | C2 | 77/85 - 150+ | 10YR7/2,3,4 (dm) | SL | no structure | none / few | |

a) m, moist; dm, dry moist.
b) Grade: 1, week; 2, moderate.
Class: vf, very fine; f, fine; m, medium ; c, coarse.
Type: g, granular; sbk, subangular- blocky; abk, angular blocky.
c) cs, clear smooth; cw, clear wavy; gs, gradual smooth; gi, gradual irregular
* ) Carbollized root.

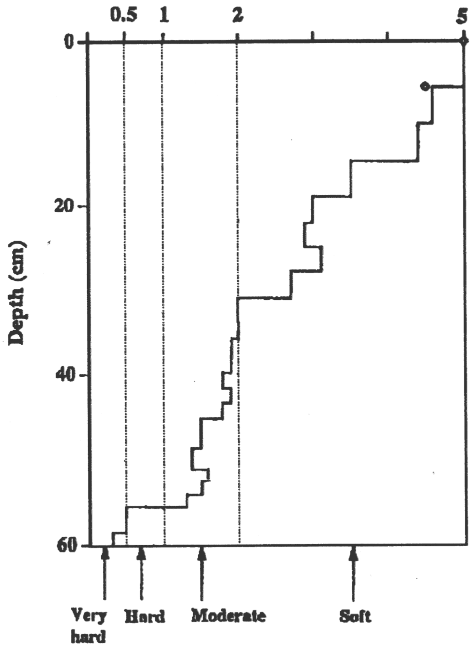


**Fig. 3. One drop penetrability (ODP) and definition of soil hardness** (Sakurai *et al*., 1995).

depth of 60 cm. At the same point, the soil sample was taken at the depth of 10-15 cm, and its texture was determined by hand in situ. Its result can be depicted as Fig. 3. Horizontal axis represents the penetrating depth (cm) per one drop of weight (termed as one drop penetrability, ODP) and vertical axis does the cumulative depth (cm). In short, the smaller the area in the figure, the harder the soil. In this paper, soil hardness is classified using the value plotted on the horizontal axis as follows: very hard, ODP less than 0.5; hard, ODP between 0.5 and 1.0; moderate, ODP between 1.0 and 2.0; soft, ODP more than 2.0.

**Physico-chemical and mineralogical properties**

Soil samples were air-dried and crushed to pass through a 2 mm-mesh sieve. The pH was measured with a glass electrode using a soil to solution ($H_2O$ or 1M-KCl) ratio of 1: 5 after reciprocal shaking for 1 h (designated as pHw and pHk, respectively). Electric conductivity (EC) was measured using the supernatant solution after reciprocal shaking for 1 h at a soil to water ratio of 1 to 5. Exchangeable bases were extracted twice with 1M ammonium acetate at pH 7.0 for Ca, Mg, Na, and K, by reciprocal shaking and centrifugation at a soil to solution ratio of 1: 5. The amounts of Ca, Mg and K in the extract were determined by atomic absorption spectrophotometry, and that of Na by flame photometry (Shimadzu, AA-610S). Exchangeable Al and H were extracted with 1M KCl, and their contents were determined by the titration method. After replacement of exchangeable bases, washing with a deionized water and a 99 % ethanol and replacement of $NH_4^+$ with 10 % NaCl were successively performed by centrifugation. The amount of ammonium ion was determined as cation exchange capacity (CEC) by Kjeldahl distillation and titration method. Total Carbon and Nitrogen were determined by a dry combustion method using NC-analyzer (Sumitomo Chemical, Sumigraph model NC-80). Available phosphorus was extracted with 0.001M $H_2SO_4$ for 30 min. and the content was determined by the molybdenum blue method. Particle size distribution was determined by pipette method for silt and clay fraction, and sieving for fine sand and coarse sand fraction. Al, Fe, and Si oxides were extracted twice with an acid ammonium oxalate solution (0.2M, pH 3.0) by reciprocal shaking in the dark for 1 h (Mckeague and Day, 1966), at a soil to solution ratio of 1 to 25. They were extracted twice with a citrate-bicarbonate mixed solution buffered at pH 7.3 with the addition of sodium dithionite for 15 min. at 75 to 80℃ (Mehra and Jackson, 1960), using a soil to solution ratio of 1 to 100. Al, Fe, and Si contents in the extract were designated as Alo, Feo, and Sio for the former extractant, and Ald, Fed, and Sid for the latter. The contents of all the cations were determined using a sequential plasma spectrometer (Shimadzu, ICPS-1000IV). Clay minerals were identified by X-ray diffraction method (Shimadzu, XD-D1w). Specimens of K- and Mg-saturated clay with parallel orientation were prepared by the alternate saturation technique using acetate and chloride salts. X-ray diffractogram was taken for the air dried K-saturated clay, then for clay heated to 100, 350, 550℃ for 2 h successively as well as for the air-dried Mg-saturated clay and for clay treated with 10% glycerol. Point of zero salt effect (PZSE) and $\sigma_p$ value of soils were determined by a modified salt titration (STPT) method (Sakurai *et al.*, 1988).

**Physical properties**

For the determination of three phase distribution, soil samples were collected by 100 cc core cylinders. The volume and weight of sum of water and solid phase were measured by voluminometer (Daiki Rika Kogyo, DIK-1120) and balance, respectively.

Water holding capacity was measured for the pF value of 1.5 by sand column method (Daiki Rika Kogyo, DIK-3520), for the pF values of 2.0 and 3.0 by the pressure plate method (Daiki Rika Kogyo, DIK-3420), for the pF value of 4.2 by the centrifugation method.

For monitoring of soil moisture and soil temperature, two data loggers (North High-tech Co., Hokkaido, Japan) were set at the ridge (L1) and valley (L2) part in 8 ha plot in 1995. Soil moisture and temperature sensors were installed at the depth of 10 cm and 40 cm in L1, at the depth of 10 cm and 30 cm in L2.

## RESULTS AND DISCUSSION

### Soil morphological characteristics

The L1 site is located on a stable hill ridge, and its parent material was residium. On the other hand, the L2 soil is located in the lower slope near valley bottom. The soil in the valley was colluvium and found to be unstable from the stand point of pedogenesis, and therefore, transported materials can be supplied from the surroundings continuously.

Based on the soil profile descriptions shown in Table 1, little organic layers were found except for thin L (1-2 cm) and F (<0.5 cm) layers at both sites. Soil moisture conditions at both sites were mostly moderately dry except for A horizon in the L1 soil where wet and dry conditions alternate easily. There was no reduced mottle throughout the profiles. The color of the deeper horizons (CB, C1, and C2) of the L2 soil was duller than the L1 soil, indicating a relatively wet condition for some period. The A horizon was thicker in the L2 soil than in the L1 soil. The root mat (<3.0 cm) was well-developed at the L1 soil, whereas that (<1.0 cm) was not developed at the L2 soil. Soil depth of the L1 soil was deeper than 200 cm, and there is no gravel in the pedon. On the other hand, Soil depth of the L2 soil was shallow, and coarse fragments in subsurface horizon were abundant suggesting an unstable pedogenetic condition. Structural development of the L1 soil was stronger than the L2 soil. In the upper BA3 horizon of the L1 soil and Bw horizon of the L2 soil a subangular blocky structure predominated. In the lower parts of the L1 soil, Bw1 and Bw2 horizons, contained an angular blocky structure, indicating the frequent dry condition.

### Physical properties

Percentage of air phase for the layer from 0 to 50 cm was higher in the L1 soil than in the L2 soil (Table 2). Value of the total porosity percentage was higher in the L1 soil than in the L2 soil. For the L2 soil, sand content was higher than 80 % and clay content was less than 11 %, whereas for the L1 soil, the former ranged from 62.4 to 73.4 % and the latter from 13.9 to 21.6 %. There was no significant difference in particle size distribution throughout the profiles of both L1 and L2 pedons. In summary, surface layers of the L1 soil were characterized by the high air-phase and total porosity percentage due to the presence of root mat, and hence, subjected to a low moisture condition during the dry period. On the other hand, the deeper layers showed a high solid percentage even though the soil texture was almost consistent throughout the profile. Since a slight accumulation of clay was found in the deeper layers, soil formation in the L1 pedon seemed to proceed in situ. In the surface most horizon with a development of root mat, the process of erosion and/or accumulation would have occurred easily, which may cause an relative accumulation of clays only at the surface horizon. The properties in the L2 soil were characterized by high solid-phase percentage caused by the densely packed sand. The newly transported materials would be always accumulated in the valley.

**Table 2.** Soil physical properties.

| Soil | Depth (cm) | Three phase distribution: Air (%) | Water (%) | Solid (%) | Total Porosity (%) | Particle size distribution: Clay (%) | Silt (%) | Sand (%) |
|---|---|---|---|---|---|---|---|---|
| Ll | 0 - 10 | 50.2 | 17.8 | 32.0 | 68.0 | 21.6 | 15.9 | 62.4 |
| | 10 - 30 | 37.3 | 24.2 | 38.5 | 61.5 | 13.9 | 12.7 | 73.4 |
| | 30 - 50 | 20.7 | 33.3 | 46.0 | 54.0 | 15.9 | 12.2 | 71.9 |
| | 80 - 100 | 16.4 | 28.8 | 54.9 | 45.2 | 18.2 | 11.0 | 70.8 |
| | 100 - 120 | 11.3 | 30.0 | 58.7 | 41.3 | 18.8 | 12.2 | 69.0 |
| L2 | 0 - 10 | 30.6 | 19.2 | 50.2 | 49.8 | 7.7 | 5.2 | 87.1 |
| | 10 - 30 | 21.9 | 28.1 | 50.1 | 50.0 | 9.5 | 8.1 | 82.4 |
| | 30 - 50 | 18.7 | 28.3 | 53.0 | 47.0 | 10.5 | 6.4 | 83.1 |
| | 60 - 80 | 20.0 | 23.9 | 56.2 | 43.8 | 10.1 | 7.1 | 82.8 |
| | 80 - 100 | 21.2 | 20.0 | 58.8 | 41.2 | 7.5 | 5.6 | 86.8 |

**Table 3.** Soil chemical and physical properties.

| Soil | Horizon | Depth (cm) | EC*1 (dS m$^{-1}$) | pH$_w$ | pH$_k$ | Exchangeable cations: Ca (cmol(+) kg$^{-1}$) | Mg | K | Na | Al | H | CEC*2 | Available $P_2O_5$ (mg kg$^{-1}$) | Total N (g kg$^{-1}$) | Total C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ll | A | 0 - 5 | 0.172 | 4.03 | 3.03 | 0.26 | 0.09 | 0.19 | 0.25 | 0.74 | 1.23 | 15.6 | 18.8 | 115 | 4.19 |
| | BA 1 | 5 - 50 | 0.069 | 4.25 | 4.09 | 0.00 | 0.14 | 0.03 | 0.07 | 0.27 | 0.47 | 5.42 | 0.58 | 11.2 | 0.62 |
| | BA2 | 50 - 75 | 0.015 | 4.87 | 4.17 | 0.00 | 0.08 | 0.01 | 0.07 | 0.22 | 0.44 | 3.61 | 0.89 | 5.70 | 0.33 |
| | BA3 | 75 - I00 | 0.013 | 5.12 | 4.03 | 0.05 | 0.11 | 0.03 | 0.12 | 0.31 | 0.46 | 3.61 | 0.29 | 3.18 | 0.21 |
| | Bwl | 100 - 150 | 0.007 | 5.13 | 3.95 | 0.65 | 0.05 | 0.01 | 0.04 | 0.33 | 0.50 | 4.21 | 0.32 | 1.88 | 0.19 |
| | Bw2 | 150 - 200+ | 0.008 | 5.16 | 3.92 | 0.01 | 0.03 | 0.01 | 0.05 | 0.31 | 0.44 | 2.61 | 0.36 | 1.56 | 0.19 |
| L2 | A | 0 - 8/10 | 0.087 | 4.50 | 3.50 | 0.06 | 0.56 | 0.07 | 0.05 | 0.06 | 0.21 | 4.61 | 7.99 | 17.3 | 1.75 |
| | Bw | 8/10 - 27/30 | 0.091 | 4.10 | 3.95 | 0.01 | 0.19 | 0.04 | 0.05 | 0.17 | 0.28 | 3.81 | 2.43 | 4.93 | 1.06 |
| | CB | 27/30 - 45/60 | 0.053 | 4.50 | 4.11 | 0.60 | 0.11 | 0.05 | 0.43 | ().12 | 0.20 | 3.01 | 0.88 | 4.23 | 0.37 |
| | Cl | 45/60 - 77/85 | 0.025 | 4.68 | 4.18 | 0.00 | 0.06 | 0.02 | 0.05 | 0.12 | 0.18 | 2.41 | 0.81 | 2.18 | 0.21 |
| | C2 | 77/85 - 150+ | 0.024 | 4.76 | 4.18 | 0.01 | 0.03 | 0.01 | 0.11 | 0.05 | 0.09 | 2.61 | 1.63 | 0.58 | 0.06 |

* 1)Electric conductivity, *2)Cation exchange capacity.

**Table 4.** Charge of characteristics, sesquioxide properties and clay mineral composition.

| Soil | Horizon | Depth (cm) | Alo (%) | Sio | Feo | Ald | Sid | Fed | Alo/Ald | Feo/Fed | PZSE | $\sigma_p$ | Clay mineral composition*1: HIV. | It. | Kt. | Gb. | Gt. | Qz. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L1 | A | 0 - 5 | 0.14 | 0.00 | 0.17 | 0.13 | 0.20 | 0.62 | 1.06 | 0.27 | 2.97 | 2.15 | ++ | | +++ | + | + | + |
| | BA1 | 5 - 50 | 0.19 | 0.01 | 0.24 | 0.20 | 0.04 | 0.89 | 0.92 | 0.27 | 4.14 | 0.68 | +++ | | ++ | + | - | + |
| | BA2 | 50 - 75 | 0.19 | 0.01 | 0.18 | 0.26 | 0.32 | 1.18 | 0.73 | 0.15 | 4.19 | 0.39 | +++ | | ++ | + | + | + |
| | BA3 | 75 - 100 | 0.11 | 0.01 | 0.07 | 0.32 | 0.03 | 1.47 | 0.33 | 0.05 | 4.06 | 0.52 | +++ | | ++ | + | - | + |
| | Bw1 | 100 - 150 | 0.07 | 0.01 | 0.03 | 0.29 | 0.01 | 1.45 | 0.25 | 0.02 | 4.14 | 0.32 | +++ | - | ++ | + | - | + |
| | Bw2 | 150 - 200+ | 0.07 | 0.01 | 0.03 | 0.30 | 0.24 | 1.70 | 0.24 | 0.02 | 4.02 | 0.39 | +++ | - | + | - | + | + |
| L2 | A | 0 - 8/10 | 0.02 | 0.00 | 0.08 | 0.04 | 0.08 | 0.28 | 0.36 | 0.29 | 2.87 | 2.07 | - | ++ | +++ | - | - | ++ |
| | Bw | 8/10 - 27/30 | 0.07 | 0.00 | 0.22 | 0.03 | 0.19 | 0.20 | 2.44 | 1.08 | 3.88 | 0.23 | - | + | +++ | - | - | ++ |
| | CB | 2 7/30 - 45/60 | 0.06 | 0.00 | 0.19 | 0.03 | 0.01 | 0.16 | 2.16 | 1.19 | 4.02 | 0.27 | + | ++ | +++ | - | - | ++ |
| | C1 | 45/60 - 77/85 | 0.05 | 0.00 | 0.13 | 0.06 | 0.02 | 0.33 | 0.92 | 0.38 | 4.06 | 0.28 | + | ++ | +++ | - | - | ++ |
| | C2 | 77/85 - 150+ | 0.02 | 0.00 | 0.04 | 0.04 | 0.00 | 0.11 | 0.55 | 0.38 | 4.00 | 0.17 | - | + | +++ | + | + | ++ |

*1) -, 0-5(%); +, 5-20; ++, 20-40; +++, 40-60.

HIV., Hidroxy-interlayered vermiculite; It., Illite; Kt., Kaolinite; Gb., Gibbsite; Gt., Goethite;Qz., Quartz.

## Physico-chemical and mineralogical properties

The L1 and L2 soils were strongly acid with pHw and pHk values below 5.2 and 4.2, respectively, due to the presence of exchangeable Al and H (Table 3). The level of available phosphorus was extremely low for both sites, ranging from 0.29 to 18.8 mg $kg^{-1}$. The value of electric conductivity (EC), the amount of exchangeable Ca, K and Na, total N and C, and cation exchange capacity (CEC) were relatively higher in the A horizon (0-5 cm) for the L1 soil, whereas those were low for the other horizons of both L1 and L2 soils. Furthermore, because of water deficiency for some period of a year, the root mat develops on the surface layer resulting in a high total carbon content, which also becomes a cause of acidity. On the other hand, the nutrients in the surface soil of L2 were lower than those of L1 because of eluviation by the water at the valley.

The result of charge of characteristics, sesquioxide properties, and clay mineral composition in soils was shown in Table 4. The PZSE and $\sigma_p$ values of the variable charge soils were mainly affected by the following factors (Sakurai *et al.* 1989); the presence of organic matter, exchangeable Al, and 2 : 1 type crystalline clay minerals which shifted the PZSE value toward a lower pH range, resulting in a higher $\sigma_p$ value, whereas, presence of amorphous materials and accumulated sesquioxides shifted the PZSE value toward a higher pH range, resulting in a lower $\sigma_p$ value.

The values of Alo in the surface layers of the L1 soil were higher than in the subsurface layers, whereas the values of Ald were vice versa. The value of Alo/Ald was decreasing with depth of the L1 soil. The values of Feo/Fed at A and BA1 horizons were highest and decreased with depth. The PZSE value of the surface layers for the L1 soil was lowest and increased toward the lower layers because organic matter content in the surface layers was highest and decreased with depth and clay mineral composition was almost same throughout the profiles. Furthermore, it was considered that the increasing of PZSE values at subsurface layers was related to the increasing of the amounts of Fe and Al oxides. As kaolinite and hydroxy-interlayered vermiculite (abbreviated to HIV hereafter) were the dominant clay minerals for the L1 soil, followed by quartz, gibbsite, and geothite, the L1 soil could not be strongly weathered. The values of Alo and Ald were quite low for the L2 soil, indicating the absence of active Al oxides. The values of Fed of the L2 soil were slightly lower than those of the L1 soil, and values of Feo were almost same for both soils. The values of Feo/Fed were high in the subsurface horizons of the L2 soil, suggesting the predominance of reductive condition and the transportation of soil particles from the surroundings. Kaolinite was the dominant clay minerals for the L2 soil and illite was relatively rich, whereas HIV was not dominant. HIV transported from the surroundings was removed selectively with water because HIV are easy to be dispersed. The PZSE values were lowest and the $\sigma_p$ values were highest in the surface layers of the L2 soil same as the L1 soil. Therefore, clay mineral composition and the amount of sesquioxides in the profiles were considered to be modified by the water. Though the PZSE and $\sigma_p$ values of both sites were almost same, the composition and the amount of sesquioxides were different. The difference between two soils is affected by the current environmental condition rather than the past weathering process.

## Soil moisture condition

The data of soil moisture and soil temperature at the L1 soil on the stable ridge and at the L2 soil in the valley are shown in Figs. 4 and 5. The data were recorded every 6 hour from Aug. 17, 1995 to Jan. 17, 1997. Because of the troubles of the instrument, some data were missing.

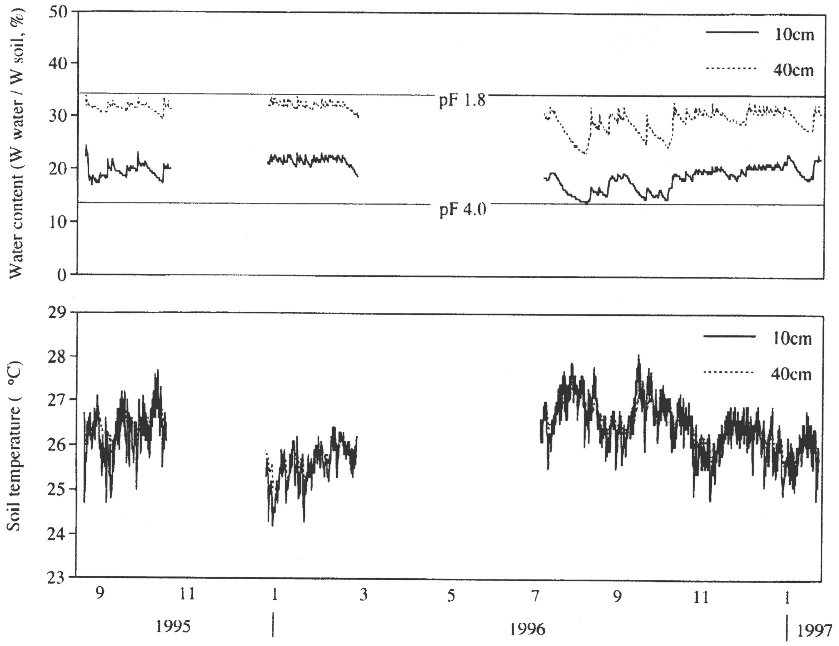


**Fig. 4. Changes in water content (W water / W soil, %) and soil temperature of L1.**

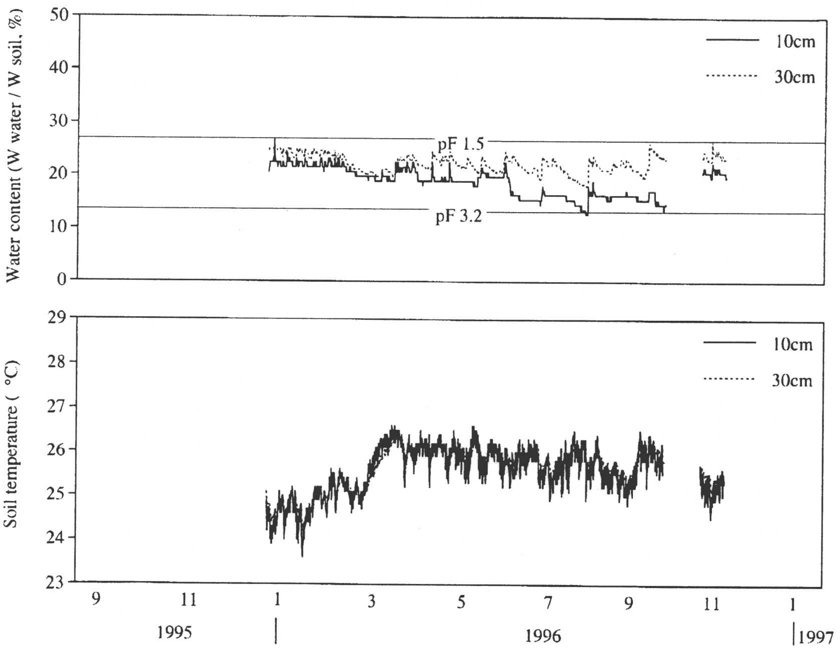


**Fig. 5. Changes in water content (W water / W soil, %) and soil temperature of L2.**

Water content (W/W %) at 10 cm and 40 cm fluctuated from 14 to 25 and 22 to 34 for the L1 soil from August 1995 to January 1997, respectively. This moisture range corresponds to the pF values from 2.0 to 4.0 and 1.8 to 2.5 at 10 cm and 40cm for the L1 soil, respectively. Soil temperature at both

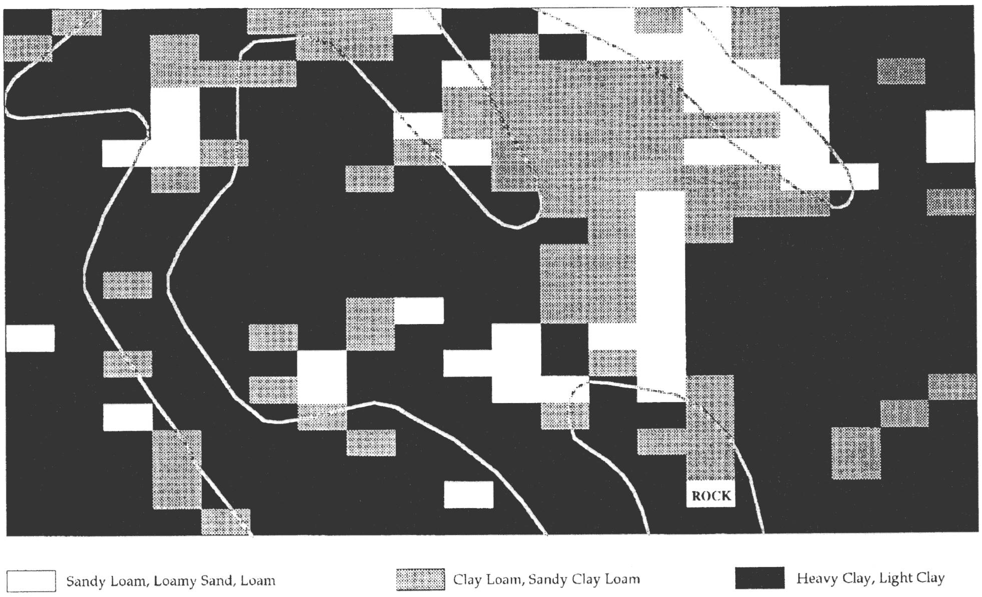


**Fig. 6. Distribution of soil texture in 8 ha plot.**

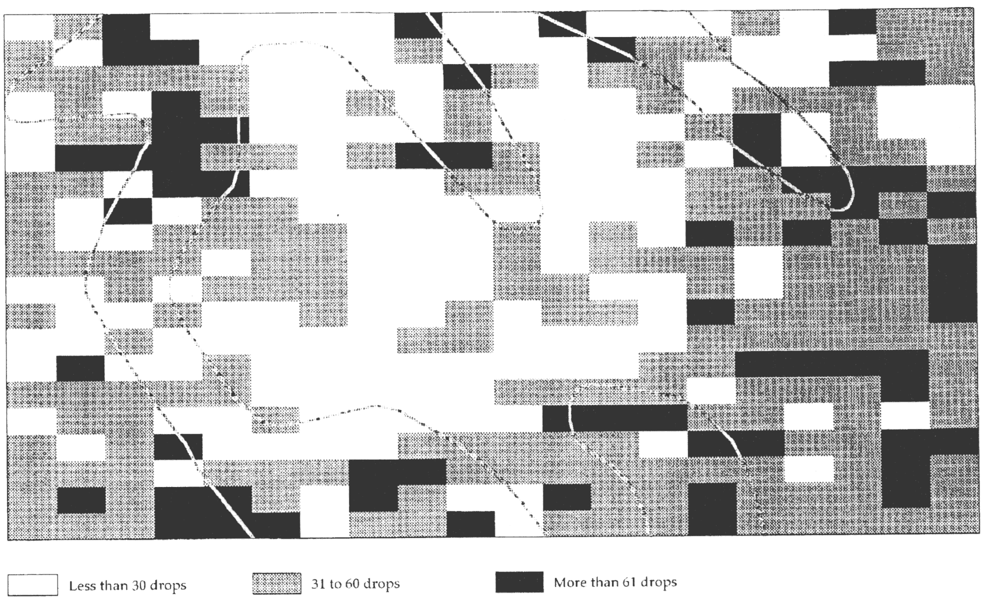


**Fig. 7. Distribution of total count of soil hardness measurement.**

depths was not much different, but the fluctuation pattern was sometimes very sharp, ranging from 24℃ to 28℃. At the L2 soil, water content at 10 cm and 30 cm ranged from 13 to 27 and 19 to 27, respectively. The pF value at the depth of 10 cm and 40 cm ranged from 1.5 to 3.2 and 1.5 to 2.3, respectively. Soil temperature at the L2 soil ranged from 23.5℃ to 26.5℃. Soil moisture and soil temperature were easy to fluctuate in the L1 soil on the ridge, whereas these are relatively stable even

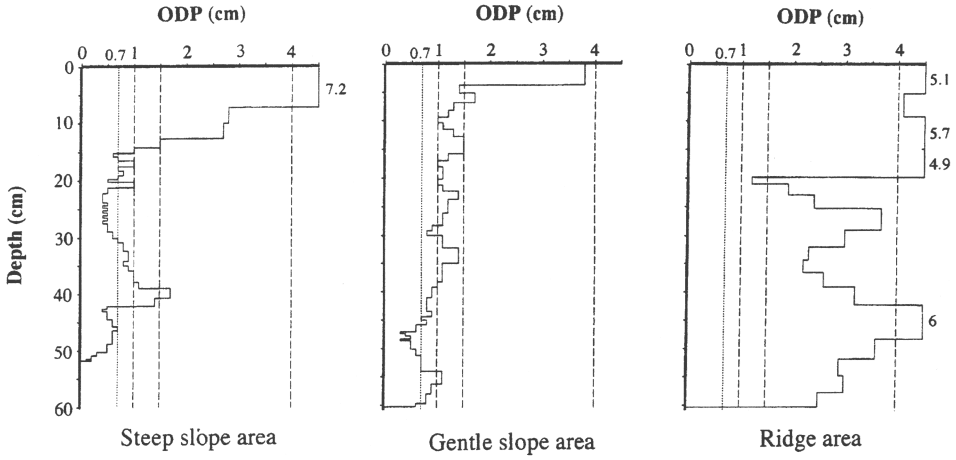


**Fig. 8. The typical pattern of soil hardness at each area.**

after the frequent rainfall in the L2 soil in the valley.

Mass flowering is a unique phenomenon in lowland mixed dipterocarp forests, and occurs at intervals of 2 - 9 years (Ashton *et al.*, 1988). Mass flowering of tropical rain forest occurred in the peninsular Malaysia and the northern part of Borneo island in 1996. Ashton *et al.*(1988) suggested that mass flowering may occur by extraordinary low temperature associated with El Niño phenomenon less than 20℃. Extremely low air temperature were recorded at Tree Tower in the 8 ha plot. It was under 20℃ during January 20 - February 12, 1996 (Sakai *et al.*, 1997). In this period, though there were no special changes in soil moisture content compared with other period, daily minimum soil temperatures of surface and subsurface layers were relatively lower with daily minimum air temperature than the other period. This phenomenon may be related to the mass flowering.

## Distribution of soil texture and soil hardness

Judging from topographical map and field investigation in 8 ha plot, topography in the plot was roughly divided into 3 areas (Fig. 2). One is a steep slope area where soil status and vegetation may be often changing caused by land slide and/or soil erosion. Second one is a gentle slope area which is kept stable for a relatively long time. Third one is a ridge area which is stable in view of topography, but the moisture condition is very different from other two areas. Fig. 6 shows distribution of soil texture at the depth of 10-15 cm in 8 ha plot. Clay percentage of soils at the steep area was very low, and soil texture was sandy loam, loamy sand, or loam. Soil texture at the gentle slope area was heavy clay or light clay. At the ridge area, soil texture was clay loam or sandy clay loam, and within intermediate range of soil texture between steep slope area and gentle slope area.

In Fig. 7, the total count needed for a soil penetrometer test was summarized. Fig. 8 shows an example of typical pattern of the soil hardness at each area. Soil hardness measurement provides valuable information on soils to predict a significant physical hazard for plant growth (Hasegawa *et al.*, 1984; Sakurai *et al.*, 1995). The root of an elm (*Zelkova serrata*) cannot be elongated, when the


**Fig. 9. Distribution of physical hazard for root elongation and plant growth.**

ODP value is less than 0.5 (Hasegawa *et al.*, 1984). Fig. 9 shows the site with an ODP value less than 0.5, therefore, the expected area for physical hazards against root elongation. Total count of soil hardness measurement down to 60 cm at the steep slope area is almost more than 31 drops. The ODP value at the steep slope area was more than 2.0 only at the surface 15 cm at most. Below this depth, the soil was hard to very hard ranging between 0.2 and 0.7, indicating that gravelly materials appeared at the subsurface layer, and that dense gravelly materials are too hard for root to penetrate into. Soil hardness at the gentle slope area was slightly harder than the ridge area. There were little gravelly materials below surface layer. The ODP value below 20 cm was less than 1.0, resulting in much denser soil in the deeper part of the solum without a presence of gravelly materials or rocks. These results show that clayey materials were accumulated to a depth of 60 cm, and/or were fragmented by organic matter and water (weathering) because the gentle slope area is relatively stable topographically. The physical hazard of soil hardness for root elongation was confirmed at some points within the gentle slope area due to clay accumulation in the subsurface layers. Total count of soil hardness measurement at ridge area was less than 30 drops. The ODP value at the ridge area was almost more than 2.0 until the depth of 60 cm. Especially, at the surface 20 cm ODP value was very high because of well-developed root mat layers. No gravel layers and bed rocks appeared down to the depth of 60 cm, suggesting that the physical hazard in terms of soil hardness could not be found at the ridge area. However, the physical hazard due to low moisture condition might occur. The rates of root elongation and plant growth will be slow since the soil is prone to be dry. The distribution of soil texture and soil hardness, therefore, closely related to topography of 8 ha plot. Soil hardness measurement could estimate the presence of clayey and gravelly materials and the depth of root mat in situ and it is quite convenient method for site evaluation in the field. As was reported by Ohta and Effendi (1992b), the total C, N, and P contents were directly correlated with the clay content. The investigation on soil hardness and soil texture can show the distribution of soil materials, and therefore, can grasp roughly the distribution of nutrients in soils.

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## 土壌硬度と土性からみたマレーシア・サラワク州ランビル国立公園の土壌の分布と特徴

熱帯諸国において，土壌荒廃地を修復するためには，残された自然林の状況を様々な角度から明らかにしておく必要がある．この報告は，マレーシア・サラワク州ランビル国立公園内に設けられた 8 ha プロットにおいて実施され，野外においてプロット内の地形と土壌硬度及び野外土性の分布を調べ，植物の根の阻害が予想される土壌のマクロな分布を把握しようとするものである．さらに，8 haプロット内の尾根部と谷部において，土壌水分と土壌温度のモニタリングをおこなった．同時に，より詳しく土壌の特徴を把握するために，尾根部と谷部で採取した土壌の理化学性を調べた．

尾根部では，土層が厚く，表層でのみ有機物含量が高かった．土壌水分は著しく変動しており，土壌は期間を通じて乾いていた．谷部では，土壌水分は降雨の後でさえ比較的安定していた．谷部では，周囲から多くの水の供給を受けるため，細粒質画分と養分の流亡が進んでいた．

地形調査の結果から，プロット内の地形は大きく3つのエリアに分けられた．

1）急傾斜エリア：土壌と植生は，土壌侵食や地滑りによってしばしば変化している可能性がある．土性は sandy loam，loamy sand，loam であった．レキ質が深さ 20～40 cm 付近の次層で見つかり，根の下層への伸長が困難であると考えられた．

2）緩傾斜エリア：土壌と植生は長期間安定である．土性は light clay，heavy clay であった．粘土物質が，有機物によって土壌が細分化され，また 20 cm 以深に集積していた．

3）尾根エリア：土壌と植生は地形的には安定であるが，水分状況が他の地点とは異なっている．土性は clay loam，sandy clay loam であり，急傾斜エリアと緩傾斜エリアの中間的なレンジであった．土壌硬度の観点からの物理的な阻害は確認されなかった．しかし，降雨の少ない期間には，土壌水分が不足するため，根の伸長を含め生育が遅くなる可能性があると推測された．