DEPTH AND PHYSICAL PROPERTIES OF SOIL IN A FOREST AND A RUBBER PLANTATION IN PENINSULAR MALAYSIA

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NOGUCHI, S., BAHARUDDIN, K., ZULKIFLI, Y., TSUBOYAMA, Y. & TANI, M. 2003. Depth and physical properties of soil in a forest and a rubber plantation in Peninsular Malaysia. Soil depth and soil physical properties were investigated in a tropical rain forest and a rubber plantation in Peninsular Malaysia. For the forested site, thickness of surface soil layer (A and B horizons) and total soil depth ranged from 52 to 160 cm and from 118 to 640 cm respectively. The corresponding values for riser bank in the rubber plantation ranged from 42 to 121 cm and from 106 to 162 cm respectively. Total soil depth at the terrace bench in the rubber plantation was shallower (mean: 119 cm) than at the riser bank. The saturated hydraulic conductivity (Ks) in the forested site and plantation site ranged from 6.40×10^{-6} to 7.51×10^{-4} m s^{-1} and from 1.79×10^{-6} to 5.68×10^{-4} m s^{-1} respectively. The Ks values decreased with increasing soil depth at both sites. The average Ks values in the forested site were larger (10 cm: 1466 mm h^{-1}, 80 cm: 169 mm h^{-1}) than the prevailing rainfall intensity in this region. Although the average Ks values at the riser bank in the rubber plantation were similar to those in the forested site, the average Ks values

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at the terrace bench in the rubber plantation were smaller (10 cm: 68 mm h^{-1}, 40 cm: 29 mm h^{-1}). The macro- and mesoporosity of the soil also decreased with increasing soil depth. The soil porosities were in the following order of magnitude: forest > riser bank > terrace bench. These hydrological parameters (soil depth, Ks value and porosity) between the forested and rubber plantation sites enable us to understand the difference of function for water conservation concerning land-use classification.

Key words: Saturated hydraulic conductivity - soil water retention - soil depth - water conservation

NOGUCHI, S., BAHARUDDIN, K., ZULKIFLI, Y., TSUBOYAMA, Y. & TANI, M. 2003. **Kedalaman dan ciri-ciri fizikal tanah di dalam hutan dan di dalam ladang getah di Semenanjung Malaysia.** Kedalaman tanah dan ciri-ciri fizikal tanah di dalam hutan hujan tropika dan di dalam ladang getah dikaji di Semenanjung Malaysia. Di lokasi berhutan, ketebalan lapisan tanah permukaan (ufuk A dan ufuk B) dan jumlah kedalaman tanah masing-masing berjulat antara 52 cm hingga 160 cm dan antara 118 cm hingga 640 cm. Nilai berpadanan untuk lereng tebing di dalam ladang getah, masing-masing antara 42 cm hingga 121 cm dan antara 106 cm hingga 162 cm. Jumlah kedalaman tanah di bangku teres di dalam ladang getah adalah lebih cetek (purata 119 cm) berbanding nilai untuk lereng tebing. Nilai kekonduksian hidraulik tepu (Ks) di kawasan berhutan dan di ladang getah adalah berbeza, masing-masing berjulat antara 6.40×10^{-6} m s^{-1} hingga 7.51×10^{-4} m s^{-1} dan antara 1.79×10^{-6} m s^{-1} hingga 5.68×10^{-4} m s^{-1}. Nilai Ks menurun dengan kedalaman tanah di kedua-dua lokasi. Purata nilai Ks di lokasi berhutan lebih tinggi (10 cm: 1466 mm j^{-1}, 80 cm: 169 mm j^{-1}) berbanding keamatan hujan yang biasa di kawasan ini. Walaupun purata nilai Ks di lereng tebing di dalam ladang getah tidak banyak berbeza daripada nilai yang dicatat di lokasi berhutan, purata nilai Ks di bangku teres di dalam ladang getah adalah lebih kecil (10 cm: 68 mm j^{-1}, 40 cm: 29 mm j^{-1}). Keliangan makro tanah dan keliangan meso tanah juga menurun dengan kedalaman tanah. Darjah keliangan tanah untuk berbagai lokasi mengikuti turutan berikut: hutan > lereng tebing > bangku teres. Perbandingan ciri-ciri hidrologi (kedalaman tanah, nilai Ks dan keliangan) antara kawasan berhutan dengan ladang getah dapat memberi kita kefahaman tentang klasifikasi guna tanah untuk pemuliharaan sumber air.

Introduction

High rate of deforestation in tropical regions has become a cause for global concern (FAO 1993). Knowledge of hydrological characteristics in tropical rain forest catchments is an important issue not only for managing local water resources but also for understanding global environmental problems. Recently, detailed hydrological studies have been conducted in the tropical forest (Bonell & Balek 1993, Elsenbeer & Lack 1996, Kuraji 1996, Zulkifli 1996, Noguchi *et al.* 1997a). Storage of rain water into soils in tropical rain forest contributed to decreasing stormflow production (Noguchi *et al.* 1997a). The soils in the forest play an important role in soil and water conservation. Soil disturbances caused by forest logging and forest conversion to agriculture crops have led to sediment and stormflow production (Abdul Rahim 1988, Baharuddin 1988).

There have been several researches on change in physical properties of tropical soils after forest clearing (Dias & Nortcliff 1985, Alegre *et al.* 1986, Malmer & Grip 1990, Chauvel *et al.* 1991, Eden *et al.* 1991). These studies found an increase in soil bulk density and decreases in macroporosity and infiltration rate following deforestation. However, only a few of these studies investigated thickness and water retention characteristics of the soils. Soil water storage depends on thickness and porosity of soils. Thus, this information is important to analyse runoff characteristics.

High proportions of Malaysia's natural forests were lost to conversion into agricultural plantations such as rubber and oil palm in the early 20th century. Rubber plantations in Malaysia account for 32% of the total area planted with major crops (Ministry of Primary Industries Malaysia 1996). The rubber trees are usually planted on bench terraces on steep slopes. Bench terracing has been used in many parts of the world for agriculture, especially in Southeast Asia for more than a thousand years (Sheng 1982). The forest conversions of rubber plantations cause severe disturbance to the sites. Comparing hydrological characteristics between forested and rubber plantation sites is a useful approach to evaluate not only the effects of forest disturbance on soil and water conservation but also the difference of water resources concerning land-use classification.

In this study we investigated the hydrological parameters (saturated hydraulic conductivity and water release curve of soils as well as soil depth) in order to clarify the difference in function for water conservation between tropical rain forest and rubber plantation sites.

Materials and methods

Site description

Bukit Tarek Experimental Watershed (site F) is located in Selangor, Peninsular Malaysia (latitude: 3° 31' N, longitude: 101° 35' E, altitude: 48–213 m; Figure 1). The forest was logged in the early 1960s and now it has fully regenerated. The vegetation is dominated by *Koompassia malaccensis*, *Eugenia* spp. and *Canarium* spp. Surficial geology is metamorphic rocks consisting of quartzite, quartz mica schist, graphitic schist and phyllite from the Arenaceous Series (Saifuddin *et al.* 1991). According to FAO classification (FAO 1998), the soil is classified as Acrisols (Morisada 1999).

The rubber plantation (site R), which is adjacent to the watershed (Figure 1), was established in 1949, followed by a first replanting in 1966 and a second replanting in 1993. The rubber trees were planted on terrace benches and *Pueraria phaseoloides* was grown on riser banks as a cover crop. Farmers sometimes set their cattle free to graze on the riser bank.

The air temperature ranged from 19.1 to 34.9 °C and the average annual precipitation was 2654.4 mm, based on a three-year (1992–1994) record. The minimum, maximum and average of mean monthly precipitations were 106.3 mm (January), 354.3 mm (November) and 221.2 mm respectively. The monthly precipitation had a two-peak distribution (May and November). The rainfall was characterised by short duration and high intensity (Noguchi *et al.* 1996).

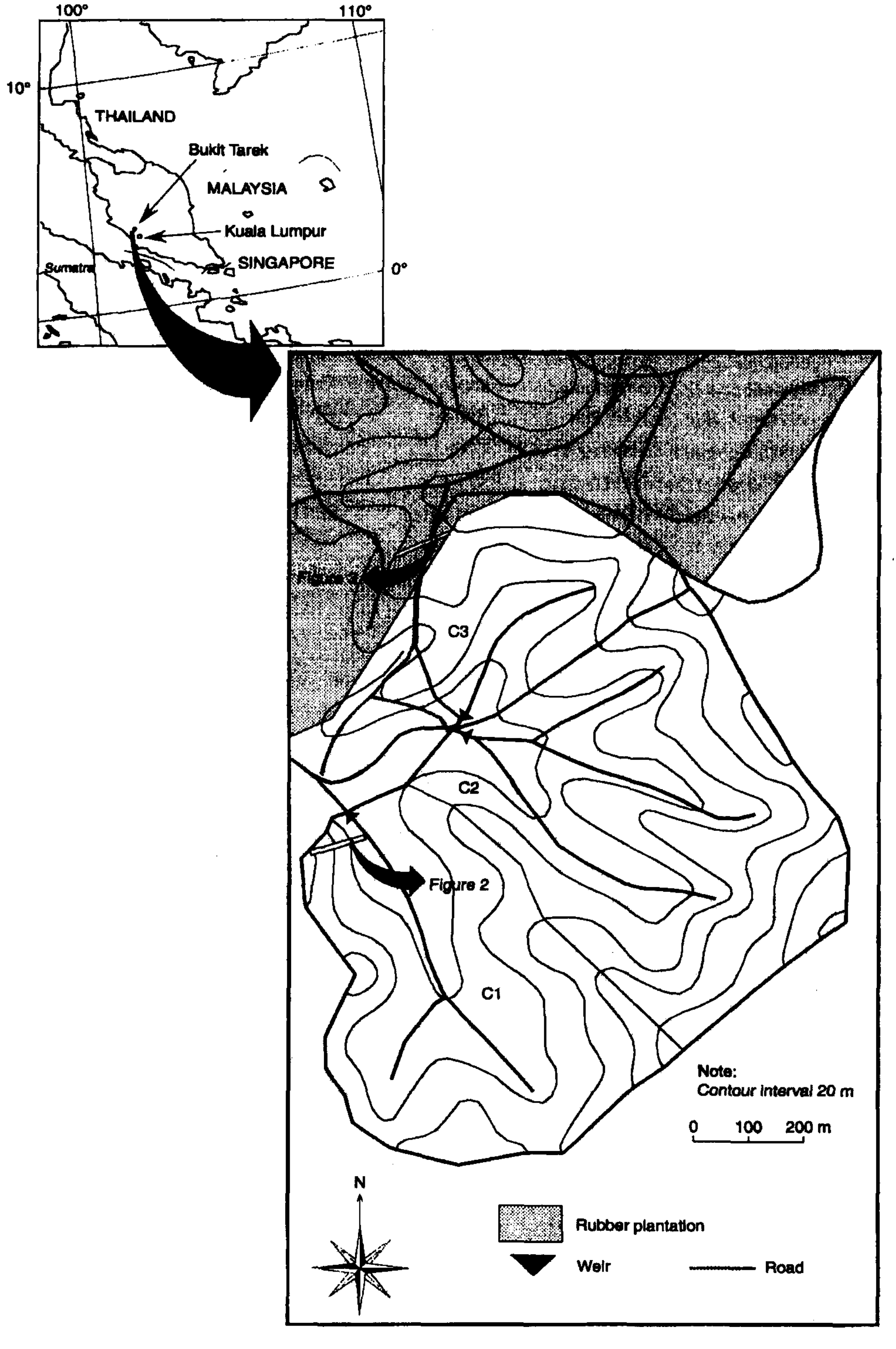

Figure 1 Map of Malaysia and location of Bukit Tarek Experimental Watershed

Soil physical properties

Vertical undisturbed soil cores, 100 cm^2 area by 4 cm depth (400 cm^3 in volume) were collected from the ridge (FR), the middle slope (FM) and near stream (FS) in site F (Figure 2). For site R, soils were sampled from the terrace benches (RU and RL) and the vegetated riser bank (RB) (Figure 3).

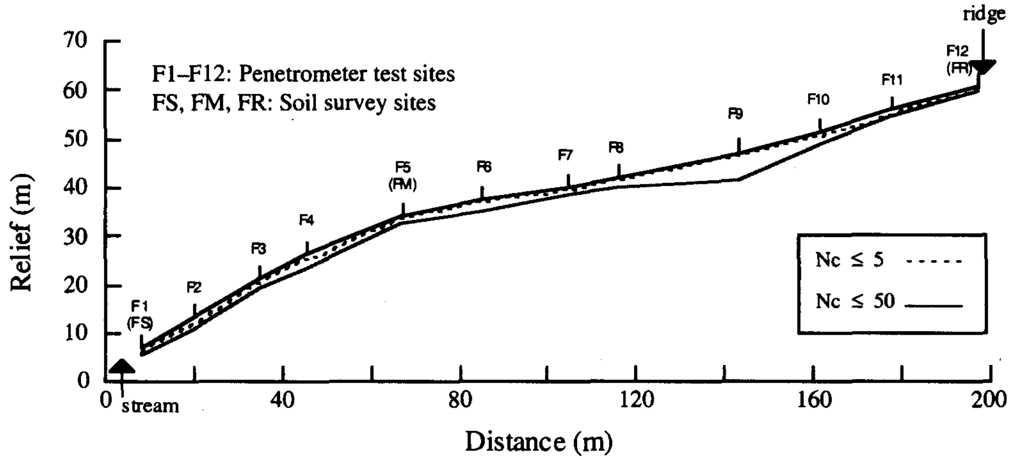

Figure 2 Depths of Nc value = 5 and 50 on the longitudinal axis of a slope, and locations of soil survey (FR, FM and FS) and penetrometer test (F1–12) points in the forested sites

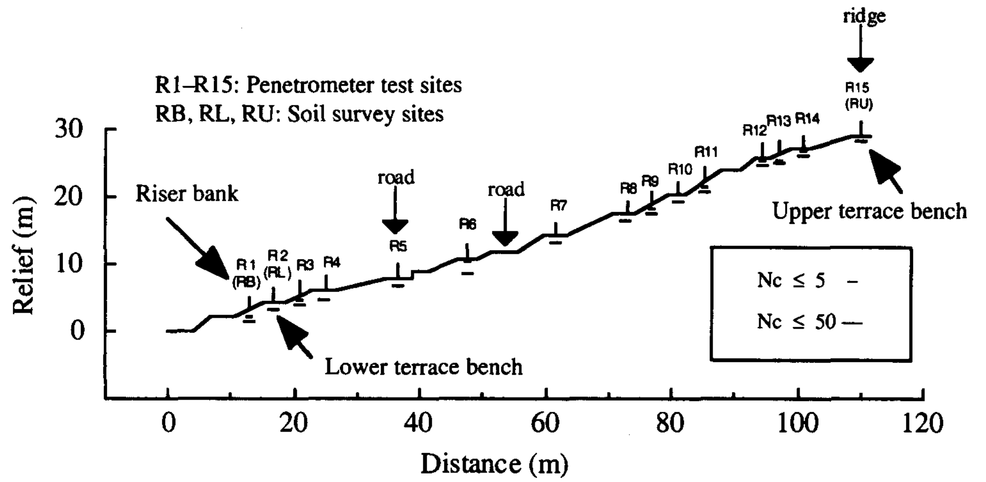

Figure 3 Depths of Nc value = 5 and 50 on the longitudinal axis of a slope, and locations of soil survey (RU, RL and RB) and penetrometer test (R1–15) points in the forested sites

Particle size distribution of the soils was determined by the pipette method (Gee & Bauder 1986). Saturated hydraulic conductivity (Ks) of the cores was measured using a constant head permeameter (Mashimo 1960). The soil water retention curve for the cores was determined by a sand column (for pressure head ≤ 31.6 cm H_2O) and a pressure chamber (for pressure head from 100 to 1000 cm H_2O) respectively (Hasegawa *et al.* 1997). The relationships between pressure head (ψ) and volumetric water content (θ) were analysed by the van Genuchten equation (van Genuchten 1980) as follows:

$$\theta = \theta_r + (\theta_s - \theta_r)\left[\frac{1}{1+(\alpha|\psi|)^n}\right]^{1-\frac{1}{n}} \quad (1)$$

where

θ_s = saturated soil-water content which was obtained experimentally
θ_r = residual water content
α and n = constants which were estimated by the Levenberg-Marquardt algorithm using observed retention data

Soil depth

Soil depth was measured at 23 points in site F and at 16 points in site R during wet conditions (Oct–Nov) using a portable dynamic cone penetrometer. The apparatus consists of five parts: a top cone with 60° sharp angle and 25 mm diameter, a guide rod, a rod, knocking head and a weight of 5 kg. The soil profiles were expressed by the number of knocking values (Nc) obtained from the penetrometer test. The Nc values were measured by counting the number of drop of the weight from a 50 cm height to drive the cone 10 cm down into the soil. In this study, such values were used to define surface soil layer ($0 \leq Nc \leq 5$), weathered soil layer ($5 \leq Nc \leq 50$) and total soil depth ($0 \leq Nc \leq 50$) respectively. These layers were compared with soil profiles in sites F and R.

Results

Soil physical properties

The main features of the six soil profiles (FS, FM and FR: site F; RU, RL: terrace bench at site R; RB: riser bank at site R) are given in Figure 4. Some of the physical properties of excavated soil pits are shown in Table 1.

The soil profiles were similar between the forested sites and riser bank (RB) at site R. Thin, dark coloured A_h horizon and light coloured underlying horizons were observed. Granular structure was observed in A_h horizon and weak medium blocky structure was common in B horizon. Termite nests were found in B horizon at FS and RB. The soil profile at the terrace bench in site R showed a lack of A_h horizon. Root abundance was much less but earthworm activities were observed at the top layer (B_1 horizon) at RU and RL.

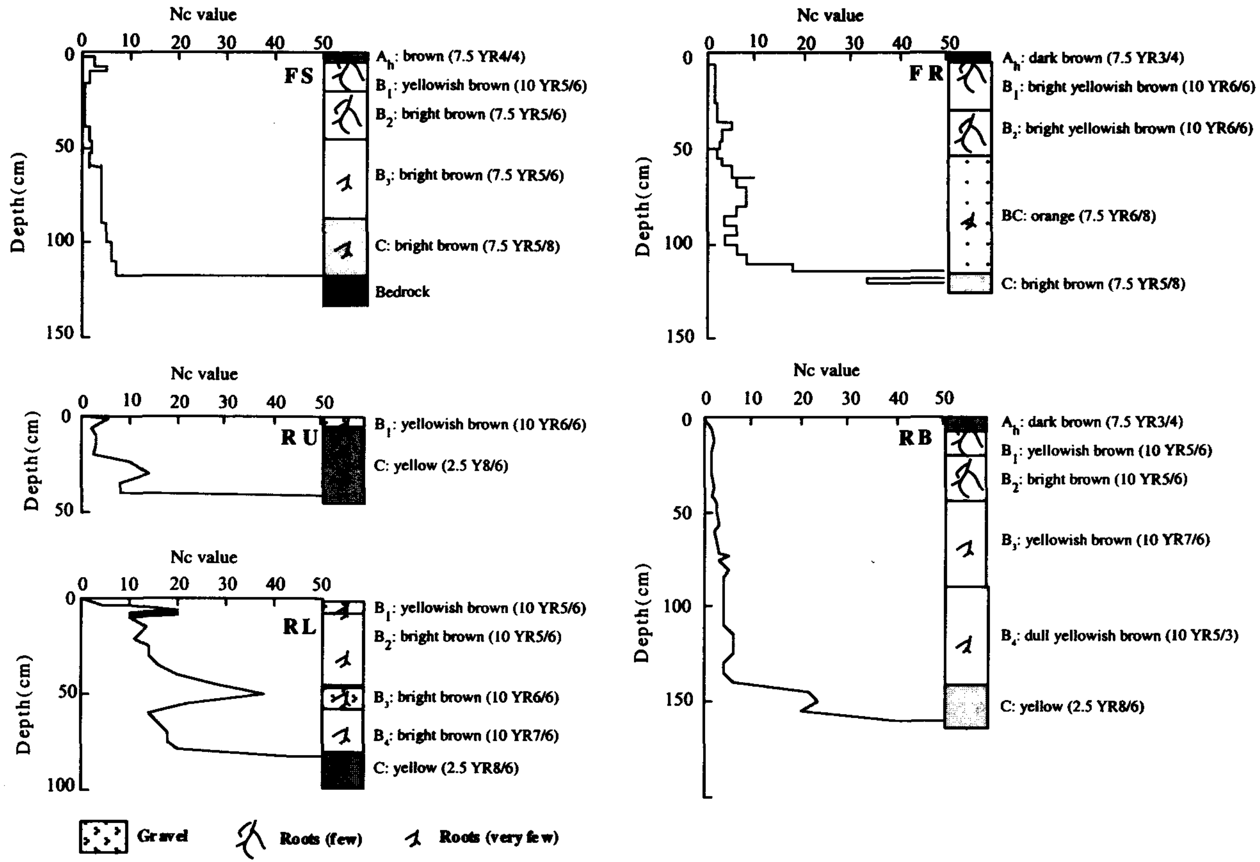

Figure 4 Examples of the relationship between soil profile and Nc value profile in the forested and rubber plantation sites

Table 1 Some physical properties of soils

Site	Horizon	Depth	Bulk density (Mg m^{-3})	Total porosity (m^3 m^{-3})	% Clay (< 0.002 mm)	% Silt (0.002–0.02 mm)	% Sand (0.02–0.2 mm)
Ridge in the forest	B_1	10	0.66	0.69	39.2	25.2	35.6
(FR)	B_1	20	0.68	0.70	38.4	26.0	35.6
	B_2	40	0.97	0.62	32.0	12.8	55.2
	BC	80	1.33	0.55	31.6	20.1	48.3
Middle of slope	B_1	10	0.67	0.72	42.8	17.4	39.8
in the forest	B_1	20	0.76	0.70	40.3	25.3	34.4
(FM)	B_2	40	1.03	0.62	46.2	19.8	26.4
	B_3	80	1.35	0.56	43.9	12.3	43.8
Near stream	B_1	10	0.77	0.71	31.2	20.3	48.5
in the forest	B_2	20	0.89	0.68	34.5	18.5	47.0
(FS)	B_2	40	1.07	0.50	28.5	26.9	44.6
	B_3	80	1.57	0.41	32.9	18.0	49.1
Upper terrace bench	C	10	1.66	0.45	23.3	24.8	51.9
in the rubber plantation	C	20	1.76	0.40	17.6	32.2	50.2
(RU)	C	40	2.02	0.29	13.6	31.3	55.1
Lower terrace bench	B_2	10	1.31	0.57	41.5	17.1	41.4
in the rubber plantation	B_2	20	1.15	0.60	29.2	46.8	24.0
(RL)	B_2	40	1.26	0.60	51.3	25.1	23.6
	B_4	80	1.67	0.45	30.6	27.0	42.4
Riser bank	B_1	10	0.97	0.60	56.9	17.4	25.7
in the rubber plantation	B_2	20	0.91	0.65	56.5	19.2	24.3
(RB)	B_2	40	1.21	0.51	48.1	22.5	29.4
	B_3	80	1.40	0.52	25.8	35.0	39.2

The bulk density increased but total porosity decreased with increasing soil depth (Table 1). The shallow soils (≤ 20 cm) in the forest and at riser bank in site R (RB) had a low bulk density (less than 1.00 Mg m^{-3}). The bulk density of terrace bench at site R was high (range: 1.15–2.02 Mg m^{-3}). The soils at upper terrace bench (RU) had a low clay content (< 24 %) and a high bulk density (1.66–2.02 Mg m^{-3}).

Figure 5 shows saturated hydraulic conductivity (Ks) profile in vertical direction with the geometric mean in site F (FR, FM and FS) and in site R (RU, RL and RB). The Ks values ranged from 6.40×10^{-6} to 7.51×10^{-4} m s^{-1} in site F and from 1.79×10^{-6} to 5.68×10^{-4} m s^{-1} in site R respectively. Although the Ks values for soil with decayed root channel at FR were 10 to 100 times larger than those of other samples at depths of 40 to 80 cm, the Ks values generally decreased with increasing soil depth at both sites. The Ks values in site F exhibited similar trends to those of RB but higher than those of RU and RL in site R. The magnitude of the differences was 10 to 100 times at a depth of 10 cm.

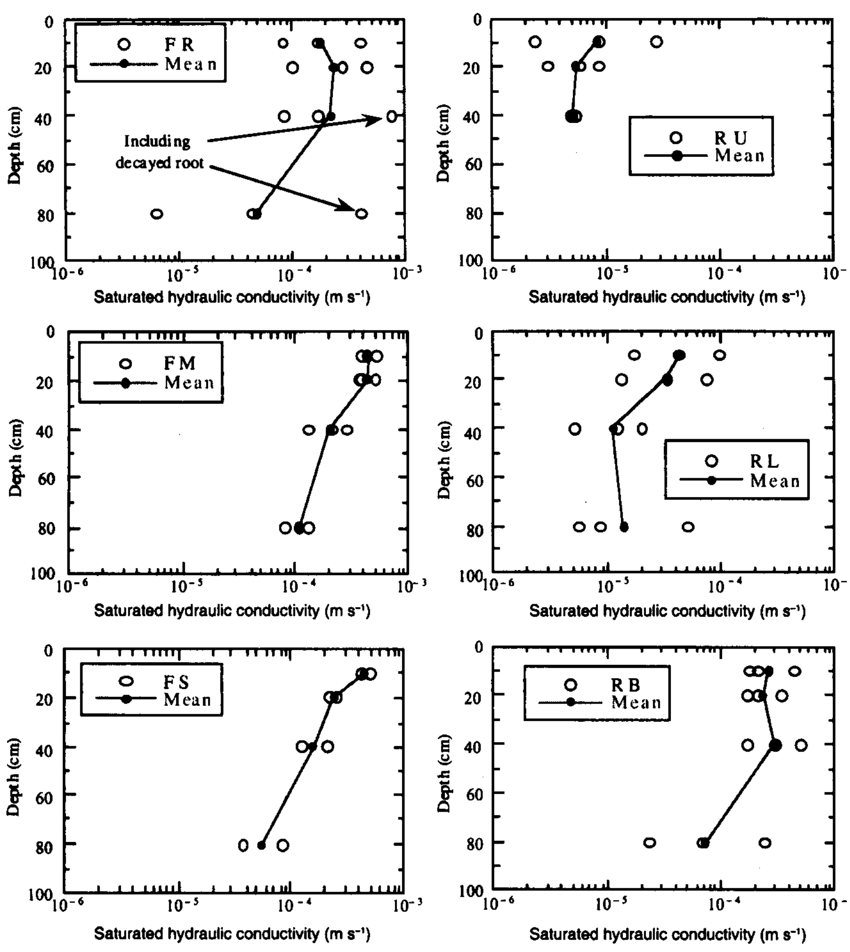

Figure 5 Relationship between depth and saturated hydraulic conductivities (Ks) with the geometric mean in the forested and rubber plantation sites

The relationships between pressure head (ψ) and volumetric water content (θ) of soils with fitted curves generated by the van Genuchten (1980) model are shown in Figure 6. The curve fitting was excellent. The optimised set of parameters for the model is presented in Table 2. There were two types of water retention curve in Figure 6. The first type showed a decrease in water content as suction was raised from 0 (saturation) to 30 cm H_2O (e.g. FR, FM, FS and RB at depths of 10 and 20 cm). The second type of water retention curve showed that the decrease in the water content was much more gradual (e.g. RU and RL, and FS and RB at depths of 40 and 80 cm). The curve type depends on volumes of macropores and mesopores. Under the definitions suggested by Luxmoore (1981), the macroporosity (ψ < 3.06 cm H_2O) and mesoporosity (3.06 ≤ ψ ≤ 306 cmH_2O) of the soil were calculated by Equation 1 respectively (Table 3). Both macro- and mesoporosities of the soil decreased with increasing soil depth at all sites.

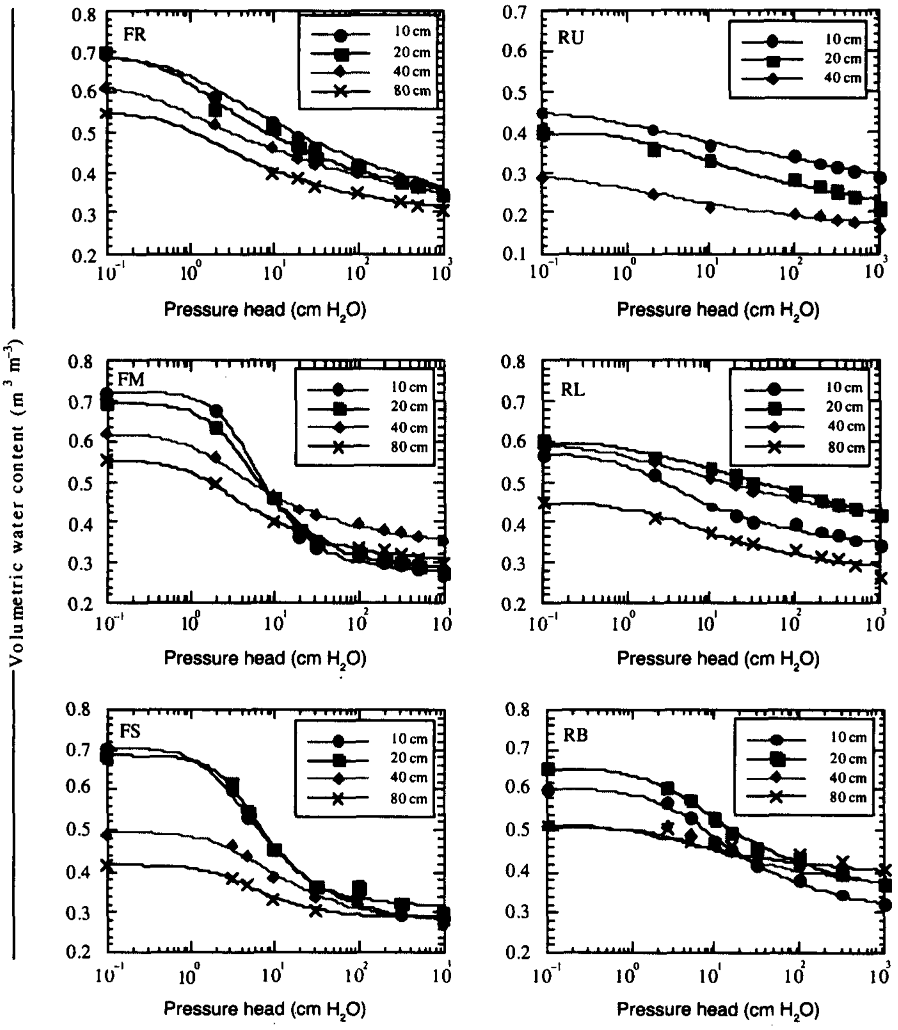

Figure 6 Observed retention data in the forested and the rubber plantation sites and fitted θ–ψ curves

Table 2 van Genuchten parameters of the soils in forested and rubber plantation sites

Site	Depth (cm)	α	n	θ_s	θ_r
Forest (FR)	10	1.091	1.19	0.688	0.252
	20	1.492	1.28	0.695	0.306
	40	3.386	1.18	0.624	0.267
	80	1.256	1.31	0.552	0.285
Forest (FM)	10	0.242	1.97	0.721	0.278
	20	0.307	1.74	0.695	0.281
	40	0.598	1.43	0.619	0.336
	80	0.560	1.51	0.555	0.291
Forest (FS)	10	0.372	1.60	0.706	0.269
	20	0.242	1.98	0.684	0.317
	40	0.273	1.52	0.496	0.268
	80	0.301	1.80	0.414	0.287
Rubber (RU)	10	3.579	1.06	0.454	0.056
	20	0.609	1.20	0.399	0.164
	40	3.180	1.16	0.292	0.127
Rubber (RL)	10	0.751	1.37	0.571	0.329
	20	0.982	1.06	0.602	0.030
	40	1.887	1.09	0.595	0.239
	80	0.696	1.27	0.451	0.257
Rubber (RB)	10	0.289	1.40	0.604	0.290
	20	0.328	1.39	0.652	0.341
	40	0.370	1.33	0.511	0.354
	80	0.949	1.28	0.517	0.383

α and n: constant, θ_s = saturated soil water content, θ_r = residual water content

Table 3 Percentage of porosity in macro- and mesoporosity change of soils in forested and rubber plantation sites

Site	Depth (cm)	Macroporosity (%)	Mesoporosity (%)
Forest (FR)	10	10.0	19.1
	20	13.9	17.7
	40	12.4	13.0
	80	9.7	12.7
Forest (FM)	10	8.5	35.2
	20	9.7	30.2
	40	8.6	16.7
	80	8.6	15.9
Forest (FS)	10	11.3	29.9
	20	7.0	29.2
	40	3.9	16.5
	80	3.0	9.3
Rubber (RU)	10	5.7	8.4
	20	4.0	11.1
	40	5.2	5.9
Rubber (RL)	10	7.7	13.3
	20	4.1	11.2
	40	5.6	10.1
	80	4.6	10.2
Rubber (RB)	10	5.0	21.1
	20	5.4	20.5
	40	2.7	9.7
	80	3.8	6.7

Soil depth

The relationship between soil profile and Nc profile at several sites is shown in Figure 4. The profile of Nc values at riser bank in site R was similar to that at site F. However, the profile of Nc values at terrace bench in site R was different from these. The profiles were characterised by the existence of a peak (Nc value $\geq$ 10) at shallow depth (e.g. RL in Figure 4). The A and B horizons had similar hardness (Nc value $\leq$ 5) except those at terrace bench in site R. Thus, the surface soil layer corresponded to these horizons in site F and at riser bank in site R. The Nc value changed at the boundary between B and C horizons or between B and BC horizons. The depths correspond to bedrock or C horizon when Nc value is equal to 50. Therefore, the weathered soil layer ($5 <$ Nc value ≤ 50) corresponded to BC or C horizons in site F and at riser bank in site R. On the other hand, total depth at terrace bench in site R corresponded to the thickness of B and C horizons.

Depths of Nc value = 5 and 50 on the longitudinal axis of a slope in site F are shown in Figure 2. The thickness of the weathered soil layer varied depending on locations (18.0–580.0 cm) whereas that of the surface soil layer was less variable (52.0–160.0 cm). The maximum, minimum, mean and SD of the total soil depth were 640.0, 118.0, 276.5 and 149.7 cm respectively. Total soil depth was shallower at the ridge (F12) and the lowest point of the slope (F1), and deeper at the middle upper slope (F9). The total soil depth depended on the depth of weathered soil layer.

Depths of Nc value = 5 and 50 on the longitudinal axis of a slope in site R are shown in Figure 3. The thickness of surface soil layer and the total soil depth at riser bank ranged from 42.0 to 121.0 cm and from 106.0 to 161.5 cm respectively. Total soil depth at the terrace bench was shallower (mean: 119.4 cm) than at the riser bank.

Discussion

Soil physical properties

The magnitude of the Nc value shows a dependable logarithmic correlation with the bulk density of the saprolite (Yoshinaga & Ohnuki 1995, Ohnuki *et al.* 1999). The relationships between Nc value and bulk density (BD) deeper in the soil ($\geq$ 40 cm) in this study and those of Ohnuki *et al.* (1999) are shown in Figure 7. Ohnuki *et al.* (1999) found lower bulk density to Nc value compared with that in this study. The relationship in this study also showed a dependable logarithmic correlation ($p < 0.005$). The penetrometer test is easier to use and creates less disturbance than collecting soil sample for bulk density deeper in the soil. Thus, the penetrometer test is useful for estimating soil bulk density in deeper site, but the test must be conducted at similar soil moisture conditions because these relationships depend on soil moisture conditions (Ohnuki *et al.* 1997).

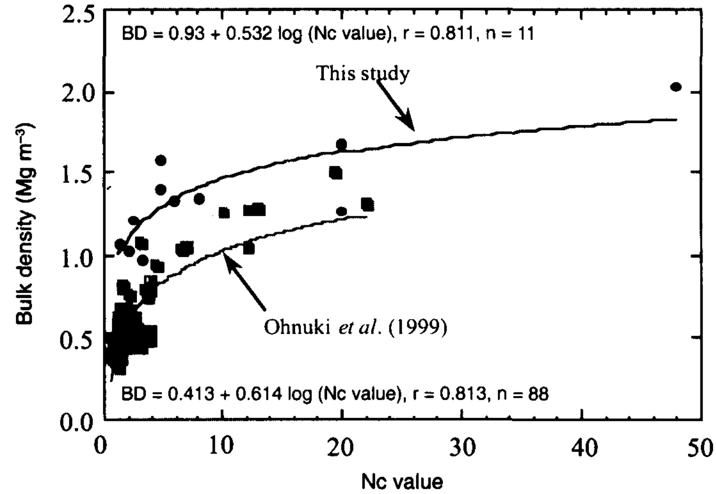

Figure 7 Relationships between Nc value and bulk density for this study and Ohnuki *et al.* (1999)

Both macro- and mesoporosities of the soil decreased with increasing soil depth at all sites (Table 3). The forest soil has the largest macro- and mesoporosities, followed by riser bank and the least for terrace bench. Sharp reductions in the macro- and mesoporosities were observed between 20 and 40 cm except at the terrace bench (RU and RL). Root densities were relatively high in soil beyond 40 cm depth in the sites (Figure 4). Root channels are one of the origins for macropores (Beven & Germann 1982). It has also been reported that root channels become the main agents of macropores into a forest soil (Noguchi *et al.* 1997b). In addition, lateral roots run beneath the soil surface at depths of 15 to 40 cm and can extend to 35 m from the stem in tropical forests (Baillie & Mamit 1983). Root activity can play an important role in development of the soil porosity (Allen 1985).

Rubber plantation establishment usually leads to serious soil disturbance and destruction of soil structure. The terrace benches are the most affected part of the system due to compaction by machines. Only rubber trees had effect on terrace bench and the activity and density of roots in the soil were lower than those in site F and at riser bank in site R (Figure 4). These could explain why the soil porosities at terrace bench were the lowest.

Soil depth

Besides porosity of soil, soil depth is an important parameter to estimate water storage capacity of soils. Storage of rain water into the soils contributed to decreasing stormflow production (Noguchi *et al.* 1997a). Greater soil depths at the forest site could store much more rain water in the soils than at the rubber plantation site.

Mechanical establishment of rubber plantation results in considerable topsoil removal and soil compaction. The surface soil on the terrace bench could be further compacted by plantation workers during tapping and collection of latex. These could contribute to shallower total soil depth at the terrace bench in site R, compared with that in site F and riser bank in site R. The reason why terrace bench showed high Nc value (≥ 10) at shallow depth was also considerably due to topsoil removal and soil compaction.

An Nc value of 5 seems to be the limiting hardness for tree root penetration, which also corresponds to the possible depth of the development of B-soil horizons (Tsukamoto & Ohta 1988). The depth of surface soil layer (Nc value ≤ 5) corresponded well to A- and B-soil horizons except on the terrace bench (Figure 4). Tree roots were found below the surface soil layer (Figure 4) because the roots could penetrate into weathered soil layer, particularly through local soft parts such as joints, cracks and decayed root channels. However, tree roots could develop easier into a depth of Nc < 5.

Recent studies stressed the importance of bedrock topography for subsurface flow generation (McDonnell *et al.* 1996, Montgomery *et al.* 1997, Noguchi *et al.* 1999). Nc value of 50 corresponded to a weakly weathered saprolite (C horizon) or bedrock (Figure 4). Ohta (1988) surveyed the soil structure in a tertiary hill using the penetrometer. He pointed out that saturated throughflow took place at depths represented by Nc value of 20 during storms. In addition, Tsuboyama *et al.* (1994) observed ground water at depths represented by Nc value of 50 in a forested basin of Japan. On the other hand, Noguchi *et al.* (1997b) reported that positive pressures occurred at 160 cm depth of FM in this forest and the total soil depth ($Nc \geq 50$) at FM was 161 cm. The results suggest the presence of the hydrologic impeding layer at the depths corresponding to Nc value of 50 in this area. It may be useful to employ penetrometer tests to investigate the topography of the hydrologic impeding layers.

Function of water conservation in forested and rubber plantation sites

Saturated hydraulic conductivity (Ks) and macro-mesoporosity of soils decreased with increasing soil depth at both sites. The magnitudes of total soil depth, Ks values and the porosities were in the following order: forest > riser bank (rubber) > terrace bench (rubber). Differences in runoff processes occur in forested and rubber plantation sites due to differences in total soil depth, Ks values and porosities.

Rainfall intensity was frequently over 50 mm h^{-1} at the study site (Noguchi *et al.* 1996). The Ks values at site F were larger than the observed prevailing rainfall intensity in this area. Therefore, saturation overland flow may not be dominant but subsurface flow must play important roles in stormflow generation. Although the Ks values at RS (riser bank) were similar to those in site F, those at terrace bench in site R were small. Percolation might be deflected laterally at these depths to produce subsurface stormflow. Moreover, saturation overland flow is possible during storms because of the shallow impeding layer. In fact, overland flow and surface detention were observed at the terrace bench in site R during storms (Figure 8).

Figure 8 Overland flow at the terrace bench in the rubber plantation during a heavy storm

The soils at site F are deep with high permeability and large porosity. These lead to a large water retention capacity of the soils, thus generating less stormflow and high base flow production. In contrast, the soils on the terrace bench at site R have low permeability, small porosity and shallow depth. All of these contribute to larger stormflow and smaller water retention capacity. These findings enable us to understand the difference in function of water conservation between tropical rain forest and rubber plantation sites.

The magnitude of change in soil physical properties caused by forest clearance depends on the harvesting practices, such as burn-soil tillage combination and hand-felling (Dias & Nortcliff 1985, Alegre *et al.* 1986, Chauvel *et al.* 1991). We need future research to reduce the alteration of soil physical properties by harvesting practices (Kamaruzaman 1996). If rubber plantation is stopped and forest is replanted at the same place, soil bulk density decreases and permeability and porosity of soils increase because of root activity (Allen 1985) and supply of organic matter (Malmer *et al.* 1998). However, Kamaruzaman (1996) showed that soils under the skid trail would require long time (19 years) to recover from soil compaction. Therefore, the soils in rubber plantation, especially on terrace bench, take a longer period to recover to forested soils.

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