RELATIONSHIP BETWEEN TOPOGRAPHY AND SOIL PROPERTIES IN A HILL DIPTEROCARP FOREST DOMINATED BY *SHOREA CURTISII* AT SEMANGKOK FOREST RESERVE, PENINSULAR MALAYSIA

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TANGE, T., YAGI, H., SASAKI, S., NIIYAMA, K. & ABD. RAHMAN, K. 1998. Relationship between topography and soil properties in a hill dipterocarp forest dominated by *Shorea curtisii* at Semangkok Forest Reserve, Peninsular Malaysia. To obtain a better understanding of major tree species distribution in a hill dipterocarp forest, differences in soil properties and in topographical conditions were studied in the Semangkok Forest Reserve, Peninsular Malaysia, where *Shorea curtisii* was the dominant tree species on the ridges. The differences in nutrient status of *S. curtisii* saplings by topography were also examined. *Shorea curtisii* was absent in the valleys where the soil horizons with mottles of iron indicated the presence of seasonal anaerobic soil conditions. The soft soil was thin on ridges and convex slopes where *S. curtisii* was dominantly distributed. Differences in chemical properties of soil by topography were characterised by the surface soil. Surface soil with low pH, high contents of carbon, nitrogen and available phosphoric acid and high C-N ratio were distributed on the ridges and convex slopes. The soil acidity tended to increase as the C-N ratio increased. Differences in soil chemical properties by topography appeared to be strongly influenced by environmental conditions such as litter decomposition and soil moisture regime. As foliar nutrient contents of *S. curtisii* saplings did not differ with topography, the nutrient status of *S. curtisii* seemed to be little influenced by soil chemical properties.

Key words: Hill dipterocarp forest - *Shorea curtisii* - soil properties - topography

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TANGE, T., YAGI, H., SASAKI, S., NIIYAMA, K. & ABD. RAHMAN, K. 1998. Kaitan antara topografi dan ciri-ciri tanah di hutan dipterokap bukit yang ternaung oleh *Shorea curtisii* di Hutan Simpan Semangkok, Semenanjung Malaysia. Untuk memahami taburan spesies pokok utama di hutan dipterokap bukit, perbezaan dalam ciri-ciri tanah dan keadaan topografi dikaji di Hutan Simpan Semangkok, Semenanjung Malaysia yang ternaung oleh spesies pokok *S. curtisii* di rabung bukit. Perbezaan status nutrien anak pokok *S. curtisii* oleh topografi juga diselidiki. *Shorea curtisii* tidak didapati di lembah yang horizon tanahnya mempunyai tompokan besi yang menandakan kehadiran tanah anaerobik bermusim. Terdapat sedikit tanah lembut di atas rabung bukit dan di kawasan cerun cembung yang mana taburan *S. curtisii*nya adalah dominan. Perbezaan ciri-ciri kimia tanah oleh topografi dicirikan oleh permukaan tanah. Permukaan tanah dengan pH yang rendah, kandungan karbon, nitrogen, asid fosforik tersedia dan kadar C-N yang tinggi disebarkan di rabung bukit dan cerun cembung. Keasidan tanah bertambah dengan bertambahnya kadar C-N. Perbezaan ciri-ciri kimia tanah oleh topografi sangat dipengaruhi oleh keadaan persekitaran seperti penguraian sarap dan regim lembapan tanah. Oleh kerana kandungan nutrien daun anak pokok *S. curtisii* tidak berbeza dengan topografi, status nutrien *S. curtisii* kurang terpengaruh dengan ciri-ciri kimia tanah.

Introduction

The distribution of tree species at elevated altitudes in the tropics is primarily influenced by temperature regimes and frequency of fog (Grubb & Whitmore 1966, Nakashizuka *et al.* 1992). Dipterocarps are representative tree species of tropical forests in Southeast Asia and are found in elevations ranging from lowlands to low mountains in Peninsular Malaysia. In addition to temperature regimes, soil properties also influence tree distribution and tree growth (Gartlan *et al.* 1986, Baillie *et al.* 1987, Amir & Miller 1990, Yamakura & Sahunalu 1990, Johnston 1992). In Peninsular Malaysia, hill forests can be distinguished from typical lowland forests by the presence of the dominant tree species, *Shorea curtisii* (Whitmore 1984). In hill forests, trees of *S. curtisii* are found mainly on ridges where soils are infertile with low water holding capacity (Whitmore 1984). As *S. curtisii* is also found just above sea-level on coastal hills, it is suggested that the distribution of *S. curtisii* is more strongly influenced by soil conditions than by temperature regime (Whitmore 1984, Burslem *et al.* 1994).

Shorea curtisii is one of the most useful timber tree species belonging to the Dark Red Meranti group. Its ecological properties (Swan 1988, Turner 1990), shade tolerance (Turner 1989) and responses to soil fertility (Turner *et al* 1993, Grubb *et al.* 1994) have been studied. As distribution of *S. curtisii* is site specific, it is important to investigate the environmental conditions by topography and soil properties, especially soil moisture regimes. However, although soil properties of hill dipterocarp forests have been studied (Burgess 1975, Grubb *et al.* 1994), the relationship between topography and soil properties needs more detailed examination.

Materials and methods

Study site

A 6-ha plot has been established in a virgin hill dipterocarp forest of the Semangkok Forest Reserve (3° 40'N, 101° 40'E). The reserve is located about 60 km north from Kuala Lumpur. The objective of establishing the plot was to study the population structure and dynamics of major tree species in the hill dipterocarp forest (Niiyama *et al.* 1993). In this study, differences in soil properties in relation to topography were examined to obtain a better understanding of major tree species distribution in a hill dipterocarp forest.

Topographically, the plot consisted of a main ridge and two steep slopes with altitude ranging from 340 to 450 m above sea-level (Figure 1). The bedrock of the plot is granitic acid volcanic rock, which is poor in bases. The soils are classified as Acrisol (FAO-UNESCO). Mean annual temperature and rainfall at the Forest Research Institute Malaysia (about 50 km south from the plot and 97 m above sea-level) are 26.9 °C and 2481 mm respectively (Manokaran & Swaine 1994). Although dry periods and rainy periods are indistinct, there are months where the monthly rainfall ranges from 150 mm to more than 250 mm.

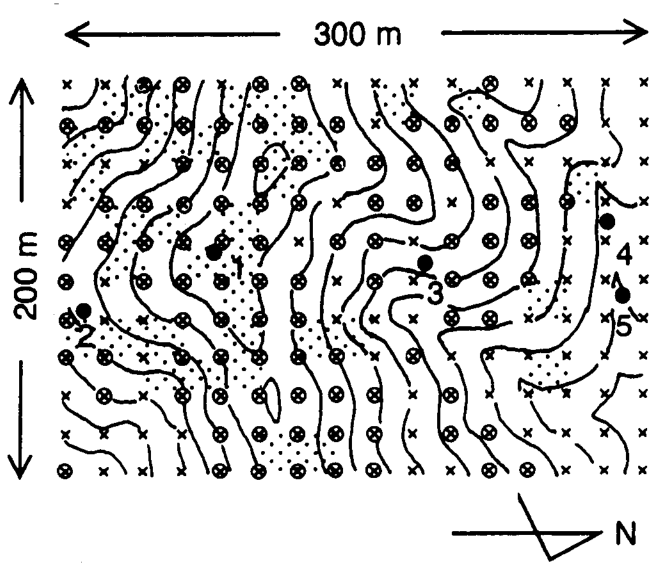

Figure 1. Study plot and arrangement of soil survey points

×: Points for measurement of soil penetration resistance and chemical properties of surface soil. Encircled symbol ⊗ shows that *Shorea curtisii* trees (dbh >5 cm) were growing within 10 m distance from the points (drawn from Niiyama *et al.* unpublished data). Interval of counter lines is 10 m.
● : Soil pit;
⬚ : Sampling area for foliar nutrient analysis of *Shorea curtisii*.

In the plot, spatial patterns of tree species (dbh >5 cm) were studied and a total of 455 tree species were enumerated (Niiyama *et al.* unpublished). The major tree species in the plot is *S. curtisii*, which accounted for about 29% of the total basal area (Niiyama *et al.* unpublished), and large trees of *S. curtisii* (maximum dbh of 161 cm) showed gregarious distribution on ridges and were absent in valley bottoms (Figure 1).

Soil sampling

Five soil pits were dug as shown in Figure 1, for measurement of morphological and chemical soil profiles. To study the relationship between topography and physical and chemical properties of soils, 176 points were measured at intervals of 20 m throughout the plot as shown in Figure 1. At each of these points, soil penetration resistance up to 1 m depth and chemical properties of surface soils up to 3 cm depth (corresponding to A-horizon) were determined.

Description of morphological properties of soil

Soil colour by the Munsell colour classification system, soil texture, soil moisture, and frequency of roots and gravel at each soil horizon of the five pits were measured based on FAO and ISRIC (1990). Soil hardness of each horizon was also determined using a Yamanaka-type hardness meter (Kiya Seisakusho Co., Ltd., Japan).

Chemical analysis of soil

From each horizon of 5 pits and from each of the 176 points, 100 g of soil was sampled. The soil samples were air-dried, removed of pieces of litter and dead roots, and sieved to a fraction < 2 mm before chemical analysis.

Soil pH was measured in suspension at a soil : water ratio of 1 : 2.5 and at a soil : KCl (1N) ratio of 1 : 2.5 by the glass electrode method (D-12 Model, Horiba Co., Ltd., Japan) after 12 h extraction. Cation exchange capacity (CEC) was measured with 1 N ammonium acetate solution at pH 7 after 12 h extraction. CEC was calculated on soil dry weight basis. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1 N ammonium acetate solution at pH 7 for 12 h and determined by an atomic absorption spectrophotometer (HC-60 Model, Hitachi Co., Ltd., Japan). Total carbon and the total nitrogen were determined by dry combustion/gas chromatography (NA-1500 Model, Carlo Erba Co., Ltd., Italy). Available phosphoric acid was extracted with a mixture of 0.1 N HCl and 2 % NH_4F (by the Bray P4 test) and determined by the colorimetric method using a spectrophotometer (U-2000 Model, Hitachi Co., Ltd., Japan). Exchangeable Al was extracted with 1N KCl at a soil : solution ratio of 1 : 10 for 30 min and determined by an atomic absorption spectrophotometer (HC-60 Model, Hitachi Co., Ltd., Japan) .

For the surface soils from the 176 points, only pH, total carbon, total nitrogen and available phosphoric acid were determined.

Soil penetration resistance

Soil penetration resistance, which is similar to soil hardness, increases as bulk density of soil increases and can be used as an index of soil compaction (Smith *et al.* 1997). The soil penetration resistance up to 1 m depth was measured using a Hasegawa-type soil penetration meter (Ooshima Zouyen Co., Ltd., Japan). A 2-kg weight was dropped on a cone (3.14 cm^2 in section area) from a height of 0.25 m, and the depth of the cone penetrated was measured. This operation was repeated until the depth reached 1 m. The penetration resistance at each depth was calculated from the penetrated depth of the cone by taking one drop to correspond to a penetration energy of 4.9 m^2 kg s^{-2}. Thus, for a hard soil with a small penetrated depth, the penetration resistance is large. In this study, soils with penetration resistance larger than 1.55 MPa as determined by the Hasegawa-type soil penetration meter were regarded as hard soils.

Foliar nutrient concentrations of Shorea curtisii saplings

Matured and undamaged leaves were sampled from the upper part of crowns of 63 *S. curtisii* saplings growing at various topographic locations in October 1995 (Figure 1). Sapling heights ranged from 1 to 4 m. Chlorophyll concentration of leaves was determined as SPAD value using a chlorophyll meter (SPAD-501 Model, Minolta Co., Ltd., Japan). SPAD value is proportional to chlorophyll concentration (Tadaki & Kinoshita 1988). Nitrogen content was determined by dry combustion/ gas chromatography (NA 1500 Model, Carlo Erba Co., Ltd., Italy). After digestion by perchloric acid and nitric acid, phosphorus and potassium contents were determined with a spectrophotometer (U-2000 Model, Hitachi Co., Ltd., Japan) and an atomic absorption spectrophotometer (HC-60 model, Hitachi Co., Ltd., Japan) respectively.

Results and discussion

Morphological characteristics of soil profiles

One of the significant morphological characteristics of soil profile in relation to topography was that only the soil profile at the valley bottom had mottles of iron at depths of 5 to 40 cm (Table 1). The presence of iron mottles reflects alternating conditions of oxidation and reduction of sesquioxides (FAO & ISRIC 1990). As there is seasonality in rainfall in this district (Manokaran & Swaine 1994), there was a possibility of seasonal changes in anaerobic and aerobic conditions of the soils at the valley bottom. As tolerance against anaerobic soil condition differs among tree species (Kozlowski *et al.* 1991), seasonal anaerobic soil condition on a valley bottom may be one of the influencing factors for the distribution of each tree species.

Table 1. Morphological properties of soils

Pit No.	Horizon	Depth (cm)	Colour	Texture[1]	Structure[2]	Hardness (Mpa)[3]	Moisture[4]	Root[5] F	M	C	Mottles of iron	Mycorrhiza
1	0	3 - 0										
Ridge	A1	0 - 4	7.5YR3/4	SC	(GR)	0.04	S	M	N	N[6]	N	C
	A2	4 - 6	10YR3/4	SC	AB	0.18	S	C	N	N	N	V
	B1	6 - 20	10YR7/5	SC	AB	0.39	S	C	C	N	N	N
	B2	20 - 45	10YR7/6	SC	MA	1.69	S	F	F	F	N	N
	B3	45 - 80+	10YR6/6	SC	MA	1.85	S	V	V	F	N	N
2	0	3 - 0										
Mid-slope	A1	0 - 7	7.5YR4/3	SC	(GR)	0.02	S	C	N	N	N	N
	A2	7 - 13	7.5YR5/4	SC	SB	0.18	S	C	N	N	N	N
	B1	13 - 40	10YR7/6	SC	(SB)	0.30	S	C	C	N	N	N
	B2	40 - 70	10YR6/6	SC	MA	1.15	S	F	F	N	N	N
	B3	70 - 105	10YR6/6	SC	MA	1.69	S	F	F	N	N	N
	B4	105 - 130+	7.5YR6/6	SC	MA	1.87	S	V	V	N	N	N
3	0	2 - 0										
Mid-slope	A	0 - 5	10YR5/3	SC	(SB)	0.31	S	C	N	N	N	N
	B1	5 - 22	10YR6/4	SC	(SB)	0.59	S	F	F	N	N	N
	B2	22 - 41	10YR6/6	SC	MA	0.74	S	V	F	N	N	N
	B3	41 - 62	7.5YR6/6	SC	MA	0.83	S	V	V	N	N	N
	B4	62 - 82	7.5YR6/6	SC	MA	0.83	S	V	V	N	N	N
	B5	82 - 100+	7.5YR6/7	SC	MA	1.72	S	V	V	N	N	N
4	0	5 - 0										
Foot-slope	A	0 - 8	10YR4/4	SC	(SB)	0.12	M	C	N	N	N	N
	B1	8 - 25	10YR5/4	SC	(SB)	0.15	M	C	N	N	N	N
	B2	25 - 43	10YR6/4	SC	(SB)	0.22	M	F	F	N	N	N
	B3	43 - 64	10YR6/4	SC	MA	0.36	M	F	F	N	N	N
	B4	64 - 85	10YR6/4	SC	MA	0.33	M	F	F	N	N	N
	B5	85 - 105	10YR6/4	SC	MA	0.43	M	V	V	N	N	N
	B6	105 - 120+	10YR6/4	SC	MA	0.42	M	V	V	N	N	N
5	0	5 - 0										
Valley	A	0 - 6	7.5YR4.5/3	SC	MA	0.35	M	M	N	N	N	N
bottom	ABg	6 - 18	7.5YR5/3	SC	MA	0.57	M	C	C	N	F	N
	Bg	18 - 40	7.5YR6/4	SC	MA	0.61	M	N	F	C	F	N
	BC	40 - 60	10YR6/4	SC	MA	0.56	M	N	F	N	N	N
	R	60 - 80+	10YR8/3									

[1] SC means sandy clay [2] GR, AB, SB and MA mean granular, angular blocky, subangular blocky and massive respectively. Parenthesis means that the grade of structure is weak. [3] Hardness was measured by a Yamanaka - type hardness meter. [4] S and M mean slightly moist and moist respectively. [5] F, M and C mean fine root (diameter < = 2 mm), medium root (2 mm < diameter ≤ 20 mm) and coarse root (diameter > 20 mm) respectively. [6] N, V, F, C and M mean none, very few, few, common and many respectively.

Another important soil property was the soil depth up to hard subsoil, which depended on topography (Table 1). These horizons were under 20 cm depth on the ridge and under 80 cm depth at the middle part of slopes. There was no hard subsoil up to 100 cm depth on the foot-slope. The relations between topography and the soil depth up to the hard subsoil are shown in Figure 2. Thin layers of soft soil were mostly distributed on ridges and convex slopes. On the other hand, thick layers of soft soil were distributed at valley bottoms and on convex slopes.

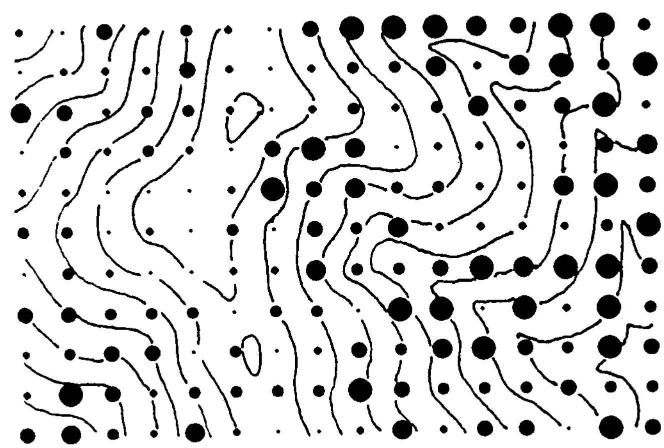

Figure 2. Relationship between topography and soil depth up to hard subsoil whose soil penetration resistance was more than 1.55 MPa.

Compacted soils restrict root growth by their large penetration resistance and low air permeability, and thereby subject seedlings to drought stress (Hopkins & Patrick 1969, Tuttle *et al.* 1988). Soil physical properties such as soil compaction influence root growth (Nel & Bennie 1984). As the survival of the current year seedlings of dipterocarps was strongly influenced by drought (Turner *et al.* 1993), difference in depth up to hard subsoil due to topography may be one of the influencing factors for the spatial distribution of trees in the hill forests.

Change in chemical properties of soil with depth

Every soil nutrient content and soil acidity declined sharply with depth, as shown in Figure 3. This tendency indicated that the main source of not only organic elements but also inorganic elements was litter because the granitic mother rock was poor in bases. Low cation exchange capacities of the subsoil may result from the sandy clay soil texture which contains a large amount of quartz sand from the weathering of granite. Differences in the chemical properties of the soils at the various topographic locations were larger in the surface soil than in the subsoil. In comparison with the surface soil at the valley bottom, the chemical properties of the surface soil on the ridge were characterised by high contents of carbon, nitrogen and available phosphorus, a high ratio of carbon content to nitrogen content (C-N ratio), low pH, a high cation exchange capacity and high contents of exchangeable cations. Although the surface soil was more strongly acid than the subsoil at each profile, the exchangeable Al in the surface soil was less than that in the subsoil. Hence, the low pH of the surface soils probably did not result from an increase in exchangeable Al.

The surface soil at the ridge contained more carbon (organic matter) than at the valley bottom. Plant litter is decomposed by soil fauna, especially microorganisms. The activity of microorganisms is influenced by the chemical composition of litter and environmental conditions. One of the influencing environmental factors is soil moisture content; low moisture content in soil reduces the decomposition rate of organic matter (Wiant 1967). Therefore, a high content of carbon on ridges and convex slopes might have resulted from the dry condition of the soil.

Burgess (1975) reported that the contents of nutrients in soils up to 30 cm depth on ridges in a hill dipterocarp forest whose mother rock was granite were lower than those on hillsides because of washing-out. In our study site, subsoils deeper than 10 cm at the ridge and on the convex slopes also contained less amounts of nitrogen, available phosphorus and exchangeable potassium and showed lower base saturation than subsoils at the foot-slope and valley bottom. However, surface soils up to 5 cm depth on the ridge and convex slopes contained more amounts of nutrients than those on the foot-slope and valley bottom (Figure 3). The low pH on the surface soils did not clearly correspond to low base saturation (Figure 3). As nutrient content and acidity of surface soils are strongly correlated to the amounts of organic matter, the influence of washing-out on the chemical properties of the surface soils seemed to be less than that of litter decomposition.

Differences in soil chemical properties by topography were more apparent in the surface soil than in the subsoil and these differences in terms of acidity, C-N ratio and carbon content might have resulted from the soil moisture regime as influenced by topography. Therefore, the chemical properties of surface soils at various topographic locations clarify not only the influence of topography but also that of the environment, particularly the soil moisture regime, at these locations.

Relationship between the topography and the chemical properties of the surface soils

Chemical properties of the surface soils were plotted on the topographic maps (Figure 4). Surface soils with low pH, high contents of carbon, nitrogen and available phosphoric acid and high C-N ratio tended to be present on ridges and convex slopes. This corresponds to the soil profiles shown in Figure 3.

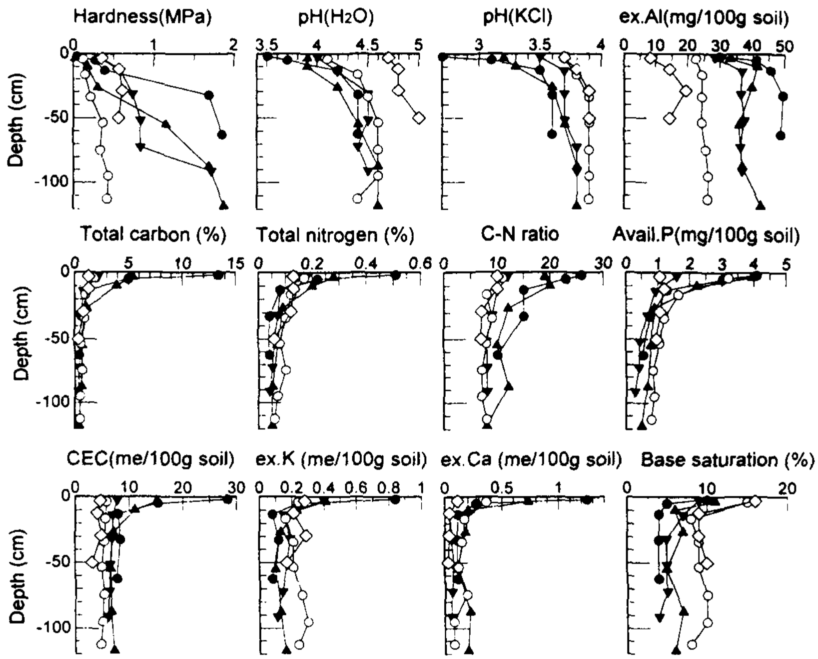

Figure 3. Change in physical and chemical properties along soil profile

Soil pit: ● ; No. 1, ▲ ; No. 2, ▼; No. 3, ○ ; No. 4, ◆; No. 5
Avail. P means available phosphorus determined by Bray P4 test. CEC means cation exchange capacity. ex. K, ex. Ca and ex. Al mean exchangeable potassium, calcium and aluminium respectively.

As shown in Figure 5, close correlations were obtained among pH, carbon contents, C-N ratio and availability of phosphorus. The pH tended to decrease as the C-N ratio increased. This implies that the soil acidity of the plot was correlated to the decomposition rate of litter and that litter decomposition was limited in the soils with low pH such as on ridges and convex slopes. Although the content of available phosphorus tended to be large in the surface soils containing much carbon, the ratios of available phosphorus to total carbon were small in the surface soils with low pH and high content of carbon (Figure 5). Thus, available phosphorus was probably supplied from the litter and was strongly influenced by the decomposition rate of the organic matter. Differences in chemical properties of the surface soils were strongly influenced by environmental conditions, probably soil moisture conditions, related to litter decomposition. In this study, the soil physical and chemical properties showed much difference among the topographic sites. Although the growth and distribution of trees are influenced by soil chemical properties, their growth response to soil chemical condition differs among species. The growth and foliar nutrient contents of *Shorea curtisii*, the dominant tree species at the plot, are little influenced by soil nutrient contents compared to other *Shorea* species (Amir & Miller 1990, Amir & Zakaria 1990, Turner *et al.* 1993). *Shorea curtisii* saplings growing in the plot were also found to have mean foliar contents of nitrogen, phosphorus and potassium that did not differ significantly among sites with different surface soil acidity (*t*-test, $p>0.05$) (Table 2). To clarify the influence of soil properties on tree distribution, more studies on the growth response of each tree species to various soil conditions such as anaerobic condition and compaction are needed.

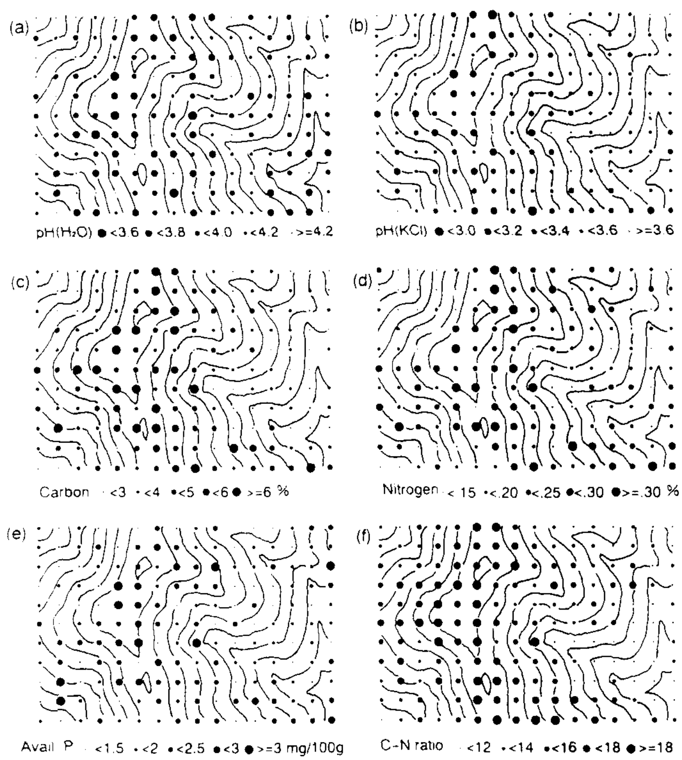

Figure 4. Relationship between topography and soil chemical properties

Avail. P means available phosphorus determined by the Bray P4 test.

Table 2. Foliar nutrient contents of *Shorea curtisii* saplings growing at different soil conditions

Acidity of surface soil	n	Nitrogen	Potassium	Phosphorus	SPAD
pH(KCl)<3.2	14	1.62(0.14) a	0.95(0.14) a	0.42(0.15) a	40.2(5.2) a
3.2 ≤ pH(KCl)<3.6	37	1.57(0.20) a	1.00(0.16) a	0.48(0.17) a	43.5(3.9) b
3.6 ≤ pH(KCl)	12	1.63(0.14) a	1.07(0.24) a	0.45(0.15) a	43.8(2.8) b

SPAD: Index value of cholorophyll content in leaves determined by cholorophyll meter (SPAD - 501, Minolta, Japan).
Standard deviations are shown in parentheses. Means sharing a common letter do not differ significantly ($p>0.05$).

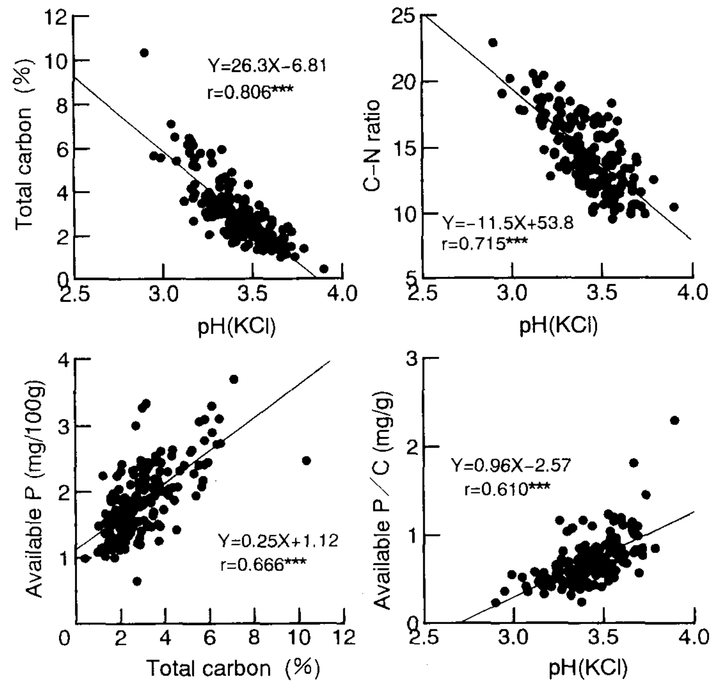

Figure 5. Interrelations among chemical properties of surface soils

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