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Ultisols under Secondary Mixed Dipterocarp Forest in Brunei and Their Nutritional Characteristics

By

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Summary : Ultisols under a lowland dipterocarp forest in a hilly area of Brunei were classified by soil color and mottles which represented hydro-catena, and the physical and chemical characteristics examined. The soil of this area was mainly Typic Paleudults (or Hapludults). The hue of the soil color was 10YR (Y type) in most areas, but was often 7.5YR − 5YR (R type) on crestslope. The grayish and reddish mottles were abundant in the deeper (>50 cm) Bt horizon on the crestslope and upper side slope (D subtype), but the mottles were found below the E or A horizon on the footslope and head hollow (W subtype). Position of the mottles were intermediate on the lower side slope (M type). Surface soils were eroded in some area of the M subtype (Er subtype). Strongly gley soils (G type) were found along stream lines. RD, YD, YM and YW type soils were distributed in the site. Clay content was less than 36% throughout the horizons. Dry bulk density, fine pore, water permeability and clay content increased with depth. Soil pH of the A horizon was 4.5 on average. Mineralized nitrogen was correlated with total N, and nitrification activity was slight. Concentration of exchangeable cations were low and organic matter was accumulated in the A horizon. Exchangeable Mg, K and total N were stored in the surface horizon in RD and YD soils. Ca and Na were stored in the deeper horizons in all soil types. Nutrient storage in soils under secondary forest was not lower than that under natural forests.

1 Introduction

Exploited tropical rain forests have become wide spread and developed into low quality secondary forests. Enrichment of the secondary forests is an urgent task. In order to re-establish high quality forest, forest management should be planned with reference to the structure and conditions of natural forest. Vegetational distribution in lowland mixed dipterocarp forests in Brunei has been connected to soil properties (ASHTON, 1964; AUSTIN *et al.*, 1972). Therefore, soil surveys and analysis of soil properties are helpful for suitable forest management and ecological studies.

Our objectives in this study were: 1) to survey and classify soils under a secondary forest in a hilly area of Brunei, 2) to determine physical and chemical characteristics of the soils, and 3) to evaluate the nutritional condition of the soils.

TAKAHASHI (1989), the primary author of this paper, tentatively classified the soils around this area and made a soil map by field survey. Here we revise soil classification and soil maps after a further field survey and detailed laboratory soil analysis.

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2 Materials and methods

2.1 Study site

The study area is located in a secondary forest adjacent to and north of Compartments 7 and 8 in the Andulau Forest Reserve, Brunei. Elevations are around 50m. The area is underlaid by tertiary sedimentary rocks of the Liang formation which comprises sand and sandy clay (WILFORD, 1961). Annual mean rainfall, humidity and air temperature are about 3 000mm, 80% and 27℃, respectively. This area underwent selective logging about 35 years ago is now a secondary forest. The vegetation type is lowland mixed dipterocarp forest. ASHTON (1964) reported on the natural vegetation and soil properties of Compartment 7 and 8 in the Andulau Forest Reserve. NIIYAMA *et al.* (1994), OCHIAI *et al.* (1994), and TANOUCHI *et al.* (1994) reported on the vegetational status of this site in this bulletin.

2.2 Soil survey and classification

We set up 10m×20m quadrats over the survey area using a compass and made a topographical map prior to the soil survey. The location of the surveyed profiles in the map area is shown in Fig. 1. An additional soil survey was made around the map area. Surface soils were sampled and described along eight slope lines. The soil profiles were described according to Keys to Soil Taxonomy (SOIL SURVEY STAFF, 1990) excepting the organic layers. The organic layers were separated into L, F and H layers. We classified the soils by soil color and mottles. The methods of classification this area was modified from the Japanese Forest Soil Survey Manual (FOREST SOIL DIVISION, 1976). This method lays emphasis on hydrocatena, that is, topographical variation of soil morphology and properties related to water conditions.

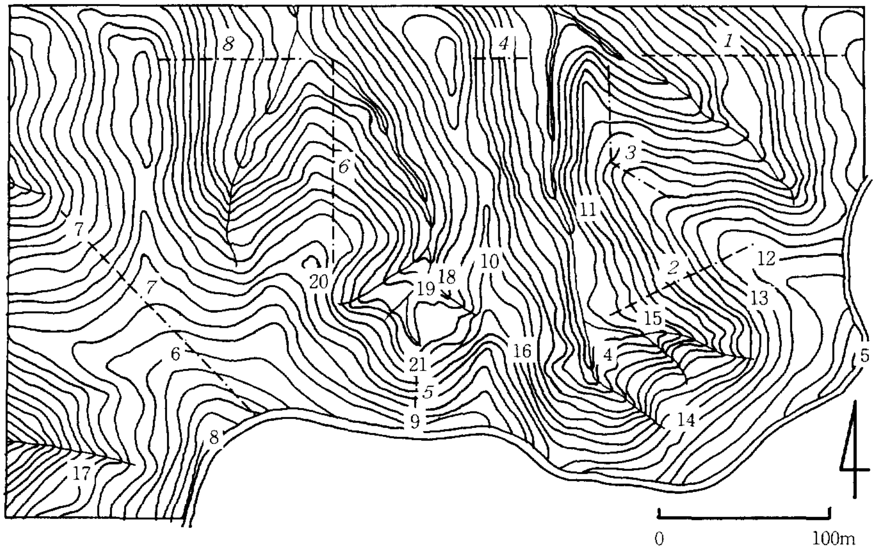

Fig. 1. Location of surveyed pits (No.4-21) and lines (No.*1*-*8*) of soil profiles.

2.3 Analytical methods

Soil samples were air dried and passed through a 2mm sieve. Soil pH was determined in 1:2.5 soil: water and 1:2.5 soil: 1M KCl suspension. Cation exchange capacity (CEC) and exchangeable cations were measured using 1M ammonium acetate at pH 7.0 in accordance with PEECH's method (1947). Exchangeable cations were determined by atomic absorbance spectrometry (AAS) for Ca and Mg and by flame emission for Na and K. Exchangeable aluminum was extracted by 1M KCl and determined by one-drop AAS (UCHIDA *et al.*, 1978). Total carbon and nitrogen were determined on combustion by automatic CN-corder (Yanagimoto Ltd.). Available nitrogen was estimated by incubation of filed moist soils (<2mm) for 14 days at 30℃ and the determination of mineral nitrogen (BREMNER, 1965). Incubation was done by duplicate and expressed as an average. Particle size distributions were determined by the sedimentation method using an NaOH solution as a disperser after hot H_2O_2 treatment. Three phase analysis and saturate water permeability were determined using a $100cm^2 \times 4cm$ cylinder (MASHIMO, 1960) and calculated hydraulic conductivity. All data were expressed oven dry (105℃) base.

3 Results

3.1 Soil morphology and classification

Organic layers were composed of a thin L layer and a fragmented F layer. Average thickness of the organic layer was 2.4cm (Table 1). The dark colored A or AE horizon was 15cm depth on the average, and there was no clear relationship between the depth of the A and AE horizon, thickness of organic layers and topography. The texture of the A and E horizons were sandy. Little gravel (>2mm) was contained throughout the profiles, and most of the roots were distributed in the A and E horizons. When the F layer was thick, many roots were found in the F layer as well. In argillic horizons (Bt horizons), clay cutan was recognized around coarse subangular or angular blocky structures, and soil texture became loamy or clayey. The clay cutan were more obvious in the deeper Bt horizons. The Bt horizons continued to at least 100cm in depth. Paralithic contact was observed around 200cm in a profile near the study site. As we did not confirm the lower boundary of the Bt horizon at every profile, we could not determine whether the soils are classified as Paleudults or Hapludults. Another diagnostic features of the profiles were ambiguous in suborder level. The soils in this area were classified as Typic Paleudults or Hapludults.

The soils were distributed according to micro-topography (Fig. 2). The classification of micro-topography followed TAMURA (1981). The color of the Bt horizon was yellowish (10YR) in most areas (yellow, Y-type). On the crestslope, especially on the narrow ridge, the soil color of Bt horizons was often reddish, 7.5YR - 5YR (red, R-type). Some of the RD soil had iron nodules in the deeper Bt horizons. OHTA and EFFENDI (1992a) also observed that the soil color of 10YR in the Bt horizons was sometimes redder on crestslopes in East Kalimantan, Indonesia and suggested that soil moisture conditions influenced soil color.

Grayish and reddish iron mottles were mostly found in Bt horizons, but the area of mottles was at most around 30%. The depth where the mottles became abundant was usually below about 50cm on the crestslope and upper side slope (dry, D-subtype). On the footslope and head hollow, the mottles, which were larger, have more grayish with diffuse boundaries, were found all over the E and Bt horizons and sometimes in the A horizon, too (wet, W-subtype). The depth of the mottles on

Table 1. Particle size distribution of selected soils.

Profile No. Soil type	Horizon	Thickness of horizons (cm)	Particle size distribution(%)			
			Coarse sand 2-0.2	Fine sand 0.2-0.02	Silt 0.02-0.002	Clay 0.002-(mm)
5	A	4	35.0	35.8	14.3	14.8
RD	EA	10	33.3	34.0	16.2	16.6
	Bt1	30	32.8	31.9	16.4	19.0
	Bt2	60	26.5	34.2	17.7	21.6
	Bt3	100+	25.6	26.4	16.2	31.8
8	A	7	46.1	33.7	9.3	10.8
YD	E	17	44.4	36.3	9.3	10.1
	Bt1	50	38.4	33.1	9.9	18.6
	Bt2	70	44.7	28.7	11.8	14.8
	Bt3	100+	37.8	27.3	9.9	25.1
16	A	5	23.9	34.8	16.9	24.4
YM	E	15	26.0	33.1	19.5	21.4
	Bt	60	19.2	26.7	28.1	26.0
	Btg	100+	16.6	24.7	23.2	35.6
4	A	5	35.1	38.0	11.1	15.8
YW	E	10	35.0	35.3	12.6	17.1
	Btg2	65	26.1	34.5	15.3	24.1
	Btg1	100+	24.3	26.1	17.0	32.6
19	A	6	47.1	34.6	4.4	14.0
G	Ag	13	61.1	23.5	4.3	11.1
	Bg1	28	58.6	26.5	3.9	10.9
	Bg2	45+	56.2	29.6	5.1	9.2

the lower side slope was intermediate (moist, M-subtype). Mottling formations of the A and E horizons characterized coarse texture Ultisols (OHTA and EFFENDI, 1992a). This suggests that the mottling formation, which is reflected by hydro-catena, is a good indicator of surface soil moisture conditions for the coarse texture area. The A horizons were often eroded on the head hollow and lower side slopes (eroded, Er-type). Bottomland along the channelway had water-saturated gley horizons (gley, G-type). The area of E and G type soils was small. The Appendix shows detailed descriptions of surveyed soil profiles.

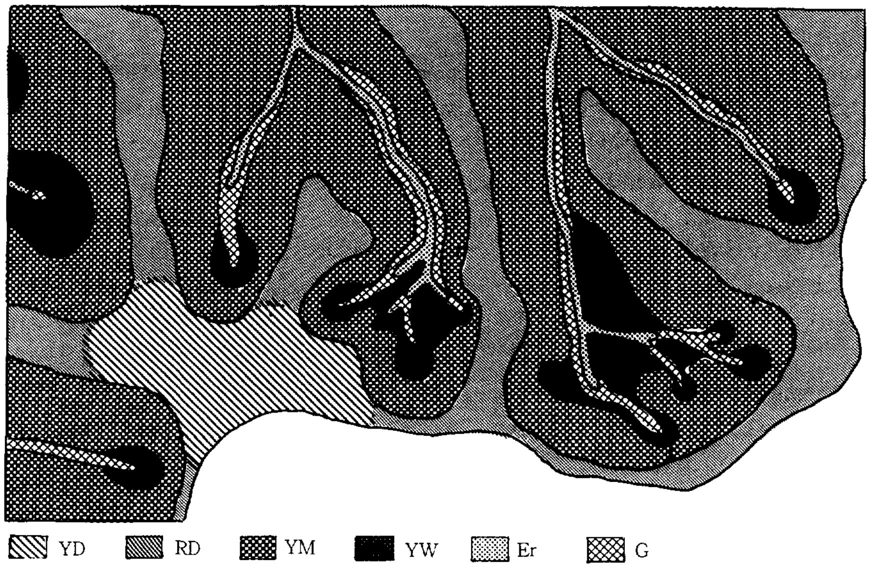

Fig. 2. Soil map of the study area.

3.2 Physical properties.

Clay content was relatively low in this area, 19% on average in the A and AE horizons (Table 2). Sand content was high in the Bt horizons, and clay content was less than 36% even in the Bt horizons (Table 1). Water permeability abruptly decreased below the upper Bt horizon (Table 3). Saturated hydraulic conductivity was 10^{-2}cm·s^{-1} in the A horizon, and 10^{-4}cm·s^{-1} in the Bt horizons. Solid phase was 30-39% in the A horizon, 48-57% in the Bt horizons. Dry bulk density was 0.81-1.04 Mg m^{-3} in the A horizon, and 1.31-1.61 Mg m^{-3} in the Bt horizons. Liquid phase of field condition, fine pore, dry bulk density and clay content increased with depth. Coarse pore, hydraulic conductivity and sand content was decreased with depth. OHTA and EFFENDI (1992a) showed that physical properties of Ultisols were controlled by texture and depth. Our results confirmed this tendency.

3.3 Chemical properties

Soil pH of the A horizon was around 4.5 by H_2O and 3.0-3.9 by 1M KCl with small variation (Table 2). Soil pH increased with depth reaching 4.9-5.3 in the Bt horizons (Table 4). The cation exchange capacity of the fine earth was less than 29cmol(+)kg^{-1}. CEC was highest in the A horizon and lowest in the E or upper Bt horizon. CEC was closely correlated with carbon and clay content (Fig. 3). CEC of clay in the Bt horizons ranged from 20 to 41cmol(+)kg^{-1}. All exchangeable cations were low concentrations and base saturation was less than 16% in all profiles. Exchangeable cations accumulated in the A horizon. Magnesium concentrations were often higher than Ca. Potassium accumulated in the A horizon in RD and YD soils, but the Bt horizon of YM and YW soils contained relatively higher K concentrations. Exchangeable aluminum increased with depth, which correlated with clay content (Fig.4). ECEC (exchangeable cations plus exchangeable aluminum) was highest

Table 2. Some characteristics of surface soils.

Sampling					Particle size				Thickness of	
Line	Point				Coarse	Fine			Forest	A and
	EW	NS			sand	sand	Silt	Clay	floor	AE horizon
			pH(H_2O)	pH(KCl)	%				cm	cm
1	2	N17	4.29	3.81	28.0	36.7	18.9	16.3	3	14
	4	N17	4.47	3.93	30.6	35.8	17.9	15.7	3	12
	6	N17	4.82	4.27	43.3	17.7	22.2	16.7	2	14
	8	N17	4.57	4.00	21.5	36.6	18.0	24.0	2	15
	10	N17	4.56	3.99	36.4	33.8	13.9	15.9	2	13
	12	N17	4.71	4.04	31.7	20.9	21.6	25.8	3	14
	14	N17	4.37	3.90	49.2	15.8	23.2	11.8	3.5	15
2	8	N6	4.45	3.83	41.5	30.4	15.8	12.3	2	15
	10	N5	4.43	3.84	26.6	40.2	17.9	15.3	4	16
	12	N4	4.39	3.80	28.6	33.8	15.0	22.5	3	16
	14	N3	4.75	4.11	43.6	28.9	13.1	14.5	4	14
	16	N2	4.48	3.82	n.d.	n.d.	n.d.	n.d.	3	14
3	12	N9	4.39	3.79	32.2	26.0	18.1	23.6	3	14
	14	N10	4.51	3.86	9.4	23.7	27.4	39.5	3	16
	16	N11	4.41	3.70	n.d.	n.d.	n.d.	n.d.	3	15
	16	N13	4.13	3.56	31.8	29.1	15.9	23.1	2	14
	16	N15	4.28	3.75	37.2	34.4	11.9	16.5	4	13
	16	N17	4.37	3.76	25.0	43.1	12.7	19.1	4	15
4	24	N17	4.28	3.72	23.5	27.5	29.2	19.8	3	16
	22	N17	4.34	3.86	45.9	22.6	10.4	21.1	5	13
	20	N17	4.42	3.91	52.9	24.8	3.8	18.5	3	16
5	26	S4	4.34	3.70	35.4	34.9	13.0	16.7	2	17
	26	S2	4.39	3.69	27.2	32.4	18.2	22.3	1.5	19
	26	0	4.50	3.84	28.8	32.5	17.0	21.7	0.5	19
6	32	N5	4.76	4.01	39.1	28.8	13.9	18.2	1.5	18
	32	N7	4.37	3.65	39.7	33.7	13.8	12.8	0.5	13
	32	N9	4.46	3.78	39.0	29.9	14.0	17.1	2.5	16
	32	N11	4.41	3.87	29.6	25.9	21.2	23.3	0.5	17
	32	N13	4.46	3.95	45.5	27.5	11.2	15.8	1.5	20
	32	N15	4.31	3.86	47.8	23.2	12.4	16.6	1.5	17
	32	N17	4.21	3.72	30.8	24.1	20.1	25.0	2	20
	34	N17	4.39	3.88	46.0	27.6	11.7	14.7	1.2	20
7	36	S4	4.18	3.74	39.1	41.1	9.0	10.8	4	7
	38	S2	4.65	3.98	36.0	43.7	9.5	10.9	2	11
	40	0	4.53	3.84	43.0	33.4	11.7	11.8	2	7
	42	N2	4.36	3.68	n.d.	n.d.	n.d.	n.d.	2.5	8
	44	N4	4.74	4.03	n.d.	n.d.	n.d.	n.d.	1.5	14
	46	N6	4.51	3.86	41.6	24.5	16.1	17.9	5	16
	48	N8	4.56	3.80	36.9	26.5	16.5	20.1	0.5	16

Table 2. (continued.)

Sampling					Particle size				Thickness of	
Line	Point				Coarse	Fine			Forest	A and
	EW	NS			sand	sand	Silt	Clay	floor	AE horizon
			$pH(H_2O)$	pH(KCl)	%				cm	cm
8	36	N17	4.47	3.94	46.5	22.5	14.1	16.8	1	18
	38	N17	4.67	4.00	40.8	22.1	16.7	20.5	0.5	17
	40	N17	4.45	3.82	41.5	22.2	18.2	18.1	1.3	20
	42	N17	4.53	3.81	30.8	33.8	19.1	16.3	1.2	19
		Mean	4.46	3.85	36.0	29.5	16.0	18.5	2.4	15.1
		SD	0.15	0.13	8.8	6.7	4.9	5.2	1.2	3.1

n.d. means "not determined".

in the deepest Bt horizon because of the increase of exchangeable Al, but less than 7cmol(+)kg^{-1}. Carbon and nitrogen concentrations were high in the A horizon. C/N ratio was 17-24 in the A and E horizon and decreased with depth to 6-15 in the Bt horizons. C/N ratio of YD and RD soil was higher than that of YM and YW soils, which suggests decomposition of soil organic matter was slower in RD and YD than YM and YW.

3.4 Available nitrogen

The amount of mineral nitrogen was 5.4 - 28.7mg kg^{-1} in the A horizon and 3.5 - 10.2mg kg^{-1} in the E horizon (Table 5). Ammonium was dominant in mineralized nitrogen. Nitrate-N was less than 1.8mg kg^{-1}. After incubation, the amount of amount of mineralized nitrogen was 10.5 - 43.2mg kg^{-1} in the A horizon, 8.6 - 27.4mg kg^{-1} in the E horizon. The relationship between the amount of mineralized nitrogen and soil type was not clear. Mineralized nitrogen correlated with total nitrogen (Fig. 5). Nitrate formation by incubation was 0-36% in mineralized nitrogen. Although LAMB (1980) reported active nitrate formation in a secondary rain forest in Australia, OHTA and EFFENDI (1992b) also reported 0-35% of nitrification in Ultisols in East Kalimantan, Indonesia.

3.5 Nutrient storage and distribution in the soils

Storage of exchangeable cations, carbon and nitrogen in the profiles as far as 100cm depth was examined (Table 6). As the average depth of humus rich A and AE horizons was 15cm, accumulation of these elements in the surface (0-15cm) soil was calculated. Apart from RD type, the concentrations and storage of exchangeable Mg were high in the soils of this area. Storage of exchangeable K was smaller in RD and YD than YM and YW. Carbon accumulated in the surface soil. Nitrogen also accumulated in the surface, but was not higher than carbon because of a low C/N ratio in the subsurface horizon. Storage of exchangeable Na and Ca in the profile was rich in subsurface horizons. Magnesium, K and total N were accumulated in the surface soil in YD and especially in RD.

Table 3. Physical properties of the selected soils.

Profile No. (Soil type)	Horizon	Water permeabilty	Hydraulic conductivity	Solid phase: Fine[1] earth	Solid phase: Gravel	Solid phase: Root	Liquid phase: Field	Liquid phase: Max	Pore: fine[2]	Pore: coarse[3]	Dry bulk density	Specific density of fine earth[1]
		$ml \cdot min^{-1}$	$cm \cdot s^{-1}$	%			%		%		$Mg \cdot m^{-3}$	
5	A	182	2.4×10^{2}	32.9	0.0	1.7	4.7	27.4	6.3	59.2	0.85	2.56
RD	EA	21	2.8×10^{3}	44.0	0.0	8.4	14.9	33.3	15.1	32.5	1.23	2.73
	Bt1	4	5.3×10^{4}	56.4	0.0	0.2	26.1	36.0	22.5	20.9	1.54	2.74
	Bt2	1	1.3×10^{4}	57.1	0.1	0.2	33.3	37.8	30.8	11.9	1.61	2.82
16	A	175	2.3×10^{2}	30.6	0.0	5.4	15.7	31.5	19.2	44.8	0.84	2.65
YM	E	106	1.4×10^{2}	40.9	0.0	3.2	20.5	40.7	23.8	32.1	1.11	2.69
	Bt	22	2.9×10^{3}	47.7	0.1	0.5	24.4	38.1	26.9	24.9	1.32	2.75
	Btg	3	4.0×10^{4}	55.9	0.1	0.2	30.2	40.1	29.5	14.2	1.56	2.78
4	A	98	1.3×10^{2}	31.8	0.0	4.0	28.3	45.0	22.3	41.9	0.87	2.67
YW	E	90	1.2×10^{2}	42.6	0.0	0.7	34.6	44.5	23.1	33.5	1.19	2.79
	Btg1	6	8.0×10^{4}	53.9	0.1	0.1	34.5	39.1	27.5	18.4	1.50	2.78
	Btg2	2	2.7×10^{4}	53.6	0.3	0.1	38.1	42.6	32.9	13.1	1.50	2.78
19	A	140	1.9×10^{2}	38.5	0.1	3.9	26.4	44.1	19.0	38.5	1.07	2.72
G	Bg1	5	6.7×10^{4}	42.1	0.0	9.7	47.7	51.2	16.8	31.3	1.18	2.70

1) $<$2mm, 2) $<$-49kPa , 3) $>$-49kPa

Table 4. Chemical properties of selected soils.

Profile No. (Soil type)	Horizon	C.E.C.	Exchangeable cation Na	Exchangeable cation K	Exchangeable cation Ca	Exchangeable cation Mg	Sum of cations	Base Saturation	Exchangeable Aluminum	ECEC	Total Carbon	Total Nitrogen	C/N	pH H_2O	pH KCl
		cmol(+)kg^{-1}soil	cmol(+)kg^{-1}soil	cmol(+)kg^{-1}soil	cmol(+)kg^{-1}soil	cmol(+)kg^{-1}soil	cmol(+)kg^{-1}soil	%	cmol(+)kg^{-1} soil	cmol(+)kg^{-1} soil	%	%			
5	A	28.8	0.09	0.40	0.56	1.51	2.56	8.9	3.9	6.45	9.44	0.402	23.5	4.03	2.98
RD	EA	10.0	0.04	0.12	0.32	0.17	0.65	6.5	6.0	6.62	2.46	0.149	16.5	4.52	3.54
	Bt1	7.2	0.03	0.07	0.04	0.06	0.20	2.8	4.9	5.11	1.05	0.073	14.5	4.64	3.83
	Bt2	5.7	0.03	0.04	0.04	0.04	0.16	2.8	4.8	4.94	0.40	0.040	10.0	5.07	3.90
	Bt3	8.7	0.04	0.07	0.49	0.08	0.68	7.8	6.9	7.54	0.29	0.040	7.1	5.15	3.86
8	A	9.2	0.04	0.14	0.19	0.64	1.00	10.9	3.3	4.32	3.18	0.187	17.0	4.79	3.46
YD	E	6.2	0.02	0.07	0.05	0.28	0.42	6.8	3.7	4.15	1.46	0.100	14.6	4.73	3.75
	Bt1	6.1	0.02	0.07	0.33	0.29	0.71	11.7	3.2	3.95	0.99	0.057	17.3	5.30	4.12
	Bt2	3.8	0.03	0.03	0.26	0.30	0.62	16.3	1.6	2.23	0.39	0.029	13.2	5.53	4.37
	Bt3	6.2	0.03	0.06	0.05	0.20	0.33	5.3	4.9	5.24	0.25	0.033	7.7	5.18	3.92
16	A	12.5	0.04	0.26	0.23	0.76	1.29	10.4	4.1	5.35	4.54	0.249	18.2	4.93	3.64
YM	E	7.7	0.03	0.16	0.13	0.37	0.69	9.0	3.2	3.90	2.11	0.147	14.3	5.30	3.91
	Bt	7.4	0.03	0.12	0.08	0.35	0.58	7.9	5.1	5.67	0.61	0.069	8.9	5.20	3.98
	Btg	8.2	0.03	0.16	0.19	0.25	0.63	7.6	6.6	7.22	0.39	0.061	6.4	5.28	3.94
4	A	9.5	0.04	0.24	0.26	0.61	1.15	12.2	2.7	3.86	2.95	0.200	14.8	5.16	3.81
YW	E	5.3	0.02	0.14	0.06	0.24	0.46	8.7	2.7	3.18	1.38	0.117	11.8	5.33	3.98
	Btg1	4.9	0.03	0.12	0.25	0.34	0.75	15.3	3.7	4.41	0.33	0.051	6.4	5.06	3.95
	Btg2	6.9	0.02	0.14	0.14	0.27	0.58	8.5	5.5	6.09	0.33	0.061	5.5	5.11	3.85

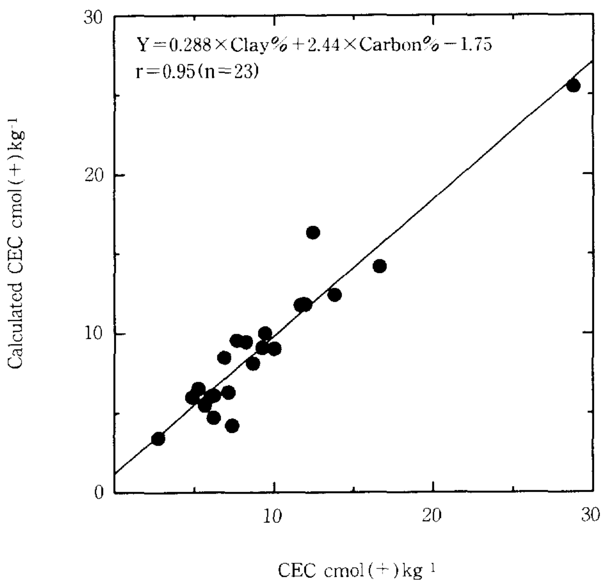

Fig. 3. The relationship between analyzed CEC and calculated CEC.

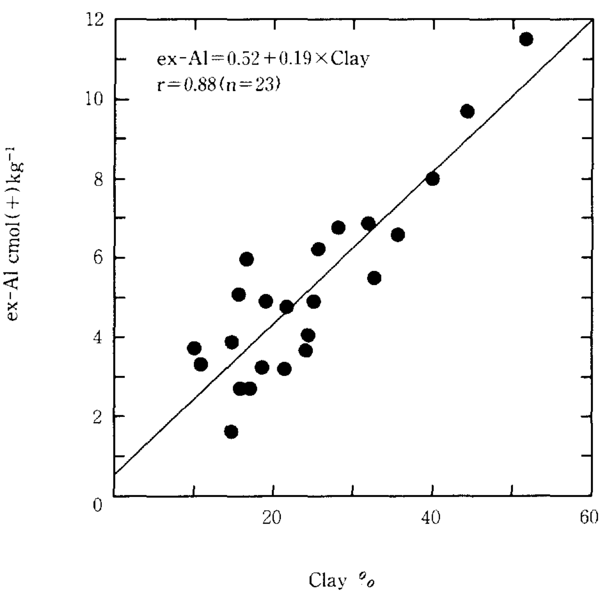

Fig. 4. The relationship between clay content and exchangeable Al.

Table 5. Mineralized nitrogen of the selected soils by 14 days incubation at 30℃.

Profile No.	Horizon	Water content (%)	Before incubation NH_4-N	Before incubation NO_3-N	After incubation NH_4-N	After incubation NO_3-N	Mineralized nitrogen NH_4-N	Mineralized nitrogen NO_3-N	Sum
			$mg \cdot kg^{-1}$						
4	A	49	27.5	1.2	59.1	5.6	31.6	4.4	36.0
YW	E	32	8.4	1.8	25.6	8.4	17.2	6.7	23.9
5	A	38	25.2	1.1	68.1	1.5	42.9	0.3	43.2
RD	EA	17	6.1	0.6	25.3	1.2	19.2	0.6	19.9
6	A	27	10.6	0.5	32.2	0.4	21.6	−0.1	21.5
YD									
7	A	33	5.7	0.9	16.9	1.1	11.2	0.3	11.5
YW	E	29	3.7	0.5	11.6	1.1	8.0	0.6	8.6
8	A	22	10.7	0.6	24.4	0.6	13.7	0.0	13.7
YD	E	19	7.4	0.3	16.7	0.4	9.2	0.1	9.3
16	A	29	15.3	0.7	40.9	2.3	25.6	1.6	27.2
YM	E	20	9.2	0.3	35.5	1.4	26.3	1.1	27.4
19	A	35	6.3	0.8	17.0	0.7	10.6	−0.1	10.5
G	Ag	39	3.9	0.9	13.2	0.8	9.3	−0.1	9.1
21	A	21	5.0	0.4	14.6	5.8	9.6	5.3	14.9
YD	E	19	2.9	0.6	12.1	2.6	9.2	2.0	11.2

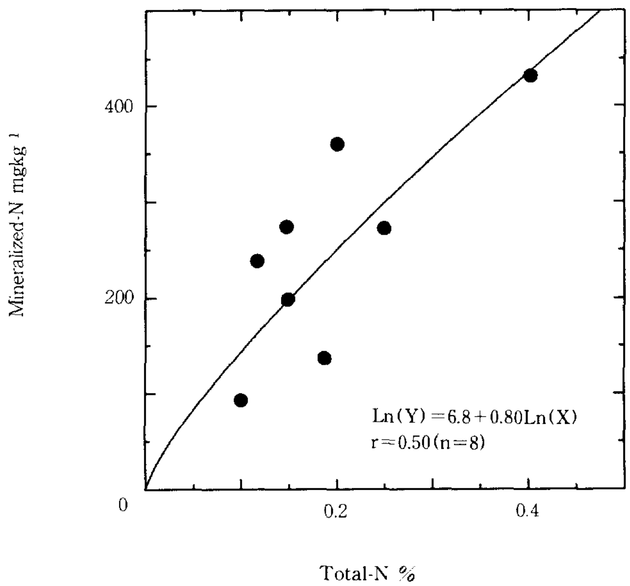

Fig. 5. The relationship between total nitrogen and mineralized nitrogen.

Table 6. Storage of exchangeable cations, total nitrogen and total carbon in the selected soils (0-100cm) and comparison among with data from tropical rain forests in Southeast Asia. Percentage of accumulation of surface (0-15cm) soils in parentheses.

Profile No. Soil type	Na	K	Ca	Mg	N	C	Reference and remarks	
	g m^{-2}					kg m^{-2}		
1	11.0	61.8	43.0	38.3	1 192	11.0		
RD	(15.1)	(19.0)	(19.9)	(28.5)	(25.5)	(39.5)		
5	12.3	39.4	76.3	17.8	847	10.9		
RD	(13.4)	(24.6)	(10.7)	(43.9)	(31.9)	(48.6)		
8	7.6	31.0	48.3	43.7	699	10.1		
YD	(10.7)	(18.3)	(6.8)	(17.1)	(27.2)	(30.5)		
16	9.5	77.3	38.2	52.5	1 051	10.2		
YM	(10.5)	(14.5)	(12.6)	(16.6)	(25.1)	(40.8)		
4	9.5	75.0	59.1	56.5	892	6.5		
YW	(12.5)	(14.2)	(11.3)	(14.2)	(21.6)	(35.7)		
mean	10.0	56.9	53.0	41.8	936	9.7		
	(12.4)	(18.1)	(12.2)	(24.1)	(26.2)	(39.0)		
Indonesia Kalimantan		35.3	5.2	9.5	717	8.67	n= 6, 0−70cm	KATAGIRI (1992)
Indonesia Kalimantan								
(Coarse soil)					782	7.34	n=10, 0−150cm	OHTA *et al.*(1992b)
(Medium soil)					1 210	7.64	n=11, 0−150cm	
(Fine soil)					1 500	8.96	n=10, 0−150cm	
(Red soil)					898	8.81	n= 4, 0−150cm	
Malaysia (Pasoh)		39.5	29.9	22.6	675	7.21	n= 7, 0−70cm	KATAGIRI (1992)
Malaysia (Sarawak)		39.5	51.0	57.3	513	5.49	n= 5, 0−70cm	KATAGIRI (1992)
Thailand (Khao Chong)	13.3	98.5	108.0	22.6	472	4.25	n= 3, 0−70cm	TSUTSUMI *et al.*(1967)

4 Discussion

Earlier studies by ASHTON (1964) showed that vegetational distribution of natural forests in Compartments 7 and 8, Andulau Forest Reserve, was related to topography and soil characteristics. AUSTIN *et al.* (1972) re-examined ASHTON's data by multivariate analysis and confirmed the relationship between them. The soil types we used were correlated with distribution and growth of tree and forest floor vegetation in this area (NIIYAMA *et al.*, 1994; OCHIAI *et al.*, 1994; TANOUCHI *et al.*, 1994). Although the morphological criteria of soil classification were simple, our classification seems to be useful for forestry and ecological study in area of coarse texture Ultisols.

Judging from the morphology, soil moisture condition in the A and E horizons, where most of the roots were distributed, differes among the soil types. However, physical properties examined showed a little variation. It is important to monitor water movement in the soil continuously in order to understand vegetational distribution and growth.

Nitrogen mineralization was in proportion to total nitrogen content (Fig.5). There is no clear relationship between soil type, C/N ratio and mineralization rate at this site, although the amount of data was limited. VITOUSEK and MATSON (1988) suggested that nitrogen mineralization in lowland tropical forests is rapid and sufficient for biological activities. PROCTOR *et al.* (1983b) reported that nitrogen turnover by litterfall is not low in mixed dipterocarp forests in Sarawak in spite of low nitrogen concentration in the soils. These studies suggest that nitrogen was not a limiting factor for vegetational distribution and growth in lowland tropical forests. On the other hand, delay of nitrification by incubation suggested a low nitrifier population (VITOUSEK and MATSON, 1985) or phosphorus deficiency in the soil (PURCHASE, 1974). As coarse texture soils in Brunei were reported to show serious phosphorus deficiency (BLACKBURN and BAKER, 1958), phosphorus may be an important factor in vegetational growth and distribution.

It is characteristic in the mixed dipterocarp forests of Sarawak and Brunei that Mg concentrations are higher than Ca (BLACKBURN and BAKER, 1958, PROCTOR *et al*, 1983a, KATAGIRI, 1992). Our results agree with this tendency, excepting those for RD soil. Exchangeable magnesium storage in RD soil was comparatively poor. In addition, exchangeable Mg, K and total nitrogen were relatively accumulated in the surface horizon in YD and RD soils. These nutritional distribution patterns may influence vegetational distribution. BAILLIE and ASHTON (1983) also reported that Mg was a high-ranking site factor for determing the vegetational distribution of mixed dipterocarp forests, although the reason was not clear.

Nutrient concentrations were low at this site. PROCTOR *et al.* (1983a) also reported most of the nutrients concentrations were low in mixed dipterocarp forests. However, nutrient storage in the tropical soils under natural forests was almost equal to or larger than those of temperate forests, because the bulk density of soils, especially in deeper horizons, was high (TSUTSUMI *et al.*, 1967). Therefore some nutrients were even rich in deeper horizons in the tropical soils (NYE and GREENLAND, 1960; OHTA and EFFENDI, 1992b; KATAGIRI, 1992). Although we did not examine natural forests, nutrient storage in the soils of this secondary forest did not seem to be low compared with the results of other natural mixed dipterocarp forests (Table 6).

Selective logging seriously damages the physical condition of surface soils by compaction and erosion (MALMER and GRIP, 1990), which results in unsuccessful regeneration and silviculture. Even if physical loss of nutrient by top soil erosion occured, the loss of nutrients from the logged area and the degradation of nutrient status would be small because of nutrient accumulation in the deeper horizons. Therefore, from the viewpoint of soil nutrient status, the enrichment of secondary forests in mixed dipterocarp forests by suitable forest management seems to be possible.

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ブルネイ混交フタバガキ二次林下のUltisolsの土壌分類とその養分環境

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摘　　要

ブルネイ丘陵地の低地混交フタバガキ二次林の土壌を分類し，その物理化学性を調べた。試験地の土壌は，Soil TaxonomyではTypic Paleudults (Typic Hapludults)と分類された。この土壌を土色と斑紋により細分した。土壌の色調は一般に10YR（Y型）であるが，狭い頂部斜面ではしばしば7.5−5YRを呈した（R型)。頂部及び上部谷壁斜面では灰色や赤色の鉄の斑紋がBt層（粘土集積層）下部（>50cm）に多く認められ（D亜型)，麓部及び谷頭凹地では暗灰色の斑紋がE層（溶脱層）以下またはA層以下全層位で認められた（W亜型)。下部谷壁斜面の斑紋の状態は中間的であった（M亜型)。M亜型の一部は表土が侵食され（Er型)，渓流沿いにグライ土壌（G型）が分布していた。RD，YD，YM，YW，Er及びGの土壌型が存在した。土壌の粘土含量は全層位を通じ36％以下で砂質であった。断面内の容積重，細孔隙，透水性，粘土含量は深さとともに増加した。A層のpHは平均4.5であった。窒素の無機化は全窒素量に比例した。硝化活性は低かった。交換性陽イオン濃度は低く，有機物はA層に集積した。RD及びYD土壌の交換性Mg，K及び全窒素の蓄積量は表層土壌に多かったが，交換性CaとNaは下層に多く蓄積していた。二次林の養分の蓄積量は天然林と変わらないと推定された。

1992年12月2日受理
(1)(2)(3)(4)　森林環境部
(5)　ブルネイ森林局

Appendix.

Descriptions of surveyed soil profiles

Remarks; Depth of horizons with wavy boundary minimum/maximum cm depth. Hardness min.-average - max. ($kgcm^{-2}$) by "Push Corn" penetrometer (Daiki co.), n=5.

Profile No.1

Soil type: RD, Location: outside of the map (near 0N20), on the ridge along the pass. Slope: 5 degree, Date: Feb. 22, 1988

L 1.5-1 cm;

F 1 cm; many roots

A 0-3 cm; brown 10YR 4/3.5; loam; strong fine angular blocky structure; dry; hardness 1.2-1.4-1.7; common medium and many fine roots; charcoal fragments; white mycelium.

E 3-10/15 cm; clear wavy boundary; dull yellowish brown 10YR 5/5; clay loam; fine angular blocky and fine blocky structure; hardness 6.3-13.1-24.5; moist; common fine and medium roots.

Bt1 10/15-40 cm; gradual wavy boundary; bright brown 7.5YR 5/5; clay; moderate coarse subangular blocky structure; continuous thin clay cutan; hardness 10.0-14.0-20.1; moist; few medium and fine roots.

Bt2 40-65 cm; clear smooth boundary; bright brown 7.5YR 5/6; clay; moderate coarse subangular blocky structure; continuous thick clay cutan; hardness 7.3-10.0-11.8; moist; common medium distinct clear red and yellow mottling; common very fine tubular pores; few medium and fine roots.

Bt3 65-100+ cm; clear smooth boundary; bright brown 5YR 5/8 ,red 2.5YR 5/8 and yellow 7.5YR 7/8 reticulate mottles (plinthite ?); clay; few angular weathered gravel of sandstone with iron accumulation; continuous thick clay cutan; hardness 5.4-8.3-11.8; moist; common very fine tubular pores; iron nodule; few fine roots.

Profile No.2

Soil type: YW, Location: outside of the map, bottom part of valley head (head hollow). Slope:5 degree, Date: March 5, 1988

F 2-0 cm;

A1 0-6/10 cm; dark brown 10YR 3/3; sandy loam; moderate medium subangular blocky structure; hardness 1.4-2.7-4.0; moist; coarse few roots, common medium and fine roots.

A2 6/10-16/20 cm; clear wavy boundary; brown 10YR 4/4; sandy loam; medium subangular blocky structure; hardness 0.3-0.7-1.9; moist; common medium and fine roots.

2Abg 16/20-23 cm; clear smooth boundary; brown 10YR 4/4; sandy loam; hardness 3.0-4.4-8.5; moist to wet; common medium and fine roots; many charcoal fragments

2EBbg 23-28/32 cm; abrupt wavy boundary; many dull yellow 2.5YR 6/4-2 mottled with reddish brown 2.5YR 4/8; clay; wet; common fine closed tubular pores; common medium and fine roots; charcoal fragments

2Bbtg 28/32-65 cm; clear smooth boundary; bright yellowish brown 10YR 6/8; clay; wet; hardness 3.5-5.6-7.3; continuous thin clay cutan; many medium distinct diffuse reddish and grayish mottles; few medium roots.

3Ab 65-74 cm; clear smooth boundary; yellowish brown 10YR 5/6; heavy clay; massive; wet; hardness 4.0-5.4-7.3; continuous moderately thick clay cutan; common distinct clear reddish mottles; few fine roots; charcoal fragments.

3Bbtg 74-100+ cm; bright yellowish brown 10YR 6/8; heavy clay; massive; wet; hardness 5.4-6.5-7.3; continuous moderately thick clay cutan; many distinct diffuse reddish and grayish mottles; few medium roots.

Profile No.3

Soil type: YD, Location: outside of the map, upper side slope. Slope:15 degree, Date: March 9, 1988

L 2/1-1 cm;

F 1-0 cm;

A1　0-4/6 cm; brown 10YR 4/4; sandy loam; strong fine and medium subangular blocky structure; hardness 0.8-2.2-4.7; moist to dry; common medium and many fine roots.

A2　4/6-11 cm; clear wavy boundary; dull yellowish brown 10YR 5/4; sandy loam; moderate medium subangular blocky structure; hardness 1.9-3.9-6.3mm; moist; common medium and fine roots.

E　11-19 cm; gradual smooth boundary; dull yellow orange 10YR 6/4; sandy loam; weak coarse subangular blocky structure; moist; hardness 0.5-2.7-4.0; common medium and fine roots

Bt1　19-48 cm; gradual smooth boundary; bright yellowish brown 10YR 6/6; sandy clay loam; weak coarse subangular blocky structure; hardness 3.0-4.8-6.3; moist; continuous thin clay cutan; few medium and common fine roots.

Bt2　48-78 cm; diffuse smooth boundary; orange 7.5YR 6/6; clay loam; hardness 4.7-5.8-8.5; moderately wet; continuous moderately thick clay cutan; few diffuse reddish mottles; few medium and fine roots.

Bt3　78-110+ cm; diffuse smooth boundary; orange 7.5YR 6/8; clay loam; hardness 6.3-7.5-10.0; moderately wet; continuous thick clay cutan; common reddish and yellowish mottles; few fine roots.

Profile No.4

Soil type: YW, Location: 16NS0, Slope:5 degree, Date:March 30, 1988

L　1/2-1 cm;

F　1-0 cm;

A　0-4/6m; dark brown 10YR 3/4; sandy loam; crumb structure; hardness 0.4-0.7-1.7; moist; common medium roots and many fine roots.

E　4/6-10 cm; gradual wavy boundary; dull yellowish brown 10YR 5/4; sandy loam; weak coarse subangular blocky structure; hardness 1.0-1.5-2.6; moist to wet; few grayish diffuse mottles; common fine roots.

Btg1　10-65 cm; clear wavy boundary; bright yellowish brown 10YR 6/8; clay; massive; moderate very coarse prismatic structure; hardness 3.0-3.5-4.7; wet; common reddish and grayish diffuse mottles; continuous moderately thick clay cutan; few fine roots.

Btg2　65-120+ cm; gradual smooth boundary; bright yellowish brown 10YR 6/8 mottled with many gray 5Y7/2 and red 10YR 7/8; clay; moderate very coarse prismatic structure; hardness 3.0-3.5-4.7; continuous thick clay cutan; few fine roots

Profile No.5

Soil type: RD, Location:1-NS0, Slope:10 degree, Date: April 9, 1988

L　4/3-3/2 cm;

F　2/3-0 cm; many roots with fungal hyphae.

A　0-3/5 cm; 7.5YR 3/3; sandy loam; strong granular and strong medium angular blocky structure; dry; hardness 0.5-1.0-2.6; white mycelium; many fine roots.

E　3/5-10/13 cm; clear wavy boundary; dull brown to dull yellowish brown 8.75YR 5/4; sandy loam; strong medium angular blocky and strong coarse subangular blocky structure; moist to dry; hardness 4.0-5.0-5.4; few large, common medium and common fine roots.

EB　10/13-30 cm; gradual wavy boundary; bright brown 7.5YR 5/6; sandy loam; moderate coarse subangular blocky structure; moist; hardness 2.6-4.2-6.3; common medium and fine roots.

Bt1　30-60 cm; gradual smooth boundary; orange 5YR 6/6; sandy loam to clay loam; weak coarse subangular blocky structure; moist; hardness 4.7-6.7-10.0; continuous moderately thick clay cutan; few medium and fine roots.

Bt2　60-100+ cm; gradual smooth boundary; orange 5YR 6/8; clay; very coarse prismatic structure; moist; hardness 5.4-7.3-10.0; continuous thick clay cutan; common grayish 2.5YR 6/6 clear mottles; few fine roots.

Profile No.6

Soil type: YD, Location:41-NS0, Slope:5 degree, Date: April 11, 1988

L　3/2-2 cm;

F　2-0 cm;

AE 0-13/18 cm; dull yellowish brown 10YR 4/3; sandy loam; strong medium angular blocky, medium subangular blocky and fine granular structure; dry to moist; hardness 0.3-0.6-1.0; few large, many medium and fine roots.

Bt1 13/18-40 cm; gradual wavy boundary; yellowish brown 10YR 5/8; sandy loam; medium to coarse subangular blocky and medium moderate brown granular structure; moist; hardness 2.6-4.3-5.4; continuous thin clay cutan; common fine to medium tubular pore; common medium and fine roots.

Bt2 40-70 cm; diffuse smooth boundary; bright yellowish brown 10YR 6/6; sandy loam; weak coarse subangular blocky structure; moist; hardness 1.7-2.9-4.7; continuous moderately thick clay cutan; few medium and fine roots.

Bt3 70-110+ cm; gradual smooth boundary; bright yellowish brown 10YR 7/6; clay loam; weak very coarse prismatic structure; moist; hardness 1.9-4.8-8.5; continuous thick clay cutan; common reddish 7.5YR 6/8 and grayish 2.5YR 7/3 mottles; few fine roots.

Profile No.7

Soil type:YW, Location: 47N7, Slope:15 degree, Date: April 11, 1988

F 5/3-2 cm;

A 0-12/16 cm; brown 10YR 4/4; sandy loam; strong medium subangular blocky and moderate medium angular blocky structure; dry to moist; hardness 0.5-1.22-2.2; common medium and fine roots.

E 12/16-34/38 cm; clear wavy boundary; dull yellowish brown 10YR 5/4; sandy loam to clay loam; moderate medium subangular blocky, medium angular blocky and moderate medium brown granular structure; moist; hardness 1.7-4.0-7.3; few medium and fine roots.

Btg1 34/38-75 cm; gradual wavy boundary; yellowish brown 10YR 5/8; clay; moderate coarse subangular blocky structure; moderate wet; hardness 4.7-5.6-6.3; continuous moderately thick clay cutan; common distinct clear reddish and grayish mottles; few medium and fine roots.

Btg2 75-100+ cm; diffuse smooth boundary; bright yellowish brown 10YR 6/8; coarse prismatic structure; clay; wet; hardness 4.7-6.0-7.2; continuous thick clay cutan; many distinct clear reddish and grayish mottles.

Profile No.8

Soil type:YD, Location: 39S5, Slope:5 degree, Date: April 13, 1988

L 3-2 cm;

F 2-0 cm;

A 0-5/9 cm; brown 10YR 4/4; sandy loam; strong medium subangular blocky, strong medium angular blocky and moderate medium granular structure; dry to moist; hardness 0.8-0.9-1.4; many fine roots and common medium roots.

EA 5/9-13/20 cm; clear wavy boundary; dull yellowish brown 10YR 5/4; sandy loam; moderate medium subangular blocky and moderate medium granular structure; moist to dry; hardness 0.5-1.5-5.4; common medium and fine roots.

Bt1 13/20- 50 cm; gradual wavy boundary; yellowish brown 10YR 5/6; sandy loam; weak coarse subangular blocky and medium brown granular structure; moist; moist; hardness 1.0-2.3-6.3; few distinct reddish diffuse mottles; few medium and fine roots.

Bt2 50-70 cm; diffuse smooth boundary; bright yellowish brown 10YR 7/6; sandy loam; moist; hardness 1.9-3.7-7.3; continuous moderate thick clay cutan; few medium and fine roots.

Bt3 70-100+ cm; diffuse smooth boundary; bright yellowish brown 10YR 6/8; clay; hardness 3.5-3.7-5.4; moist; few fine roots.

Profile No.9

Soil type:RD, Location: 27S4, Slope: 15 degree, Date: April 14, 1988

F 1/0-0 cm;

AE 0-14 cm; dull yellowish brown 10YR 5/4; clay to clay loam; angular and subangular structure; dry; hardness 3.5-5.9-11.8; many fine roots and common medium roots.

Bt1 14-30 cm; gradual smooth boundary; yellowish brown 10YR 5/6; clay to clay loam; subangular blocky and brown granular structure; dry to moist; hardness 4.5-6.3-7.5; continuous moderately thick clay cutan; common medium roots and few fine roots.

Bt2 30-48 cm; gradual smooth boundary; bright brown 7.5YR 5/8; clay; weak subangular blocky structure; moist; hardness 4.7-6.7-8.5; continuous moderately thick clay cutan; common reddish mottles; few gravel (2-5 cm) of weathered sandstone; few fine roots.

Bt3 48-65+ cm; gradual smooth boundary; orange 7.5YR 6/6; clay; weak subangular blocky structure; moist; hardness 4.0-5.8-6.3; continuous thick clay cutan; common reddish mottles; very few gravel of weathered sandstone; few medium and fine roots.

Profile No.10

Soil type:RD, Location: 23N5, Slope: 2 degree, Date: April 14, 1988, Remark: logging tractor trail

F 2-0 cm;

A 0-3/6 cm; dull brown 7.5YR 5/3; clay loam; angular structure; dry; hardness 1.7-2.1-3.5; few medium and fine roots.

E 3/6-18 cm; gradual smooth boundary; bright brown 7.5YR 5/8; clay; dry to moist; hardness 7.3-9.2-14.0; brown humus mottles; few medium and fine roots.

Btg 18-44 cm; gradual smooth boundary; orange 7.5YR 6/7; clay; moist to dry; hardness 8.5-12.6-16.7; many grayish 10YR 7/2 coarse distinct mottles; few medium and fine roots.

Bt 44-60+ cm; gradual smooth boundary; orange 5YR 6/8; clay; moist; hardness 3.0-7.5-11.8; weak very coarse prismatic structure; continuous thick clay cutan; few fine roots.

Profile No.11

Soil type:YM, Location:17N8, Slope: 30 degree, Date:April 14, 1988

F 1-0 cm;

A 0-6 cm; grayish yellow brown 10YR 4/2; clay loam; subangular blocky structure; moist; hardness 1.2-1.3-1.7; many fine and common medium roots

E 6-16/24 cm; gradual smooth boundary; dull brown 7.5YR 5/4; clay loam to sandy loam; subangular blocky structure; moist; hardness 1.9-2.9-3.5; common medium and fine roots.

Bt 16/24-30/40 cm; diffuse wavy boundary; yellow orange 7.5YR 7/8; clay; weak subangular blocky structure; moist; hardness 2.6-3.5-5.4; continuous moderately thick clay cutan; brown humus mottles; common medium and fine roots.

Btg 30/40-60+ cm; diffuse irregular boundary; yellow orange 7.5YR 7/8; clay; moist; hardness 2.6-3.7-6.3; continuous thick clay cutan; many grayish mottles; few fine roots.

Profile No.12

Soil type: RD, Location: 7N5, Slope: 2 degree, Date: April 15, 1988

L 3/4-3 cm;

F 3-0 cm;

A 0-4 cm; brown 7.5YR 4/4; sandy loam; strong subangular blocky and angular block structures; moist to dry; hardness 0.8-1.0-1.4; many medium and fine roots.

E 4-16 cm; clear smooth boundary; bright brown 7.5YR 5/6; sandy loam to clay loam; subangular blocky structure; moist; hardness 3.0-4.5-10.0; common medium and fine roots.

Bt1 16-30 cm; gradual smooth boundary; orange 7.5YR 6/6; clay to clay loam; weak subangular blocky structure; moist; hardness 5.4-6.3-7.3; common medium and fine roots.

Bt2 30-55 cm; gradual smooth boundary; orange to yellowish orange 6.25YR 7/8; clay loam to clay; moist; hardness 3.5-3.5-3.5; continuous thick clay cutan; few fine roots.

Profile No.13

Soil type: RD/YM, Location: 7N3, Slope: 15 degree, Date: April 15, 1988

F 2/3-0 cm;

A1 0-2/4 cm; dark brown 10YR 3/4; sandy loam;moderate medium angular blocky structure; moist; hardness 0.7-1.4-2.2; many fine roots.

A2 2/4-10 cm; Clear wavy boundary; brown 10YR 4/6; sandy loam; coarse subangular blocky and weak medium angular blocky structure; moist; hardness 3.5-5.3-7.3; common medium and fine roots.

E 10-20 cm; gradual smooth boundary; yellowish brown 10YR 5/6; clay loam; moist; hardness 4.7-8.0-16.7; coarse subangular blocky structure; many coarse humus mottles; common medium and fine roots.

Bt1 20-50 cm; diffuse smooth boundary; bright yellowish brown 10YR 6/6; clay to clay loam; weak very coarse prismatic structure; moist; hardness 7.3-8.8-11.8; continuous thin clay cutan; few humus mottles; common fine roots.

Bt2 50-65+ cm; gradual smooth boundary; orange 7.5YR 6/6; clay; moist; hardness 3.5-5.4-6.3; moderately thick clay cutan; many reddish mottles; few fine roots.

Profile No.14

Soil type: YM, Location: 11S4, Slope: 5 degree, Date: April 15, 1988

F 1/2-0 cm;

AE 0-3/10 cm; dull yellowish brown 10YR 5/4; clay loam; angular structure; dry to moist; hardness 1.7-3.1-4.0; common medium and fine roots.

Bt1 3/10-30 cm; clear irregular boundary; yellowish brown 10YR 5/8; clay loam to clay; subangular blocky structure; moist; 5.4-6.9-8.5; moderately thick clay cutan; brown very coarse humus mottles; white mycelium; few large, common medium and fine roots.

Bt2 30-60+ cm; diffuse smooth boundary; bright yellowish brown 10YR 6/6; clay; weak subangular blocky structure; moist; 4.7-6.1-7.3; moderately thick clay cutan; common grayish mottles; few fine roots.

Profile No.15

Soil type: YW, Location: 13S2, Slope: 10 degree, Date:April 15, 1988

F 1/2-0 cm;

A 0-4 cm; dark brown 10YR 3/4; clay loam to clay; subangular blocky structure; moist; hardness 1.2-3.2-2.6; many fine, common large and medium roots.

E 4-10 cm; gradual smooth boundary; yellowish brown 10YR 5/6; clay loam to clay; subangular blocky structure; moist to moderately wet; hardness 1.9-3.0-6.3; common clear coarse diffuse grayish mottles; common fine roots.

Btg 10-100+ cm; gradual smooth boundary; bright yellowish brown 10YR 6/6; clay; weak very coarse subangular blocky to very coarse prismatic structure; wet; 3.0-5.3-6.3; continuous thick clay cutan; many clear coarse diffuse grayish mottles; common fine and medium roots.

Profile No.16

Soil type: YM, Location: A21NS0, Slope:25 degree, Date: April 15, 1988

F 2/3-0 cm;

A 0-4/6 cm; brown 7.5YR 4/3; clay loam; strong medium to fine angular blocky and medium granular structure; dry; hardness 1.4-2.5-5.4; common medium and fine roots.

E 4/6-15 cm; gradual wavy boundary; yellowish brown 10YR 5/6; clay loam to clay; moderate fine angular blocky and brown medium granular structure; moist to dry; hardness 3.0-4.7-10.0; common medium and fine roots.

Bt 15-60 cm; diffuse smooth boundary; bright yellowish brown 10YR 6/6; clay; moderate coarse subangular blocky structure; moist to dry; hardness 7.3-9.7-16.7; continuous thin clay cutan; common medium and fine roots.

Btg 60-100+ cm; gradual smooth boundary; bright yellowish brown 10YR 6/6; clay; moderate coarse subangular blocky and fine angular blocky structure; moist; hardness 6.3-6.7-14.0; continuous thick clay cutan; many diffuse reddish and grayish mottles; few fine root.

Profile No.17

Soil type: YM, Location: 47S7, Slope:10 degree, Date:April 15, 1988

F 2-0 cm;

A 0-10 cm; brown 10YR 4/4; sandy loam; moderate angular blocky and subangular blocky structure; moist; hardness 4.0-6.9-10.0; many fine and common medium roots.

AE 10-22/26 cm; gradual smooth boundary; brown 10YR 4/4; sandy loam; moderate subangular blocky and moderate medium brown granular structure; moist; hardness 5.4-7.8-8.5; common medium and fine roots.

Bt1 22/26-50 cm; gradual wavy boundary; bright yellowish brown 10YR 6/6; sandy loam; moderate blocky and moderate medium brown granular structure; hardness 1.7-3.9-8.5; moist; continuous thin clay cutan; common medium and fine roots.

Bt2　50-70+ cm; diffuse smooth boundary; bright yellowish brown 10YR 6/6; sandy loam to clay loam; weak subangular blocky structure; moist to moderately wet; hardness 1.9-3.0-4.0; continuous thick clay cutan; few grayish mottles; few fine roots.

Profile No.18

Soil type: ER, Location: 25N4, Slope:45 degree, Date:April 16, 1988

F　2/0-0 cm;

EA　0-2/10 cm; dark brown 10YR 4/4;sandy loam; weak subangular blocky structure; moist; hardness 4.0-5.3-7.3; many roots.

Bt　2/10-30/38 cm; clear irregular boundary; yellowish brown 10YR 5/7; clay loam; weak subangular blocky structure; moist; hardness 11.8-11.8-11.8; few reddish mottles; common roots.

Btg　30/38-100+ cm; gradual wavy boundary; bright yellowish brown 10YR 6/6; clay; hardness 6.3-6.9-10.0; wet; common reddish 5YR 5/8 and grayish 2.5Y 6/2 mottles; common roots.

Profile No.19

Soil type: G, Location: 26N4, Slope: 0 degree, Date: April 16, 1988

L　1-0 cm;

F　1-0 cm;

A　0-4/8 cm; dark brown 7.5YR 3/4; sandy loam; weak coarse subangular blocky and medium crumb structure; moist; hardness 0.4-0.6-0.8; many fine and common medium roots.

Ag　4/8-12/14 cm; gradual wavy boundary; brown 7.5YR 4/6; sandy loam; weak coarse subangular blocky structure; moderately wet; hardness 0.4-1.1-1.7; common reddish and grayish mottles; common fine roots.

Bg1　12/14-25/30 cm; gradual wavy boundary; dull yellow 2.5Y 6/3 mottled with olive brown 2.5YR 4/6; sandy loam; wet; hardness 0.8-1.1-1.7; charcoal fragments; common fine roots.

Bg2　25/30-45+ cm; gradual wavy boundary; grayish yellow 2.5Y 6/2; sandy loam; excessively wet; 0.4-0.7-0.8; few large, medium and fine roots; ground water level is 45 cm.

Profile No.20

Soil type: YD, Location: 33N4, Slope: 15 degree, Date: April 16, 1988

L　3/4-2/3 cm;

F　2/3-0 cm;

A　0-2/5 cm; brown 10YR 4/4; silty loam; strong fine angular blocky and medium granular structure; dry; hardness 0.3-0.7-1.4; many fine and common medium roots.

E　2/5-20/26 cm; clear irregular boundary; dull yellowish brown 10YR 5/4; sandy loam; moderate medium subangular blocky and round brown medium granular structure; dry; hardness 10.0-13.5-20.1; common medium and fine roots.

Bt1　20/26-50/60 cm: diffuse wavy boundary; orange 7.5YR 6/6; clay loam; weak coarse subangular blocky structure; moist; hardness 6.3-11.8-16.7; continuous moderate thick clay cutan; few charcoal fragments; common medium and fine roots.

Bt2　50/60-80 cm; gradual wavy boundary; orange 7.5YR 6/7; clay; weak coarse subangular blocky structure; moist; 4.0-8.3-14.0; continuous thick clay cutan; few coarse distinct clear reddish and grayish mottles; few charcoal fragments; few fine roots.

Bt3　80-100 cm; clear smooth boundary; orange to bright brown 7.5YR 5.5/6; clay; moderate medium angular blocky structure; moist; hardness 6.3-8.0-16.7; continuous thick clay cutan; common coarse prominent clear reddish and grayish mottles; iron nodules; few medium roots.

Bt4　100-130+ cm; clear smooth boundary; bull orange 7.5YR 7/3; clay; moist; hardness 6.3-8.8-16.7; continuous moderately thick clay cutan; many coarse prominent reddish 2.5YR 4/8 and grayish 10YR 7/2 mottles;few small gravel of iron accumulated dark red sandstones.