Soils and the Distribution of *Dryobalanops aromatica* and *D. lanceolata* in Mixed Dipterocarp Forest. - A Case Study at Lambir Hills National Park, Sarawak, Malaysia

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ABSTRACT *Dryobalanops aromatica* and *D. lanceolata* (hereafter denoted as *Da* and *Dl*, respectively) are major Dipterocarp species constituting an emergent layer in the Bornean Rain Forest, and their distributions are in proximity, but never overlap. Thus, we examined the relationship between the distribution of these species and soils with reference to the soil physico-chemical, morphological, and microbiological properties.

Based on the topographical investigation, was located only on the upper slope, whereas *Dl* occupied on both upper and lower slopes. The soil solums examined around these two species were always deeper than 1.3 meter. Soil texture was always sandy for the soils around Da, on the other hand, ranging from sandy to clayey for those around Dl. Furthermore, the following differences were found; 1) organic layer was thicker in the *Da* soils, 2) soil color of subsurface horizons was duller in the *Dl* soils, and 3) only the *Dl* soils contained coarse fragments. 4) the amounts of exchangeable cations such as Ca and/or Mg and total oxides' content of K_2O, MgO, and P_2O_5 were higher for the *Dl* soils, 5) the amounts of exchangeable Al and H were higher in the *Da* soils, 6) proportion of air phase and volume of macropore, and the value of sand content were higher for the *Da* soils, showing that the *Da* soils easily attain to drier soil moisture condition after rainfall, which was proved by monitoring soil water potential, 7) ten times as much fungal colonies were detected in the *Da* soils as compared to the *Dl* soils.

These results suggest that *Da* emerges on a sandy soil with a dominance of drier soil moisture condition for some period and a low nutrient status with high acidity on the reflection of stable pedogenetic processes, while *Dl* stands on either clayey or sandy soil with a dominance of reductive condition for a certain period and relatively high nutrient status with low acidity, reflecting weak pedogenetic processes. It was well-known that shifting cultivators utilize a land where *Dl* dominates as a productive crop field. Their traditional way of land selection proves to be rationale from the standpoint of soil science.

Key Words: soil morphology / soil physico-chemical properties / mixed dipterocarp forest / Sarawak/ tropical rain forest / *Dryobalanops aromatica* / *Dryobalanops lanceolata*

There has been concerned with the relationship between soils and vegetation from the standpoint of ecology and forestry. In tropical rain forests, particularly, mixed Dipterocarp forests, such studies has been conducted, but it remains to be discussed about the relationship between soils and vegetation. There are two different ways of thinking about the relationship, that is, 1) there is some relation (Richards, 1952; Ashton, 1976; Baillie, 1987), 2) no relation (Poore,1968; Wong & Whitmore,1970; Austin *et al.*,1972). However, these comparative studies have been carried out in a huge scale where significant differences in vegetation was included, so that the relationship between their soils and the distribution of vegetation could not be clearly elucidated. Moreover, the distribution of individual tree

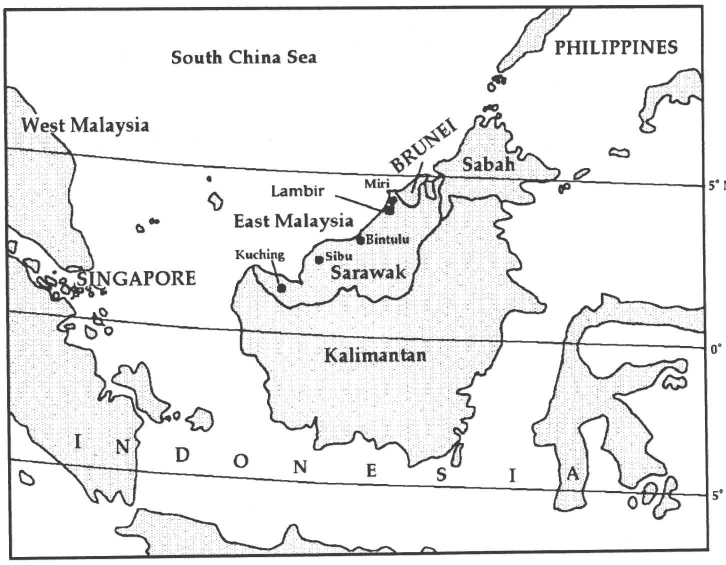

Fig. 1. Location of the study site of Lambir Hills, Sarawak, Malaysia (cited from Yamakura *et al.* 1995).

species and soils have been little focused.

As to the soil characteristics in the forest, soil chemical properties were always analyzed, but its moisture characteristics and profile description have been little examined. It is well-known in Japan that soil physical properties and soil structure are closely related to the floor vegetation. Thus, we tried to find out the soil-vegetation relationship with respect to physical and morphological properties as well as chemical properties.

Among the wide variety of tree species, *D. aromatica* and *D. lanceolata* (hereafter denoted as *Da* and *Dl*, respectively) were selected for our study. They are the most dominant and prominent species seen in the Lambir Hills National Park in Sarawak, East Malaysia, and the segregation has already been recognized through the species identification in the 52 ha permanent research plot (Itoh, 1995). Although he examined on germination and seedling establishment of the said two species (Itoh, 1995), the soil-vegetation relationship has not yet been done.

Furthermore, shifting cultivators there regard *Dl* as an indicator plant for a productive crop field (Yamakura & Ogino, personal communication), but its reason has not yet been elucidated clearly with a view point of soil science.

In order to understand the reason why these two species show a segregate distribution and why shifting cultivators utilize a land with *Dl* stand, a pedological and a microbiological approaches were conducted. In the present study, therefore, the study site is selected within a relatively narrow area where one of these species is dominant as an emergent tree.

MATERIALS AND METHODS

Study Area and Soils

Lambir Hills National Park (4° 12'N, 114°00'E) is located some 24 Kilometers south of Miri town, in Miri Division, Sarawak, Malaysia (Fig. 1). It covers an area of 6952 hectors which consists of 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 sandstone and/or shale, derived from tertiary period sedimentary rock. In Miri, mean annual temperature and precipitation is 27.2°C and 2927mm, respectively (Watson, 1985). Human impact on the vegetation and soils has been avoided as much as

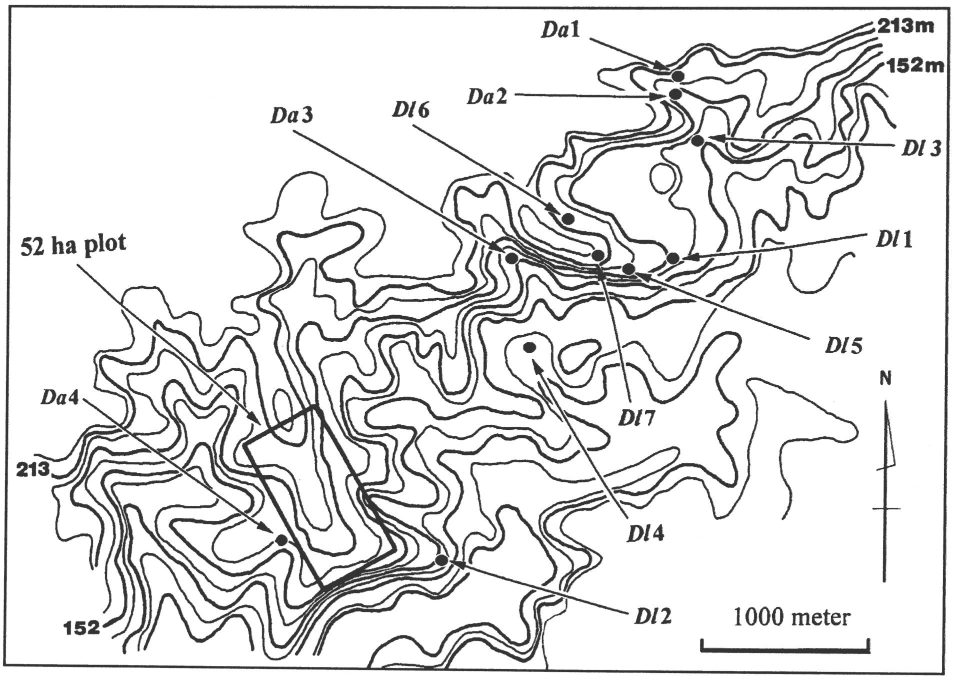

Fig. 2. Location of sampling sites in Lambir Hills National Park.

possible, because this park has an outstanding regional and global conservation significance for its extraordinary species-rich forest.

Four soil profiles each from *D. aromatica* (*Da*1-*Da*4) and *D. lanceolata* (*Dl*1-*Dl*4)(Fig. 2) were described in texture, soil color, soil structure, consistency, mottles, cutan, gravels, roots, and soil hardness. After morphological investigation of the profiles, soil samples were taken for soil physico-chemical and microbiological analyses. Furthermore, additional three profiles (*Dl*5-*Dl*7) were described to cover the wide variation of soils under *Dl*, but not used for the further analysis.

Soil general physico-chemical properties were examined for soil samples collected from three layers of each pedon at the depth of 0 to 10 cm, 10 to 30 cm, and 30 to 50 cm. Total chemical composition and mineralogical properties were analyzed for pedological horizons.

Analytical Methods

Soil chemical and microbiological properties

Soil samples were air-dried and crushed to pass through a 2mm sieve. Analyses were performed using the following methods.

1) pH was measured with a glass electrode using a soil to solution (H_2O or 1M KCl) ratio of 1:5.

2) Exchangeable cations and CEC:

(a) Exchangeable bases were extracted with 1M NH_4OAc at pH 7.0 twice, using a soil to solution ratio of 1:5 and then the amounts of Ca and Mg in the extract were determined by atomic absorption spectrometry and Na and K by flame photometry (Shimadzu, AA-640-12).

(b) Exchangeable Al and H were extracted with 1M KCl at a soil to solution ratio of 1:5 and the amount of Al was determined by ICP-AES (Seiko, SPS-1200), and the amount of exchangeable H was calculated after the determination of exchangeable acidity with 0.02M NaOH.

(c) CEC: After replacement of exchangeable bases, washings with deionized water and ethanol and replacement of NH_4^+ with 10% NaCl were successively performed by centrifugation. NH_4-N

Table 1. Morphological properties of the soils developed near *D. aromatica*.

Soil	Horizon	Depth (cm)	Soil color (moisture[a])	Texture	Structure[b]	Mottling	Roots[c]/stone	Boundary[d]
*Da*1	O	9-0						
	A	0-2/7	7.5YR2/3 (dm)	CL	2vfgr		mvf/none	cs
	AB	-15	8.75YR4/3 (dm)	CL	1mgr,1msbk		mc/none	cs
	BA	-26	7.5YR5/6 (dm)	CL	1msbk		mc/none	cs
	Bw	-44/48	7.5YR5/8 (dm)	LiC	1csbk		mc/none	gs
	Bt	-80/83	7.5YR5/8 (dm)	LiC	1-2vcabk		ff/none	aw
	CB	-130+	2.5-5YR5/8 (dm)	HC				
*Da*2	O	17-0						
	A	0-10	10YR5/6 (dm)	SCL	1vfgr,2msbk		mvf/none	cw
	BA	-23/32	10YR6/8 (dm)	SCL	1msbk		mm/none	cs
	Bw1	-65/70	7.5YR5/8 (dm)	SCL	1vcsbk		cm-c/none	ds
	Bw2	-86/93	7.5YR5/8 (dm)	CL	1csbk		ff/none	cs
	Bt	-100/110	7.5YR6/8 (dm)	LiC	1vcabk		ff-m/none	
*Da*3	O	5-0						
	A1	0-8	10YR4/4 (dm)	SL	1vfgr		mm-c/none	cs
	AB	-30	10YR5/6 (dm)	SL	1m-cabk		mm-c/none	cs
	BA	-53	10YR5/8 (dm)	SCL	1abk		fvf-m/none	gs
	Bw	-116	10YR6/8 (dm)	SCL	1vcabk		ff-m/none	ds
	BC	-180+	7.5YR6/8 (dm)	SCL	1vcabk		fvf/none	
*Da*4	O	5-0						
	A	0-5	7.5YR3/4 (dm)	SL	1vfgr		mm/none	cs
	BA	-31	10YR6/8 (dm)	SL	1m-cabk		mm-c/none	gs
	Bw	-69	8.75YR5/8 (dm)	SL	1abk		cm-c/none	gs
	BC	-115/125	5YR6/8 (dm)	SCL	1cabk		ff-c/few	

a) dm: dry moist.
b) Grade, 1: weak, 2: moderate, 3: strong. Size, f: fine, m: medium, c: coarse, vc: very coarse. Type, gr: granular, cr: crumb, sbk: subangular blocky, abk: angular blocky.
c) gs: gradual smooth, cs: clear smooth, cw: clear wavy, ds: diffuse smooth.
d) Abundance, m: many, c: common, f: few. Size, vf: very fine, f: fine, m: medium, c:coarse.

was determined by the Kjeldahl distillation and titration method.

3) Particle size distribution was determined by pipette method.

4) Total Carbon and Nitrogen were determined by a dry combustion method using NC-analyzer (Sumika Chem. Anal. Service, Sumigraph NC-80).

5) Ten major elemental oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO_2, TiO_2, CaO, MgO, K_2O, Na_2O and P_2O_5) were analyzed by the method of Ochi and Okashita (1987), using XRF (Shimadzu VF-320A). The total contents of 10 elements in the form of oxide fell in the range of 98.5 to 102 %.

6) Available phosphorus was determined by the modified Bray No. 2 method.

7) Fungal counts in every soil horizon were examined by the plate count method.

Soil physical properties

For the determination of three phase distribution, hydraulic conductivity, and moisture characteristics, soil samples were collected by 100cc 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. Then, they were saturated with 0.05 M $CaSO_4$, and saturated hydraulic conductivity was determined by the constant head method (Daiki Rika Kogyo, DIK-4000).

Subsequently, water holding capacity was measured for 0.98 kPa and 3.16 kPa by the sand column method (Daiki Rika Kogyo, DIK-3520), for 9.8 to 1553 kPa by the pressure plate method (Daiki Rika Kogyo, DIK-3420). After oven-drying for 24 hours, the weight of the solid phase was measured, and

Table 2. Morphological properties of the soils developed near *D. lanceolata*.

Soil	Horizon	Depth (cm)	Soil color (moisture[a])	Texture	Structure[b]	Mottling	Roots[c]/ stone	Boundary[d]
Dl1	O	4-0						
	A	0-6	10YR2/3 (dm)	LiC	2-3f-msbk		mvf/none	cs
	BA	-31	8.75YR4/3 (dm)	LiC	1mgr,1msbk		fc/none	cs
	Bt1	-60	7.5YR5/6 (dm)	LiC	1msbk		fc/none	cs
	Bt2g	-77	7.5YR5/8 (dm)	HC	1csbk	reduced mottles	fc/none	gs
	Bt3g	-130	7.5YR5/8 (dm)	HC	1-2vcabk	reduced mottles	fc/none	aw
Dl2	O	4-0						
	A	0-5	10YR4/6 (dm)	SL	1fsbk		mm/none	cw
	Bw1	-35	10YR5/8 (dm)	SCL	2mcsbk		cf/common	cs
	Bw2	-65	10YR5/8 (dm)	SCL	1vcsbk		ff/abun.	ds
	BC1g	-103	10YR5/8 (dm)	LiC	1csbk	reduced mottles	fvf/few	cs
	BC2g	-135	10YR6/6 (dm)	LiC	1vcsbk	reduced mottles	vf-f/few	
Dl3	O	4-0						
	A1	0-9/13	8.75YR3/4 (dm)	LS	2msbk		cvf/few	cw
	Bwg	-25/30	10YR5/6 (dm)	LS	1msbk		cf/none	cw
	Bcg	-53/63	10YR6/4 (dm)	SL	1vcsbk		cm/common	cs
	G1	-75/93	2.5Y6/3 (dm)	SL	massive	Gleyed horizon	fc/few	gw
	G2	-135+	2.5Y5/3 (dm)	SCL	massive	Gleyed horizon	none/none	
Dl4	O	4-0						
	A	0-4	10YR4/3 (dm)	SiCL	2msbk		mm/none	cs
	Bw	-35	10YR6/6 (dm)	LiC	2csbk		mvf-c/common	gs
	Bt1	-60	10YR6/4 (dm)	LiC	2cabk		cf-m/few	gs
	Bt2	-102	10YR6/4 (dm)	LiC	2vcabk		cvf-m/few	cs
	Bcg	-150	10YR6/3 (dm)	LiC	1vcabk	reduced mottles	fvf-m/common	
Dl5	O	2-0						
	A	0-7/10	10YR5/4 (dm)	LiC	2fsbk		mv-c/none	cw
	BA	-25/30	10YR6/6 (dm)	LiC	2m-csbk		mvf-c/common	cw
	Bw	-85	7.5YR6/8 (dm)	HC	2vcabk		cvf-c/few	cw
	Bcg	-115	10YR6/6 (dm)	HC	1vcabk	reduced mottles	ff-c/abundant	gs
	Cbg	-160+	10YR6/6 (dm)	HC	massive	reduced mottles	none/few	
Dl6	O	3-						
	A	0-7	10YR5/4 (dm)	HC	2fsbk		mvf-c/none	cs
	BA	-30/33	7.5YR5/6 (dm)	HC	2fsbk		cvf-c/none	gs
	Bt	-78	7.5YR5/8 (dm)	HC	2csbk		cvf-c/none	gs
	Btg	-110	7.5YR6/8 (dm)	HC	2vcabk	reduced mottles	ff-c/none	cs
	BC	-135	10YR7/4 (dm)	HC	2vcabk		ff/many	gir
	Bcg	-160+	10YR7/6 (dm)	HC	2vcabk	reduced mottles	ff-m/abundant	
Dl7	O	3-0						
	A	0-5/7	10YR5/3 (dm)	L	2mcr-2csbk		mf-c/none	cs
	AB	-10/13	10YR6/8 (dm)	L	2csbk		cf-c/none	cw
	BA	-27/33	8.75YR6/8 (dm)	L	2c-vcsbk		cf-c/none	gs
	Bw	-52/60	7.5YR5/6 (dm)	L	1-2vcsbk		cf-c/none	gs
	BC	-65/95	7.5YR5/8 (dm)	SL	1vcsbk		ff-c/none	gir
	C	-150+	7.5YR6/8 (dm)	S	single grain		cf-c/none	

a), b), c), d): see Table 1.

then water phase was calculated by subtracting the weight of solid phase from the sum of the weight of solid and water phase.

Tensiometers were installed in the field at the soil depth of 10 cm and 30 cm with an automatic data logger (Kohna system, KADEC-U2 with KDC-S5) to monitor water potential (matric suction) in

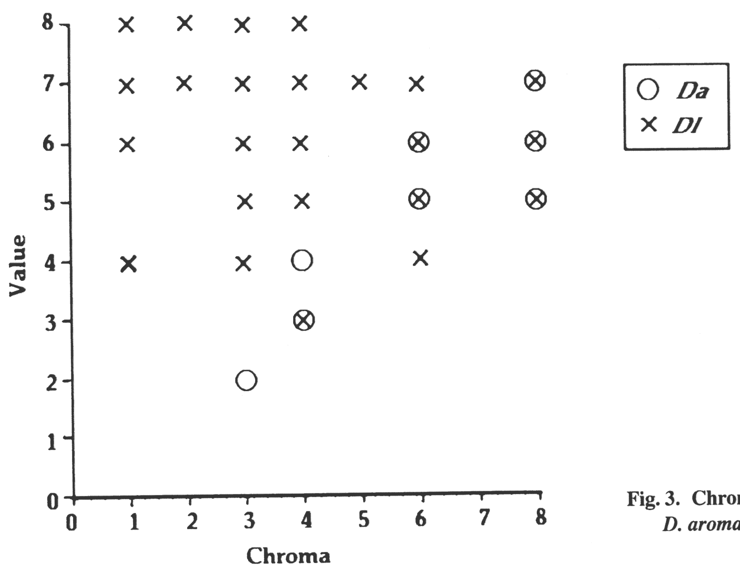

Fig. 3. Chroma and value of soil color for *D. aromatica* and *D. lanceolata*.

the soils near two species.

RESULTS AND DISCUSSION

Soil morphological characteristics

The soils near *Da* (hereafter denoted as *Da* soils) were usually situated on a stable hill ridge, and their parent materials were untransported and hence *Da* soils are considered sedentary soils. On the other hand, the soils near *Dl* (hereafter denoted as *Dl* soils) were divided into two groups in view of topography; some are located on a smaller hill ridge than the one where *Da* dominates, and/or stable hill slope (*Dl*1, *Dl*4, *Dl*5, *Dl*6, and *Dl*7) and the others are located in the lower slope near the valley (*Dl*2, *Dl*3). The soils in the valley were found to be unstable from the standpoint of pedogenesis, and transported materials can be supplied successively.

Based on the soil profile descriptions shown in Tables 1, and 2, the following characteristics were found.

1) Organic layer was thicker in the *Da* soils than in the *Dl* soils.

2) Reduced mottles and/or dull color in deeper horizons were found in the *Dl* soils whether the soil texture is either clayey or sandy, whereas no reduced mottles were found in the *Da*.

3) Soil depth of the soils under both vegetation types was deeper than 130cm.

4) Coarse fragments were often found in the profile of the *Dl* soils, whereas they were not found in the *Da* soils.

It is noteworthy that both vegetation types stand on a relatively well developed soil with a deep solum in comparison with those in Japan, so that deeper soils may be necessary for supporting a big biomass of the said vegetation. In other words, a big biomass can not stand on a less developed soil. However, it needs more work to elucidate the relationship between soil development and establishment of emergent trees with a big biomass.

Accumulation of a thicker organic layer in the *Da* soils than in the *Dl* soils may result from a slower decomposition rate of organic matter where a relatively drier soil condition was observed. This

Table 3. Soil physical properties.

Soil	Depth (cm)	HC[1] (10^{-3} cm/sec)	Three phase distribution Air (%)	Water (%)	Solid (%)	Total Porosity (%)	Macro[2] Pore (%)	Micro[3] Pore (%)	Particle size distribution Sand (%)	Silt (%)	Clay (%)
*Da*1	0-10	6.67	30.6	33.9	35.5	64.5	26.8	37.7	57	24	19
	10-30	3.68	20.9	34.4	44.7	55.3	18.1	37.2	55	24	21
	30-50	0.29	16.4	32.0	51.6	48.4	16.1	32.3	52	23	25
*Da*2	0-10	19.5	50.5	22.3	27.2	72.8	45.5	27.3	62	16	22
	10-30	38.7	43.1	23.3	33.6	66.4	42.2	24.2	60	19	22
	30-50	9.16	26.2	29.5	44.3	55.7	25.9	29.8	60	18	22
*Da*3	0-10	16.5	45.9	17.6	36.5	63.6	43.9	19.7	80	8	12
	10-30	4.97	46.4	16.8	36.8	63.2	44.1	19.1	77	8	15
	30-50	8.69	33.8	20.9	45.3	54.7	31.8	22.9	74	8	18
*Da*4	0-10	47.0	46.4	16.5	37.1	62.9	45.5	17.4	78	10	12
	10-30	9.01	34.6	20.4	45.0	55.0	34.0	21.0	76	10	14
	30-50	2.69	36.1	15.3	48.6	51.4	29.8	21.6	77	9	14
*Dl*1	0-10	51.1	31.6	30.3	38.1	61.9	29.7	32.2	38	33	29
	10-30	0.89	16.8	33.0	50.2	49.8	12.7	37.1	33	33	34
	30-50	2.42	14.2	36.5	49.3	50.7	9.5	41.2	27	31	42
*Dl*2	0-10	9.47	18.1	30.8	51.1	48.9	15.5	33.4	74	14	13
	10-30	2.33	15.4	32.1	52.6	47.4	13.0	34.4	67	15	17
	30-50	6.04	16.7	33.9	49.3	50.7	13.2	37.5	64	15	21
*Dl*3	0-10	57.9	38.7	22.4	38.9	61.1	41.9	19.2	86	8	6
	10-30	17.2	14.3	38.6	47.1	52.9	28.1	24.8	88	7	5
	30-50	0.04	6.1	46.2	47.7	52.3	36.6	15.7	84	8	8
*Dl*4	0-10	8.76	32.4	26.3	41.3	58.7	27.3	31.4	38	34	27
	10-30	1.40	21.5	26.2	52.3	47.7	16.4	31.3	34	34	32
	30-50	4.73	15.9	30.3	53.8	46.2	11.4	34.8	28	34	39

1: Hydraulic conductivity; 2: >9.5 μm in diameter, 3): <9.5 μm in diameter

finding is consistent with that of forest soils developed under cool temperate climate in Japan (Forest soil research group, 1994). The difference in soil color (Fig. 3) suggested that *Dl* should stand on the soils with reduced mottles, and hence an aquic moisture regime (Soil survey staff, 1990) in the lower horizons. The aquic moisture regime found in the lower horizons of the *Dl* soils is brought by either the water saturation of the capillary fringe when its clay content is higher, or the water saturation by ground water when the clay content is lower. Thus, soil morphology indicate that *Dl* prefer a relatively wet condition to *Da*, or that *Da* can stand only on a relatively dry condition.

One exception is found in *Dl*7 soil, because there is no reduced mottle throughout the profile (Table 2). However, as compared with the *Da* soils in Table 1, the color of surface horizon of the *Dl*7 is duller than the *Da* soils, indicating a relatively wet condition for some period. Besides the *Dl*7 soil is located on a small ridge near valley, so that the tree roots can extend to the valley with ease.

Hence, moisture characteristics can be a critical factor to differentiate the characteristics of the *Dl* soils from the *Da* soils. Furthermore, the presence of coarse fragments in the subsurface horizon of the *Dl* soils suggests an unstable pedogenetic condition. Thus, the *Dl* soils are considered younger than the *Da* soils.

As discussed above, the differences between the *Da* and *Dl* soils were considerably definite. Because of the occurrence of wide range in soil morphology, the *Dl* soils should better be classified into the following two groups. One is a soil with matrix soil color of 10YR in the subsurface horizons, while the other is a soil with matrix soil color of 7.5YR. The former is mostly located in or near the valley, or on the small ridge with gentle slope and high clay content, whereas the latter is mostly located on the hill ridge. Further investigation on the other species of Dipterocarpaceae will be helpful

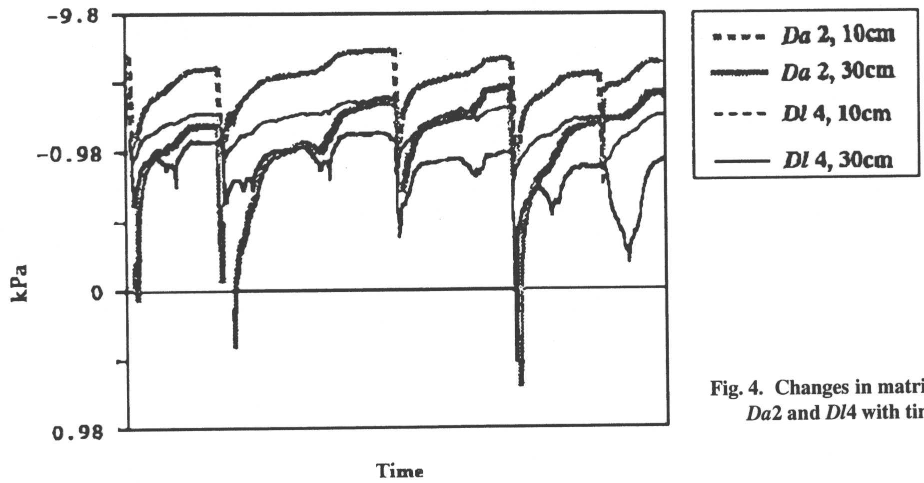

Fig. 4. Changes in matric suction of *Da*2 and *Dl*4 with time.

to make out these relationship in more detail.

Soil physical properties

Proportion of air phase and value of the macropore percentage were higher in the *Da* soils than in the *Dl* soils (Table 3). Proportion of water phase is lower in the *Da* soils than in the *Dl* soils. For the *Da* soils, sand content was higher than 50% and clay content was less than 26%, whereas for the *Dl* soils, the former ranged from 27 to 88% and the latter from 5 to 42%. In summary, physical properties common in the *Da* soils are high sand content, high macropore percentage, and high air-phase percentage and hence subjected to a low moisture condition. On the other hand, the properties common in the *Dl* soils were high water-phase percentage and low air-phase percentage in situ for the layer from 30 to 50cm: Even if the texture and pore characteristics were different among pedons, a relatively high moisture condition was prevalent for the *Dl* soils.

Generally speaking, micropore percentage depends on the clay content, whereas macropore percentage depends on the sand content. Thus, the micropore is important for the retention of both water and nutrients, whereas the macropore is important to the drainage. Judging from the data in Table 3, it can be predicted that the *Da* soils show a better drainage condition, but lower nutrient status and water holding capacity than the *Dl* soils.

Soil moisture condition

Since we found out the difference in soil moisture condition between the *Da* and *Dl* soils by the morphological observation and some of physical properties, we monitored the soil moisture using tensiometers with automatic data logger for nine days in September 1993. The locations of the tensiometers installed were around *Dl*4 and *Da*2. Based on the results shown in Fig. 4, the soil matric suction near *Da* is easy to fluctuate, whereas that near *Dl* is relatively stable even after the frequent rainfall. Moreover, the matric suction is much lower in the *Da*2 soil than the *Dl*4 soil, indicative of lower content of free water in the *Da*2 soil than the *Dl*4 soil. These facts support the evidence from soil morphological properties, although we need to conduct detailed investigation throughout a year or more.

Soil chemical properties and total chemical composition

The amounts of exchangeable cations and available phosphorus (Table 4) are considered as an active nutrient flow in the forest. The content of Ca, Mg, and K, and phosphorus were higher in the *Dl* soils

Table 4. Soil chemical properties.

Soil	Depth (cm)	pH H_2O	pH KCl	EC ($\mu S\ cm^{-1}$)	Exchangeable cations Ca	Mg	K	Na	Al	H	CEC	Total C (%)	Total N (%)	Available P_2O_5 ($g\ kg^{-1}$)
					---------- (cmol(+) kg^{-1})						----------			
*Da*1	0-10	4.42	3.54	53.9	0.32	0.34	0.09	0.04	5.87	2.53	8.14	2.73	0.15	0.008
	10-30	4.69	3.74	32.2	0.25	0.37	0.05	0.02	3.39	1.47	8.63	0.64	0.06	0.005
	30-50	4.86	3.73	29.0	0.23	0.35	0.05	0.02	4.38	0.63	7.53	0.30	0.04	0.004
*Da*2	0-10	4.18	3.39	56.0	0.04	0.09	0.02	0.14	6.69	3.14	15.75	4.78	0.21	0.018
	10-30	4.56	3.64	26.0	0.03	0.03	0.02	0.07	4.04	2.03	9.46	1.10	0.06	0.007
	30-50	4.72	3.73	23.0	0.02	0.03	0.02	0.06	2.88	1.18	7.65	0.52	0.04	0.005
*Da*3	0-10	4.47	3.65	33.5	0.04	0.08	0.02	0.12	3.12	1.70	7.88	1.62	0.08	0.011
	10-30	4.87	4.00	16.2	0.00	0.03	0.01	0.05	1.85	0.82	5.14	0.84	0.05	0.006
	30-50	5.14	4.09	11.6	0.00	0.01	0.01	0.03	1.71	0.63	4.76	0.34	0.03	0.006
*Da*4	0-10	4.66	3.78	33.3	0.06	0.06	0.01	0.11	2.41	1.22	6.58	1.26	0.07	0.014
	10-30	4.74	3.96	28.2	0.01	0.03	0.01	0.06	1.64	1.14	4.80	0.57	0.04	0.007
	30-50	4.81	4.00	22.0	0.00	0.01	0.01	0.04	1.49	0.83	3.97	0.24	0.02	0.004
*Dl*1	0-10	4.39	3.38	61.0	1.07	1.59	0.24	0.04	4.25	2.12	12.58	2.36	0.17	0.012
	10-30	4.44	3.51	30.1	0.28	1.02	0.12	0.03	5.54	1.83	10.21	0.82	0.09	0.004
	30-50	4.67	3.61	24.3	0.27	1.22	0.09	0.03	5.83	1.66	11.37	0.56	0.08	0.006
*Dl*2	0-10	4.77	3.74	29.1	0.39	0.76	0.08	0.02	1.92	1.03	4.95	1.01	0.10	0.040
	10-30	4.93	3.75	23.8	0.34	0.47	0.05	0.05	2.50	1.19	5.18	0.61	0.07	0.004
	30-50	4.63	3.77	19.2	0.30	0.44	0.05	0.03	2.60	1.08	4.98	0.38	0.05	0.002
*Dl*3	0-10	5.00	3.93	62.3	0.50	0.49	0.09	0.08	1.26	0.84	5.60	1.41	0.11	0.019
	10-30	5.22	3.93	26.3	0.25	0.51	0.16	0.04	0.91	0.50	2.36	0.44	0.05	0.008
	30-50	5.31	3.89	21.8	0.26	0.35	0.03	0.01	0.99	0.67	2.27	0.25	0.03	0.008
*Dl*4	0-10	5.19	3.76	44.3	1.26	0.46	0.23	0.05	1.13	0.67	13.13	1.74	0.18	0.027
	10-30	5.36	3.80	33.9	0.47	1.97	0.13	0.05	2.52	1.09	9.65	0.84	0.11	0.008
	30-50	5.49	3.78	27.1	0.28	1.86	0.12	0.07	3.72	1.11	11.33	0.37	0.07	0.004

Oven dried basis

than in the *Da* soils. Moreover, base saturation was much higher in the *Dl* soils than in the *Da* soils, although it was less than 50% for both soils. The values of pH (H_2O) and exchangeable H of surface horizon (0-10cm) ranged from 4.18 to 4.66 and 1.22 to 3.14 for the *Da* soils, respectively, whereas 4.39 to 5.19 and 0.67 to 2.12, respectively for the *Dl* soils. The amount of exchangeable Al is generally higher in the *Da* soils, and that is higher in the surface horizons for the *Da* soils and in the subsurface horizons for the *Dl* soils. On the other hand, the amounts of exchangeable Ca and Mg were much lower in the *Da* soils than the *Dl* soils. These data reflected the difference in the topography as will be shown in the following paper (Sakurai *et al.*, in prep.) and related moisture condition. The *Da* soils on the stable ridge underwent a strong leaching of the basic nutrients and became more acidic soil condition. 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 promotes acidity as reported in forest soils in Japan (Forest Soil Research Group, 1993). On the other hand, the *Dl* soils on the slope would be supplied with nutrients accompanied with water and soil particles from the surroundings, because of lower slope, and moist moisture condition would be suitable for the rapid mineralization of basic cations to the surface horizon. Further analysis in view of clay mineralogy and charge characteristics may be helpful to interpret the soil-plant relationship.

The total chemical composition (Table 5) was analyzed for the pedogenetic horizons as a measure of nutrient stock. Total chemical composition changed with clay content, as indicated by the report of Ohta *et al.* (1993). The values of CaO and Na_2O were quite low, indicating that both *Dl* and *Da* soils

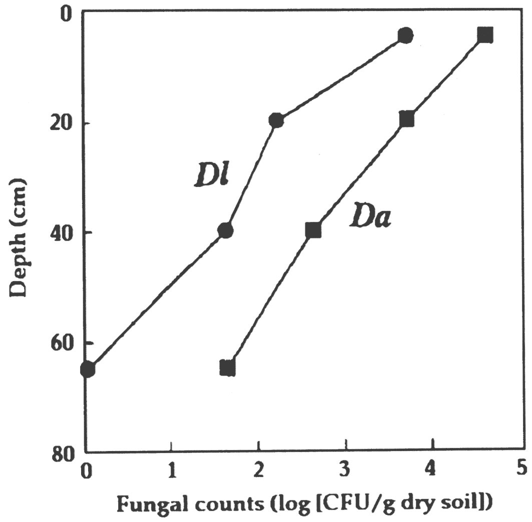

Fig. 5. Fungal counts of *Da* soil and *Dl* soil with depth.

Table 5. Total chemical composition and particle size distribution.

Soil	Horizon	Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO_2	CaO	K_2O	MgO	Na_2O	P_2O_5	Total	Sand	Silt	Clay
			Total chemical composition[1] (%)											Particle size distribution[2] (%)		
*Da*1	A	0-2/7	91.06	6.01	2.68	0.83	<0.01	<0.01	0.41	0.21	0.02	0.04	101.26	56	25	20
	AB	-15	89.32	7.16	3.33	0.86	<0.01	<0.01	0.47	0.23	0.02	0.02	101.41	53	27	21
	BA	-26	88.20	7.51	3.47	0.85	<0.01	<0.01	0.48	0.25	0.02	0.02	100.80	54	24	23
	Bw	44/48	84.02	9.07	4.20	0.95	<0.01	<0.01	0.63	0.29	0.06	0.02	99.24	49	21	30
	Bt	-80/83	79.54	11.69	6.19	0.96	<0.01	<0.01	0.98	0.39	0.01	0.02	99.78	45	18	37
	CB	130+	66.51	16.74	11.76	0.93	0.01	<0.01	1.86	0.62	0.07	0.03	98.52	39	15	46
*Da*3	A	0-8	94.88	3.50	0.89	0.48	<0.01	<0.01	0.08	0.07	0.01	0.02	99.93	81	8	13
	AB	-30	93.90	4.24	1.25	0.45	<0.01	<0.01	0.11	0.10	<0.01	0.02	100.07	79	9	16
	BA	-53	92.37	5.15	1.53	0.44	<0.01	<0.01	0.14	0.10	<0.01	0.01	99.74	75	7	17
	Bw1	85	91.14	5.74	1.68	0.45	<0.01	<0.01	0.21	0.14	<0.01	0.02	99.38	76	7	17
	Bw2	116	90.91	6.11	1.86	0.41	<0.01	<0.01	0.24	0.14	0.03	0.02	99.72	75	8	19
	BC	-180	90.84	6.14	1.93	0.45	<0.01	<0.01	0.31	0.15	0.02	0.01	99.85	73	10	12
*Dl*3	A	0-9/13	94.89	3.20	0.93	0.39	0.01	<0.01	0.34	0.14	0.00	0.02	99.92	86	8	6
	Bwg	25/30	96.75	2.63	0.80	0.27	<0.01	<0.01	0.23	0.09	0.00	0.02	100.79	88	7	5
	BCg	53/63	94.35	3.53	1.16	0.28	<0.01	<0.01	0.23	0.12	0.01	0.01	99.69	84	8	8
	Cg1	75/93	94.53	3.88	1.03	0.36	<0.01	<0.01	0.24	0.10	0.01	0.01	100.16	81	10	10
	Cg2	135+	88.20	6.94	2.52	0.48	<0.01	<0.01	0.84	0.32	0.08	0.02	99.40	67	15	18
*Dl*4	A	0-4	83.65	10.16	3.51	0.88	0.07	0.10	1.55	0.71	0.28	0.07	100.98	38	34	27
	Bw	-35	78.49	12.60	4.63	0.87	0.03	<0.01	1.93	0.86	0.23	0.05	99.69	35	34	31
	Bt	-60	74.34	15.44	5.21	0.85	0.03	<0.01	2.39	1.15	0.33	0.04	99.78	33	31	36
	Btg	102	71.65	16.69	5.13	0.90	0.02	<0.01	2.72	1.36	0.35	0.04	98.86	30	33	37
	BCg	150	69.98	18.00	5.96	0.93	0.02	<0.01	2.85	1.44	0.38	0.04	99.60	19	38	43

1) Ignition loss basis, 2) Oven dried basis

are strongly leached out, unlike MgO and K_2O. This finding is consistent with that of Ohta *et al.* (1993). It is difficult to differentiate the *Da* soils from the *Dl* soils from these data, but if soils with the same clay content were compared, the *Dl* soils show much higher content of MgO, K_2O, Na_2O, and P_2O_5 than the *Da* soils. More significant weathering for the *Da* soils than the *Dl* soils and nutrient

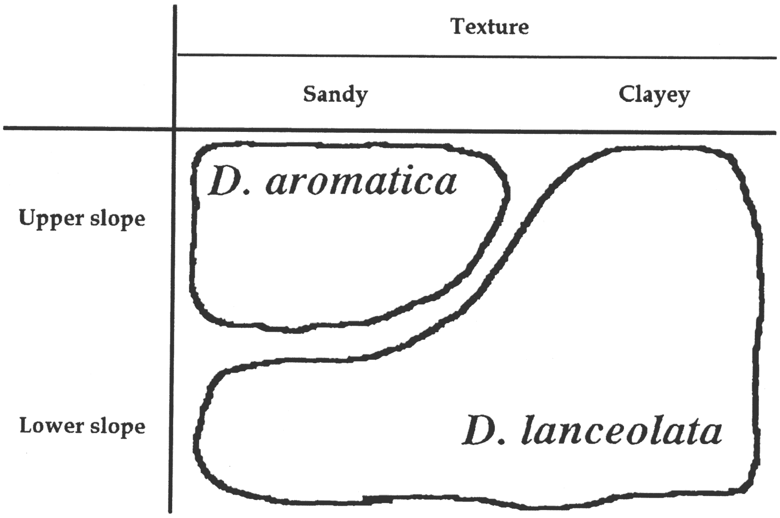

Fig. 6. Characteristics of the soils developed near *Da* and *Dl*.

addition from the surroundings for the *Dl* soils are thus confirmed by this analysis as well.

Thus, the *Da* soils are highly leached because of their geomorphologically stable condition, that is, prolonged leaching time under heavy rainfall, and acidification due to the release of proton from thick organic layer accumulated under drier moisture condition. On the other hand, the *Dl* soils were considered relatively young soils rich in basic cations. That is because both organic matter and soil particles associated with enough water and nutrients may be always transported in the profile, and basic cations may be mineralized rapidly under suitable moisture condition.

It was well-known that shifting cultivators utilize a land where *Dl* dominates as a productive crop field. Their traditional way of land selection proves to be rationale from the standpoint of soil science.

Microbial evidence

Fig. 5 shows the fungal counts at the different depth of *Da*2 and *Dl*3 soils. Fungal counts in subsurface layers were within a range normally seen in the temperate regions. Smaller figure was obtained from samples taken from deeper horizons in both soils. Such decrease is a common observation and generally considered as a result of decrease in available nutrients.

Between these profiles, ten times as much fungal counts were recorded in *Da* soils compared with *Dl*. This seems not to agree with our data on chemical analysis that more available nutrients are found in the *Dl* soils, provided that fungal level reflected a nutrient status of the soil. When physical properties were taken into account, the *Da* soils are higher in macropore percentage than the *Dl* soils. The higher macropore percentage, i.e., the higher air percentage, may have contributed to yield the higher fungal counts within the *Da* soils, although the difference may be attributed to greater sporation ratio due to dryness. In other words, fungi may not favor a more reductive condition in the *Dl* soils.

CONCLUSIONS AND FUTURE SCOPE

Characteristics of the *Da* soils examined are relatively uniform (Fig. 6) and summarized as follows. 1) Soil color in deeper horizon is 7.5YR5/8 or 7.5YR6/8 or redder, 2) sand content of surface 50 cm is higher than 50 %, 3) no coarse fragment is found, suggesting stable pedogenetic processes, 4) coarse pore (>9.5 μm) and air phase percentage are high, leading to drier moisture condition, and 5) acidity increases towards the surface horizon, probably due to organic acid released from thick organic layer, resulting in the higher exchangeable Al content.

On the other hand, the *Dl* soils, in general, are characterized by 1) dull color in deeper horizons, reflecting high moisture content, 2) high exchangeable Ca and/or Mg in the surface horizon and hence relatively weak acidity and low exchangeable Al content, and 3) younger in pedogenetic processes. The reason why shifting cultivators identify the land where *Dl* dominates as a productive crop field is obvious from these soil characteristics.

Since their morphological and physico-chemical properties are ranging widely in the *Dl* soils, it is adequate to differentiate them into two groups; One is located on a small ridge with high clay content, and the other is located in a valley whether the texture is clayey or sandy (Fig. 6). More detailed investigation is necessary along with tree species around *Dl* and slope analysis including the geological stratification.

Further investigation is promising in relation to the dynamics of water and nutrients associated with the vegetation type. To accomplish it, soil micro-environment such as rainfall, soil moisture, soil temperature, lateral and vertical movement of water and composition of the soil solution are needed to be monitored. In addition, physical and chemical reactions occurred at the rhizosphere, charge properties and mineralogy, and production of organic materials by a given plant are to be clarified.

Finally, it is commonly believed that in tropics termites play an important role in circulation of nutrients. However, this does not mean that microorganisms are less important at the final stage of litter decay. We consider that studies on soil microorganisms should be progressed in tropical rain forests and feel that analysis on microflora must be promoted to study the nutrient cycle prevailing in the rain forests.

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平井英明，松村　弘，広谷博史，桜井克年，荻野和彦，LEE Hua Seng　熱帯雨林におけるフタバガキ科 *Dryobalanops aromatica* および *D. lanceolata* 下に発達する土壌の特性ーマレーシア，サラワク州，ランビルヒルズ国立公園における事例

Dryobalanops aromatica (*Da*)と *D. lanceolata* (*Dl*) はボルネオ熱帯雨林において突出木層を構成している主要なフタバガキ属の樹種である。その分布は近接しているが，決して重なり合うことはない。本論文では，これら2樹種の分布を，土壌形態学的，物理学的，化学的，微生物学的特性から吟味した。

地形的にみれば，*Da* は斜面上部のみに分布していたが，*Dl* は斜面の上部および下部に分布していた。この2樹種の優先する土壌の深さはいずれも 1.3 m 以上であった。土性は*Da* 土壌では砂質であったが，*Dl* 土壌では砂質から粘質とその範囲が広かった。さらに，次のような差異が両土壌に認められた。1) リター層は*Da* 土壌で厚かった。2) 次表層の土色は *Dl* 土壌の方が鈍い色調を示していた。3) *Dl* 土壌にはレキが認められたのに対して，*Da* 土壌では認められなかった。4) 交換性陽イオンのうち，Ca および Mg 含量は *Dl* 土壌の方が高かった。5) 交換性 Al と H 含量は*Da* 土壌で高かった。6) 気相，粗孔隙量と砂含量は*Da*土壌の方が高かった。このことは，降雨後*Da*土壌はより乾燥した土壌水分条件になることを示すが，それは土壌水分ポテンシャルのモニターによって証明された。7) カビは*Da* 土壌の方が*Dl* 土壌よりも 10 倍多く認められた。

以上の結果を総合すると*Da* は乾燥し易く，貧栄養で酸性の強い，安定した土壌生成過程を経た土壌に成立する。一方，*Dl*はある期間還元を受けるような湿潤条件下で，かつ*Da* 土壌に比較して養分状態がよく，酸性が弱く，土壌生成過程の弱い土壌に成立することが明らかとなった。現地の焼畑農民は*Dl* が成立する土地を耕地として利用するが，この*Dl* 土壌の特性を考慮すると，農民の伝統的な土地識別方法はきわめて適切であることが土壌学的観点から明らかとなった。