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Properties of Soils in Kerangas Forest on Sandstone at Bako National Park, Sarawak, East Malaysia

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Introduction

Red-yellow podzolic soils (ultisols) are found extensively in Southeast Asia, occupying about 55% of the region according to FAO/UNESCO [1978]. The predominant vegetation on red-yellow podzolic soil is tropical evergreen rainforest, which has the greatest number of species of any rainforest. Ecologically, the most important feature is the occurrence of extensive dipterocarp forests in the western block of tropical lowland evergreen rainforest, that is, the mixed dipterocarp forests widespread in Sarawak, East Malaysia.

Kerangas forest, which was named heath forest by Richards [1957], is the particular vegetation of Sarawak. Heath forest formation is found on podzolized siliceous sands (spodosols), drained by characteristic blackwater streams. It occurs mainly in Borneo, where it is found on sandstone plateaus and cuesta formations; and it is usually found on dip slopes in hilly country in Sarawak, Sabah, and Brunei [Whitmore 1984].

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Bako National Park consists of a rocky promontory located northwest of the mouth of the Sarawak river. The study of Brunig [1960; 1965] represents an attempt to identify 9 main associations and 25 vegetation types in this area. The unique kerangas vegetation occupies much of plateau area of Bako National Park. Although several studies have examined the relationship between soil and vegetation, the relationship between the floristic and structural peculiarities of kerangas forest remain uncertain.

The parent material of kerangas forest soil is a sandstone and the rock is a member of Plateau Sandstone Formation. In Bako National Park in west Sarawak, Brunig [1965] recognized a series of forest types which can be correlated with variations in the degree of podzol development and in soil texture. Redloams cannot result from weathering of sandstone, since such parent material does not contain any clay-forming minerals. Such soils are characterized by poor nutrient contents. The vegetation on this soil is a poor forest such as heath forest and differs from the typical tropical rain forest (Fig.1).

Jordan [1985] points out that the nutrient contents are in a critical condition in the tropical rainforest and the human impact of rapidly increased cutting and burning has influenced nutrient cycling. Heath forest is

Fig. 1 Vegetation of Kerangas Forest Occurring on Sandstone at Bako National Park

easily degraded by felling and burning to an open savanna of shrubs and scattered trees over a sparse grass and sedge ground layer.

Under such conditions it is very important to investigate the property of soil and the relationship between soil and vegetation in the tropical rainforest, especially in heath forest having poor vegetation and poor nutrient contents.

This paper deals with the properties of soil with poor vegetation developed on sandstone in Bako National Park in Sarawak, East Malaysia.

Research Site and Methods

The research site was in the Bako National Park, located northwest of the mouth of the Sarawak river in Sarawak, East Malaysia. Bako National Park occupies 2,742 hectares of a rugged sandstone peninsula on the coast of southwestern Sarawak. The park is dominated by a sandstone plateau which averages about 100 meters above sea level. Many different forest types can be found within a relatively small area: beach forest, mangrove forest, swamp forest, mixed dipterocarp forest, and kerangas forest. On the top, the plateau is dominated by kerangas forest, scrub and padang. A linear transect with dimensions of 50 m × 5 m was established in the kerangas forest (padang) at the plateau in the national park. In this transect, all living trees equal to or above 2.0 cm in diameter at breast height were enumerated, by measuring their diameter and tree height and recording their species name.

The accumulation of dead organic matter in the A_0 horizon was measured at five subplots measuring 1 m × 1 m. A soil pit was dug in the transect so as to represent the major soil type identified. The pit measured 1 m × 1 m × 1 m. Some soil horizons were identified and the soil thickness, color, structures, root distribution, soil hardness, water conditions and boundaries of each horizon were described using the methods of standard forest soil survey of Japan [Government Forest Experiment Station 1982]. Soil color was described according to the 'Revised Standard Soil Color Charts' [Oyama and Takehara 1967]. Soil hardness was tested by Yamanaka's penetrometer.

Soil samples were collected for chemical and physical analysis using a soil sampler of 100 cc in volume. The depth of soil samples collected was as follows: 0–5 cm, 5–10 cm, 10–20 cm, 20–30 cm, 30–50 cm, and 50–70 cm.

Physical and chemical properties were analyzed in terms of the following items: soil texture, water holding capacity, bulk density, concentrations of carbon, nitrogen, available phosphorus, exchangeable calcium, magnesium and potassium, pH, cation exchange capacity (CEC), and exchange acidity (Y_1). Soil texture was determined by particle-size analysis by the pipette method with 2 mm mineral soil (peroxide-treated). Carbon and nitrogen concentration were determined by the Tyurin and the Kjeldahl method, respectively. Available phosphorus was determined by Bray's No. 4 method. Exchangeable cations were determined by atomic absorption photometry for an extract with 1N ammonium acetate at pH 7. CEC and Y_1 were determined by the normal methods. The value of pH was measured for 1:2.5 soil-water or soil-KCl solutions using a electric pH meter.

Results

1. Aboveground Biomass, Density and Basal Area of Kerangas Forest

The study site was a heath forest, called padang, which degraded to scattered trees over a sparse grass and sedge ground layer. The tree density, mean diameter at breast height, mean tree height and total basal area are shown in Table 1. Tree density was very high, more than 6,000 per hectare, because of the inclusion of trees of less than 5 cm in diameter at breast height. Fig. 2 shows the high frequency of small trees, of which trees less than 5 cm in diameter at breast height accounted for about 90% of the total number in the study site.

Mean diameter and tree height were very small. Basal area also was very small. The H/D ratio indicated that the tree form was large and it suggested that trees of the heath forest

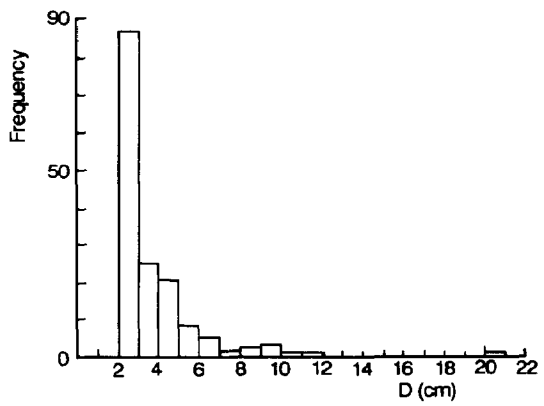


Fig. 2 Frequency Distribution of Tree Diameter in a Heath Forest at Bako National Park

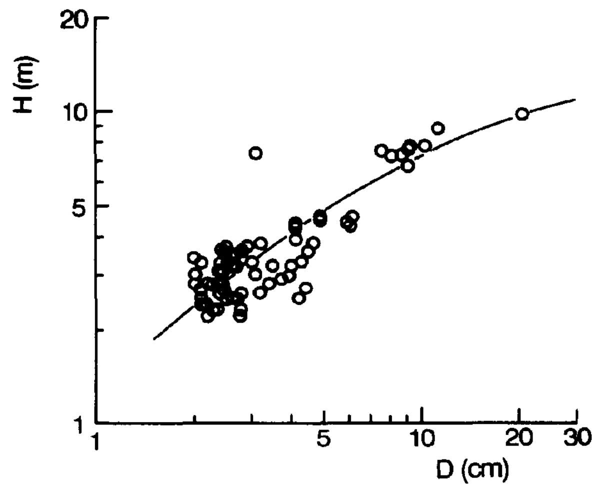


Fig. 3 Relationship between Tree Height and Diameter at Breast Height in a Heath Forest at Bako National Park

Table 1 Description of Kerangas Forest of Bako National Park in Sarawak, Malaysia

Tree density (/ha)	6160
Mean diameter at breast height (cm)	3.6
Mean tree height (m)	3.5
Basal area at breast height (m^2/ha)	8.60
Mean height-diameter ratio	106.3

were slender.

The relationship between diameter at breast height and tree height is shown in Fig. 3. Although it fluctuated widely within the small diameter range, this relationship could be expressed by the following equation,

$1/H = 0.73619/D + 0.06726$ $(r=0.683)$.

The aboveground biomass in this study site was estimated by the equations for tropical rainforest in Indonesian Borneo as reported by Yamakura *et al.* [1986]. The biomass of each species is given in Table 2. *Callophyllum langigerum* showed the largest biomass and accounted for 40 % of the total. This species had the third highest species density, while the two species with higher density, *Ploiarium alternifolium* and *Cratoxylon glaucum*, accounted for 8.2% and 12.9% of total biomass, respectively.

Leaf biomass in this plot was extremely low compared with other tropical, subtropical and temperate forests. These characters of tree size and aboveground biomass in kerangas forest were due to the soil conditions of poor nutrient accumulation and being leached.

Table 2 Composition of Tree Species and Mean Diameter, Height, Basal Area, H/D Ratio and Above Ground Biomass of Species of Kerangas Forest in Sarawak, Malaysia

Species Name	Density (/ha)	Dbar (cm)	Hbar (m)	B.A. (m^2/ha)	H/D	Above ground biomass (t/ha) Stem	Branch	Leaf	Total
Cratoxylon glaucum	1,880	3.2	3.1	1.71	101.4	2.06	0.25	0.18	2.49
Ploiarium alternifolium	1,660	2.8	3.0	1.08	109.6	1.25	0.15	0.12	1.52
Callophyllum langigerum var. *austraiaceum*	1,000	5.4	4.8	2.92	94.7	6.37	0.88	0.34	7.59
Rhodamnia uniflora	680	2.7	3.2	0.40	121.2	0.47	0.05	0.05	0.57
Parastemon spicatus Ridley	440	3.5	3.7	0.47	113.0	0.04	0.00	0.00	0.05
Casuarina nobile	160	4.6	5.4	0.36	133.9	0.82	0.11	0.05	0.98
Eugenia multi-bractedata Merr	80	2.5	2.7	0.04	109.9	0.04	0.00	0.00	0.05
Xanthophyllum owatifolium Chod.	40	20.6	9.8	1.33	47.6	4.13	0.65	0.12	4.90
Baeckia frutescens	40	5.9	4.4	0.11	74.6	0.16	0.02	0.01	0.19
Glochidion aluminescens Airy Shaw	40	4.1	4.4	0.05	107.3	0.08	0.01	0.01	0.10
Dacrydium becarii Parl	40	3.3	3.4	0.03	103.8	0.04	0.00	0.00	0.05
Garcinia caudiculata	40	3.0	3.2	0.03	106.0	0.03	0.00	0.00	0.04
Ilex cymosa	40	3.0	3.2	0.03	106.0	0.03	0.00	0.00	0.04
Dracaena elliptica var. *gracilis*	40	2.1	2.7	0.01	128.6	0.01	0.00	0.00	0.02
Barringtonia longisepala Payens	40	2.1	2.4	0.01	113.1	0.01	0.00	0.00	0.01
Plot mean or total	6,160	3.6	3.5	8.60	106.3	16.17	2.23	0.95	19.35

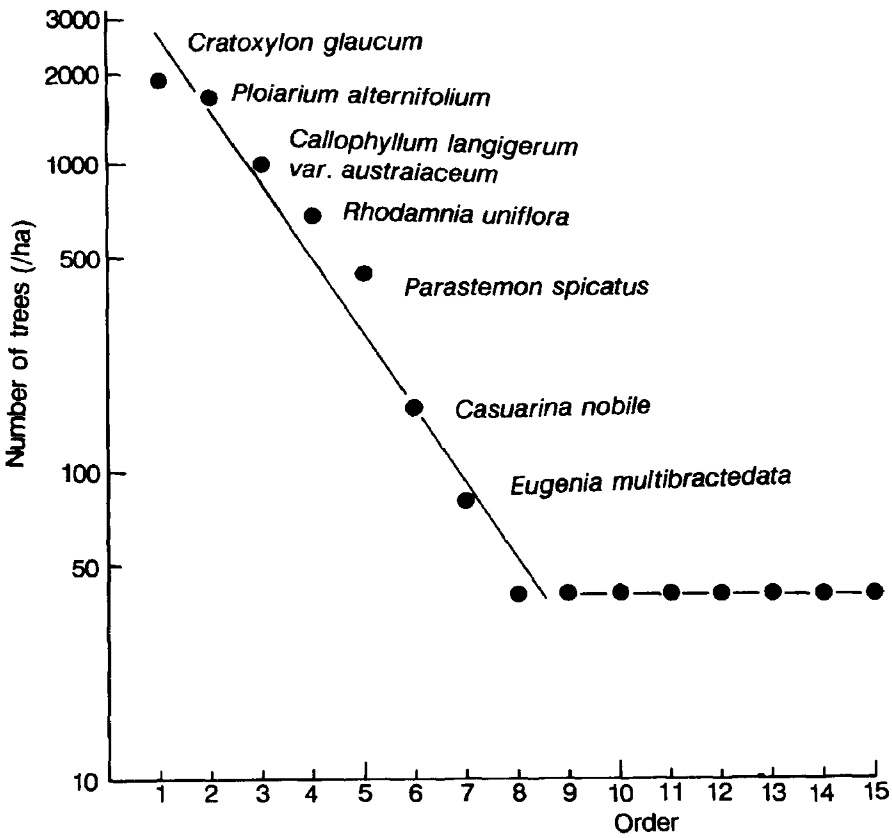


Fig. 4 Species Importance Curve in a Sampling Plot

2. Composition of Tree Species

The soils of tropical rainforest, in contrast to those of temperate forest, are very old and show great depth of weathering. However, an overlying humus layer is entirely absent and there is no humus-enriched horizon in mineral soil. Therefore, the nutrient content of the soils in tropical rainforest is usually extremely low. In heath forests on sandstone the nutrient content is ever lower than in typical tropical rainforest. Proctor [1983] shows that heath forests occur on soils derived from siliceous parent materials which are low in bases and coarse-textured.

Fifteen species were observed in this heath forest (Fig. 4). The dominant species were *Cratoxylon glaucum, Ploiarium alternifolium,* and *Callophyllum langigerum* var. *austraiaceum,* which together accounted for 75% of the total tree number and 66 % of the total basal area. These dominant trees were of small diameter and low height. The mean diameter

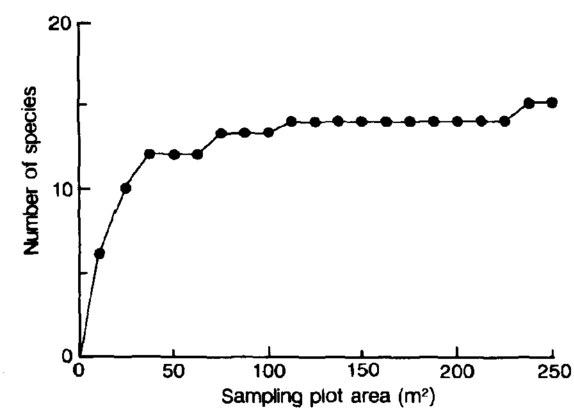


Fig. 5 Species-area Curve in a Sampling Plot

of the dominant species was 2.7–5.4 cm and the mean height was 3.0–4.8 m. The maximum diameter and tree height in this plot was shown by *Baeckia frutescens*.

The number of species observed in the plot was less than that of mixed dipterocarp forest, which is distributed widely in the tropics. The composition of this heath forest thus seemed to be simple. The number of species increased rapidly with the spread of sampling area, and the relationship between the species number and the sampling plot area showed a saturating curve(Fig. 5).

The index of diversity ($\alpha=4.1097$) was calculated from the composition of species shown in Table 2. The diversity of this forest was much smaller than those of mixed dipterocarp forests in the tropical zone, which were 85–175.2 by Paijmans [1975]. Kira [1983] points out that the species compositions of heath forests in Kalimantan are simple and are dominated by *Cratoxylon glaucum* etc.

Fig. 6 Soil Profile of Sampling Plot in Heath Forest at Bako National Park

Table 3 Soil Profile in a Heath Forest in Bako National Park

Locality: Bako National Park in Sarawak, East Malaysia
Vegetation: Heath forest
Soil type: Giant tropical podzols
Topography: Flat on the plateau
Parent material: Sandstone
Direction of slope: North-west
Gradient: 0°

Horizon	Depth(cm)	Description
LH	6–0	Dead leaves and other organic matter partially with humus
A_1	0–12	Brownish black (7.5YR 2/2); fine sand; slightly firm; granular structure; abundant fine and medium roots; very moist; no gravel; clear wavy boundary to :
A_2	12–35	Brown (7.5YR 4/3); loamy sand; slightly firm; medium angular blocky structure; very moist; many medium roots; no gravel; distinct wavy boundary to :
A_3	35–52	As above, but dull brown (7.5YR 5/3); exceedingly moist; gradual wavy boundary to :
A_4	52–65	Light gray (10YR 8/1); loamy sand; soft; exceedingly moist; granular structure; no root; no gravel.
R	65–	Rock of sandstone

3. *Soil Profile*

A soil profile in this site is described in Table 3 and shown in Fig. 6. The litter layer, composed of leaves and twigs partially with humus, was thick. The A-horizon was fairly deep but a B-horizon was not recognized. The upper layers (A_1 and A_2) were brownish black and brown, respectively. These layers contained considerable organic matter carried from the litter layer into soil. The lower layers (A_3 and A_4) were dull brown and light gray reflecting the process of leaching by water.

The soil texture was dominated by sand or silty sand, reflecting the soil formation from interbedded sandstone. The contents of sand, silt and clay were 89–92, 3.2–6.9, 3.6–4.1%, respectively. The soil texture was sand or silty sand throughout the horizon. The sand content increased and the silt content decreased from the surface to the bottom layer.

The moisture content was high large in all layers, and water flowed with sand in the A_4 layer.

Fine and medium roots penetrated abundantly into the A_1 layer, but none penetrated into the A_3 and A_4 layers.

4. *Accumulation of Organic Matter in the A_0 Horizon*

The A_0 layer was thick and mixed with such ground flora as grasses, sedge and mosses. The accumulation of organic matter was 4.86 t/ha on average and ranged from 2.11 to 7.25 t/ha. This was less than that in the mixed dipterocarp forest in Bako National Park, 8.3–9.8 t/ha.

The concentrations of nitrogen, phosphorus, potassium, magnesium, and calcium in the A_0 layer were 0.5%, 0.006%, 0.013%, 0.075%, and 0.34%, respectively. These values were lower than those of mixed dipterocarp forests in Bako National Park. The values of pH were 4.04 with H_2O and 3.24 with KCl solution. This strong acidity was due to the slow decomposition in the litter layer.

The amounts of nutrient elements accumulated in the A_0 horizon were 24.3 kg/ha of nitrogen, 0.29 kg/ha of phosphorus, 0.63 kg/ha of potassium, 3.65 kg/ha of magnesium, and 16.5 kg/ha of calcium. This result showed the nutrient deficiency of the A_0 horizon.

Table 4 Chemical Properties of A_0 Horizon in a Heath Forest in Bako National Park

Dry weight of organic matter (t/ha)	4.865
Carbon concentration (%)	54.80
Nitrogen concentration (%)	0.50
Phosphorus concentration (%)	0.006
Potassium concentration (%)	0.013
Magnesium concentration (%)	0.075
Calcium concentration (%)	0.34
Ash content (%)	3.64
pH (H_2O)	4.04
pH (KCl)	3.34

Table 5 Chemical Properties of Mineral Soil in a Heath Forest in Bako National Park

Layer(cm)	0–5	5–10	10–20	20–30	30–50	50–70
Bulk density (g/100cc)	70.0	97.6	125.3	136.7	148.7	155.1
Carbon (%)	5.10	3.43	1.66	0.82	0.29	0.09
Nitrogen (%)	0.20	0.12	0.08	0.03	0.03	0.01
C/N	25.5	28.6	20.8	27.3	9.7	9.0
Avail-P (mg/100g soil)	3.32	2.79	2.95	2.33	2.53	2.28
Exch-K (me/100g soil)	0.13	0.11	0.07	0.12	0.10	0.14
Exch-Mg (me/100g soil)	4.52	1.94	0.50	0.20	0.60	0.90
Exch-Ca (me/100g soil)	0.96	0.15	0.18	0.36	0.10	0.16
CEC (me/100g soil)	13.43	7.01	1.67	1.15	0.22	0.22
Y_1	—	3.47	1.74	1.16	1.16	0.58
pH (H_2O)	3.48	4.48	4.60	4.20	3.98	5.12
pH (KCl)	—	2.76	3.20	3.38	3.98	4.18
Ash content (%)	90.5	95.0	98.3	98.3	99.8	99.8

—: undetermined

5. *Chemical Properties of Mineral Soil*

The concentrations of nutrient elements in mineral soil decreased with soil depth, especially those of carbon, nitrogen, exchangeable calcium and magnesium as shown in Fig. 7. Carbon concentration ranged from 5.1% to 0.09%, and nitrogen concentration from 0.20% to 0.01%. The C/N ratio ranged from 28.6 to 9.0 and was higher at 0–30 cm depth than at 30–70 cm depth.

Available phosphorus fluctuated from 2.3 to 3.3 mg per 100 g of soil, but no relationship with depth was apparent. Exchangeable potassium was also fairly constant except the layer of 10–20 cm. Exchangeable magnesium showed the highest concentration among the three cations determined in this study. Exchangeable calcium ranged from 19.3 to 2.08 mg per 100 g of soil and declined with soil depth as well as carbon and nitrogen concentrations.

Cation exchange capacity (CEC) also declined from the surface to the bottom of the sample and was related to the concentration of total cations. Exchange acidity (Y_1) decreased from 3.47 to 0.58, although the top layer was not determined because of a shortage of sample for analysis.

The pH values of soil extracted with distilled water and potassium chloride solution were 3.48–5.12 and 2.76–4.18, respectively. The values with potassium chloride solution were lower than those with distilled water and showed strong acidity throughout all layers.

Discussion

1. *Species Composition and Tree Size in a Heath Forest*

Under favorable conditions, heath forest is usually composed of dipterocarp species. In

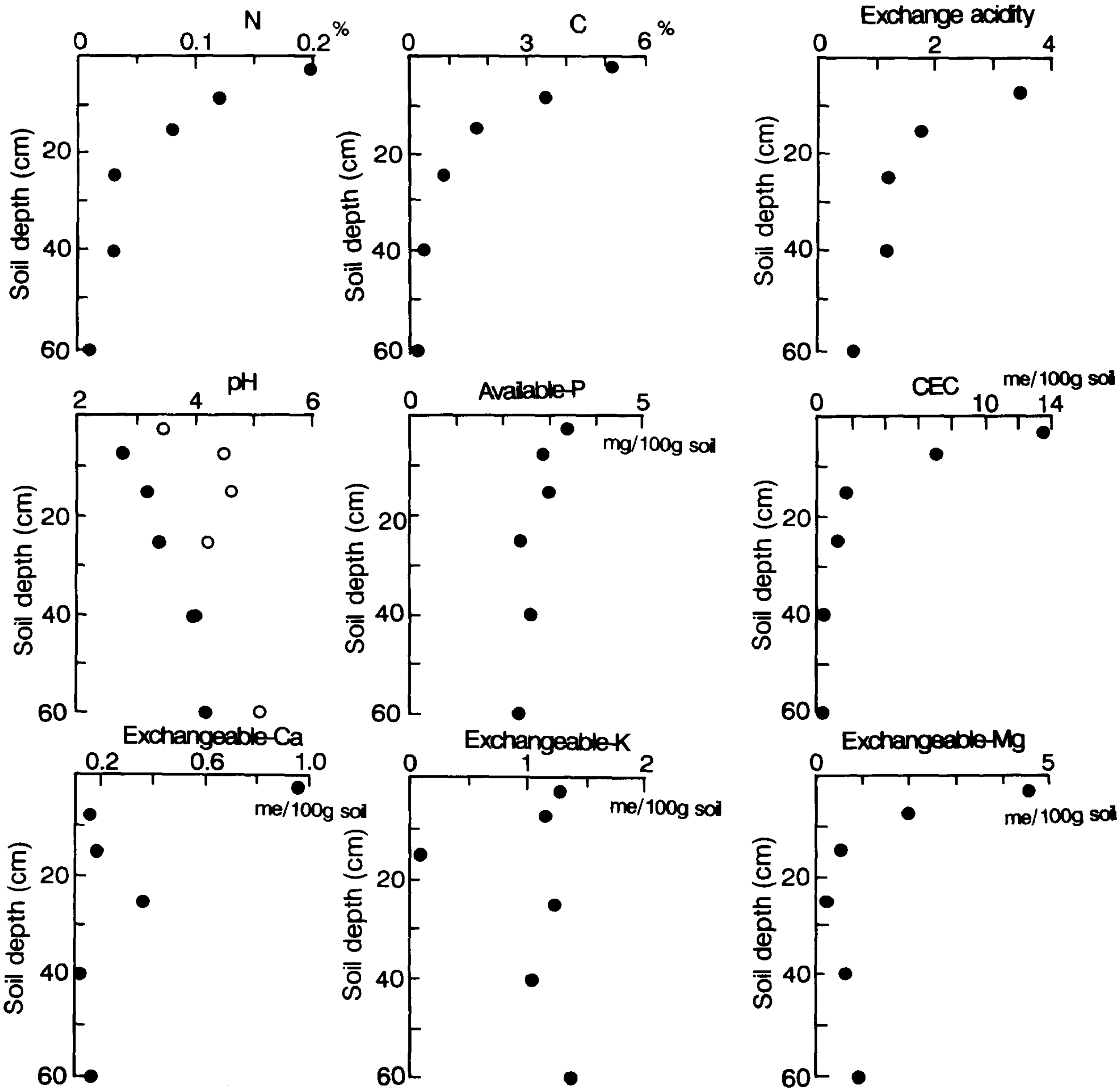


Fig. 7 Vertical Changes of Nutrient Concentrations in a Heath Forest at Bako National Park

Bako National Park various heath forests were observed ascending the plateau. The present study site was located on an open area on the plateau. The tree density of the heath forest was high, and trees were small both in diameter and height. The total basal area of stems in this forest was extremely small, and there were many small trees which were classified as 2–6 cm in diameter. From this viewpoint, the forest was judged to be fairly thin and scattered.

The species composition of the forest was simple compared with mixed dipterocarp forests. The diversity of this forest was very low. The relationship between the area and the number of species became saturated within a small area as shown in Fig. 4.

According to Butt[1984], heath forest on plateau soils are segregated into three vegetation types in Bako National Park. The first is transition forest of Kerangas-MDF, which is taller and floristically more diverse. The second is kerangas-pole forest, a closed or semi-closed forest ranging from about 5 to 10 m in height. The last is "padang" vegetation dominated by shrubs and herb, especially sedge. Padang vegetation has a wide but discontinuous distribution on the plateau. The vegetation of this study site was considered to be padang vegetation. Padang is very slow to revert to "pole" or kerangas forest because of poor soil conditions [Brunig 1974].

The scattered forest results from the deficiency of nutrients in the soil. The parent material of Bako National Park is sandstone and the soil texture is sand or silty sand. The soil of the heath forest in Bako National Park has a low clay content and a low capacity of cation adsorption. The growth of trees is inferior under such soil conditions compared with the more clayey soil conditions. Thus, it was considered that the condition of this heath forest was influenced by the physical and chemical properties of the soil.

2. *Chemical Properties of Heath Forest Soil*

The soil of the heath forest in this study was exceedingly moist and strongly acidic. The flow of so-called black water was recognized in the bottom layer of mineral soil. Sanchez [1989] states that coffee-colored water accounts for the presence of Spodosols. It appears that nutrient elements were easily leached out, and nutrient concentration decreased suddenly from the surface to the lower layer. Close relationships between exchangeable magnesium and calcium concentrations, and between cation exchange capacity and

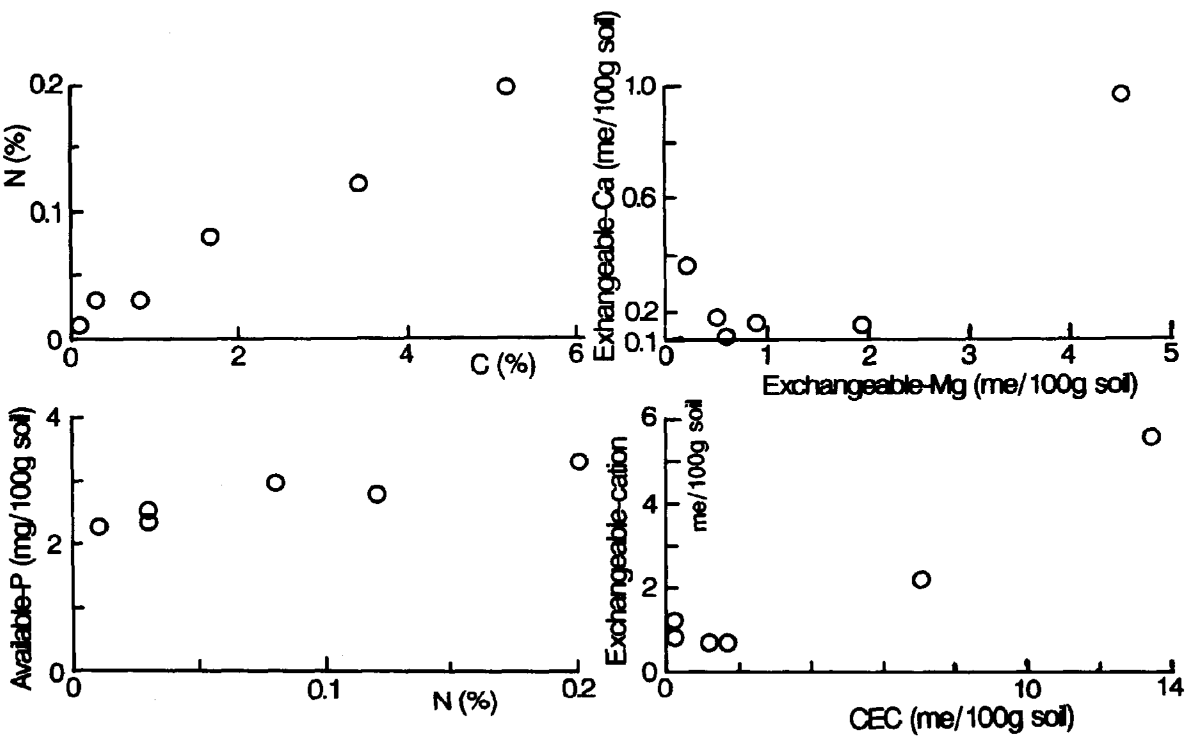


Fig. 8 Relationships between Nutrient Concentrations in a Heath Forest at Bako National Park

total exchange cation are observed (Fig. 8). The carbon concentration declined to a low level with decreasing nitrogen concentration. However,the carbon content of the surface soil was higher than the nitrogen content. Therefore, the C/N ratio of the surface soil was higher than that of bottom soil. Available phosphorus and exchangeable potassium were relatively constant compared with the carbon, nitrogen, exchangeable calcium and magnesium.

Compared with red-yellow podzolic soil, which is distributed widely in the tropics, the heath forest soil was very shallow and its texture was very sandy. Because of this, the amounts of nutrient elements were very low, as shown in Table 6. The accumulations of carbon, nitrogen, and available phosphorus in mineral soil were 80.7 t/ha, 3.9 t/ha, and 240 kg/ha, respectively. The accumulations of exchangeable potassium, magnesium, and calcium were 0.39, 0.97, 0.40 t/ha, respectively. These amounts were less than those of MDF soil on parent rocks of shale in Lambir National Park in East Sarawak. The accumulations of nutrient elements were much less than those in temperate deciduous broad-leaved forest on B_D type soil in Japan. However, it was similar to the accumulation in B_B type soil under dry conditions in Japan.

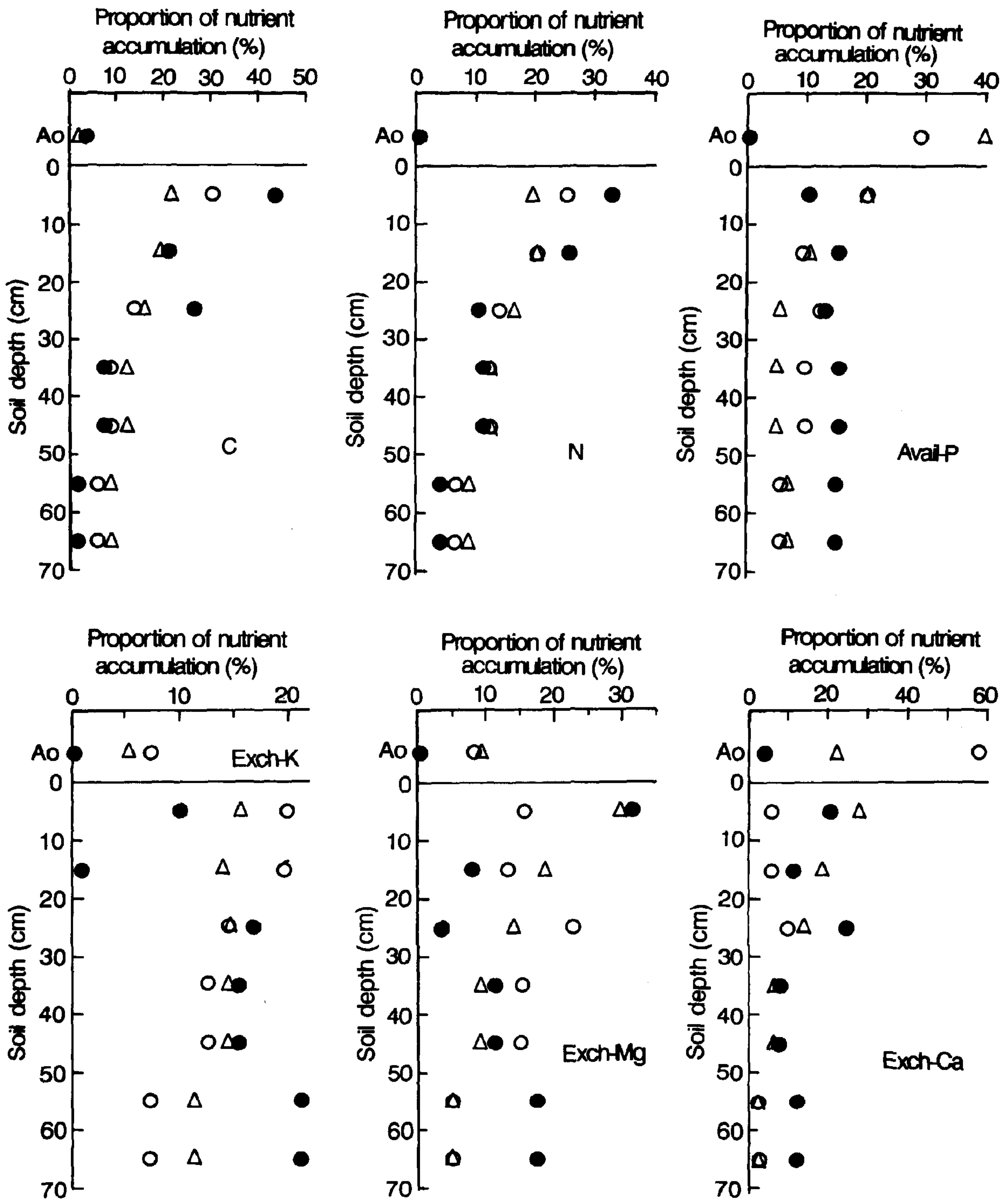
The accumulation of A_0 horizon in the heath forest was very little and its nutrient content was low. This low nutrient accumulation resulted from the low supply of organic matter returned by litter fall and the rapid decomposition caused by high temperature. These are characteristics peculiar to tropical rainforest. Jordan [1985] suggests that the low nutrients in the A_0 horizon were absorbed by the roots concentrated in the surface soils in tropical rainforests.

The distribution of nutrient elements in the heath forest soil are shown in Fig. 9 compared with two types of brown forest soil in Japan.

Table 6 Accumulation of Nutrient Elements in Mineral Soil

	C t/ha	N kg/ha	P kg/ha	K kg/ha	Mg kg/ha	Ca kg/ha	pH	
Heath forest	81	3,923	240	394	975	401	3.48–5.12	1
MDF in Bako	104	5,764	249	347	387	1,420	4.61	2
MDF in Lambir	56	5,870	277	375	705	533	4.25	2
MDF in Pasoh (Average of four plots)	75	5,423	50	339	74	152	4.3–4.8	3
Dry evergreen forest in Thailand	53	5,760	11	985	226	1,080		4
Deciduous broad-leaved forest in Japan (B_D)	90	7,460	18	252	140	402		4
Deciduous broad-leaved forest in Japan (B_B)	76	4,300	9	138	36	47		4

1: this study, 2: unpublished, 3: Yoda [1982], 4: Tsutsumi [1989].



● Heath forest at Bako National Park

○ Deciduous broadleaved forest on mor type soil in Japan

△ Deciduous broadleaved forest on mull type soil in Japan

Fig. 9 Vertical Distribution of Nutrient Elements in Soils

Nutrient elements, especially carbon and nitrogen, of the heath forest soils were concentrated in the surface layer of 0–20 cm. Although exchangeable magnesium was also concentrated in the surface soil, exchangeable calcium and potassium were distributed in deeper layers. This is because the amounts of calcium and potassium were less than that of magnesium in the mineral soil. In B_B type soil in a deciduous broad-leaved forest in Japan, these nutrients were also concentrated in the surface soil, but in B_D type soil they were distributed from the surface to the bottom layer. Katagiri [1989] showed that the turnover ratio of nutrients in soil was high in the B_B type soil, where nutrients were concentrated in the surface soil and A_O horizon. This was dependent on the role of mycorrhiza and tree fine roots which were distributed in the A_O layer. Walter [1971] indicated that the roots act as a filter, absorbing the nutrient from the mineralization of organic matter and allowing humus colloids to pass by in the tropics.

Although the climatic conditions of heath forest and deciduous broad-leaved forest are different, in both case the nutrient elements are concentrated in the surface soil and absorbed by roots distributed in the A_O horizon and surface soil. However, under such soil conditions, nutrients are deficient and tree growth is poor.

The heath forest soil was strongly acidic and water was apt to be always tied up. Its capacity of cation adsorption was poor because of the low clay content due to sandstone. Therefore, nutrients were easily leached from all layers of the soil. The growth of trees was inferior and a thin forest was formed. The thinner this forest is, the poorer the supply of organic matter to the forest floor becomes. The heath forest known as padang is thus a peculiar ecosystem in which this vicious cycle is repeated.

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