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Improvement of Biological Productivity in Degraded Lands in Thailand III. Soil hardness measurement in the field.

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ABSTRACT Rehabilitation of the degraded and abandoned land in Thailand is one of emergent problems to be solved because the decline in forest area was quite severe within these 30 years. This work is a part of Waste Land Project to find out a better management plan for four different types of the degraded land throughout Thailand, with reference to soil hardness measurement.

Especially, in case that the distribution of soil materials are quite heterogeneous in Ratchaburi, seasonal change of soil hardness were found to be sensitive to differentiate the water shortage stress and/or hardness stress to plant root. In case of Somdet sandy soil, rain water could easily loosen the hard condition of the surface soil formed in the dry season. Furthermore, in Huey Tung Jaw, the presence of rock in the soil profile could be inferred from the hardness measurement, which caused a better drainage during rainy season to supply oxygen for the sound root growth.

When we work abroad, we need some kinds of procedure easily accomplished in the field to obtain variable information on soils at hand. We found that the soil hardness measurement could do it to predict a significant physical hazard for plant growth.

Key Words: degraded land / soil hardness / Thailand / Waste Land Project / soil penetrometer

Once natural forest is cleared and the land is utilized to several years' agricultural production without using any fertilizer, the original stocks of nutrients in soils will be exhausted severely. Consequently, depletion in productivity of soils make the farmers give those land up, resulting in a heal of degraded land, namely, wasteland. These types of land might be subjected to severe erosion because of the absence of surface plant cover. As shown in our previous paper (Sakurai *et al.*, 1989), soil degradation proceeded in various way throughout Thailand.

Soil degradation problem in the world wide scale was reviewed in Advances in Soil Science Volume 11(Lal & Stewart, 1990) in detail. The world's arable land resources are finite. Seventy-eight percent of the total earth's surface area is unsuitable for agricultural purposes. Out of the 22% of the land that is agriculturally suitable, 13% has low productive capacity, 6% a medium, and only 3% is characterized with a high capacity for an intensive crop production. At present, 5 to 7 million hectares of arable land (0.3% to 0.5%) are lost every year through soil degradation (Lal & Stewart, 1990). The countermeasure for restoration has recently been summarized by the same editors (Lal and Stewart, 1992) as Volume 17 of Advances in Soil Science.

Improvement of soil fertility are somewhat easier than that of soil physical properties, because, as long as the farmers can afford it, amendment of organic and inorganic fertilizer can accomplish it to a greater extent within a short period. On the other hand, soil physical properties often need more effort and investment to be improved. The world is now losing some 23 billion tons of top soil per year from uplands in excess of new soil formation (Lal & Stewart, 1992). Even if a big fund is available, building up a good soil structure will take quite a long time. Furthermore, it is still very difficult to evaluate the degree of the development of soil structure quantitatively without collecting the bulk samples which may disturb or destruct the real structure. In order to evaluate the influence of soil physical properties on plant growth, it is necessary to establish an appropriate way of diagnosis for the soils in the field. Especially on the research in the tropical countries, we need a simple but a valuable technique which can be easily conducted by the cooperative researcher and/or worker routinely.

Among soil physical properties, three phase distribution, bulk density, true density, moisture content, and saturated hydraulic conductivity is measurable using some portable equipment at any place after we collect 100 to 400 mL of the undisturbed core sample. Soil hardness of each depth has been measured at the soil pit using a push cone type penetrometer. These methods, however, may not applicable when it is not possible to prepare a big soil pit without disturbing the pedo- ecology and without spending lots of time to dig one.

To know the vertical distribution of the soil hardness, we better use a cone penetrometer

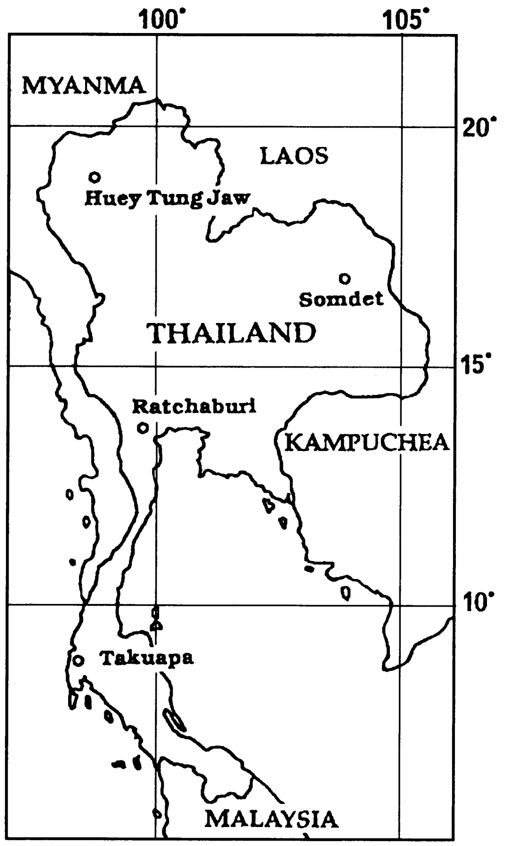


Fig. 1. Study sites. Cited from Sakurai *et al.*, 1991.

equipped with a metal cone on top and a weigh to push and make the cone penetrating into soils. We just fall the 2 kg of weigh at a given distance (50 cm), and record the penetrating depth by an attached scale. Based on the readings, penetration resistance can be estimated. We conveniently use Hasegawa type cone penetrometer (hereafter called soil penetrometer). This apparatus is suitable for evaluating the soil hardness down to the depth of 60 or 100 cm. Total length is about 130 cm, and it is less than 10 kg in total weight. This type of penetrometer is usually much bigger and heavier and used for the evaluation of the natural and mechanical compaction of far more deeper layer underground. Thus, the development of technology was oriented for the evaluation of earth crust hardness in a scale of several tens meter depth. However, the measurement should be done in the surface soils for the purpose of agricultural and natural scientific research.

Since Hasegawa type cone penetrometer was devised for the evaluation of the planting point of the tree seedlings along the road, surface soils can be evaluated conveniently (Hasegawa *et al.*, 1984). In this paper, therefore, we will try to show the availability of soil penetrometer for the research work aiming at rehabilitation of the degraded land. In addition, the seasonal change of the soil hardness will be discussed briefly in relation to the soil moisture content.

MATERIALS AND METHODS

Study area

Representatives of different types of wastelands was selected, on the basis of original vegetation, present land use, and soil properties throughout Thailand (Fig. 1). This "Wasteland project" was carried out from 1984 to 1990 academic year by a mixed team from Osaka City University, Kyoto University, Kochi University, Osaka Kyoiku University, University of Osaka Prefecture, Shimane University (Japanese team), Kasetsart University, Royal Forest Department, Department of Land Development, and Forest Industry Organization (Thai team). Since study area, profile description of the pedons in and out of our sites, and some physical properties were already described in detail in our previous paper (Sakurai *et al.*, 1989), the outline of each experimental site will be given below. Information on each site is described with reference to major soil problem, climate, original vegetation of the area, and topography, and the tree and crops planted.

Takuapa (Panga-nga province, Southern Thailand) This site were covered with the siliceous sandy deposit after tin mining procession, where no weed can grow well. During 5 years from 1985 to 1989, annual rain fall ranged from 4721 to 2388 mm yr^{-1}, a drought period continued for 3 to 5 months. Mean temperature of the plot was 30.6 to 32.5 °C, which were measured at the approximate height of 50 cm with a simple sheltering for the thermometer. There was not any significant fluctuation in monthly temperature throughout the year. Original vegetation was secondary mangrove forest and swamp forest of *Melaleuca leucadendron* because of the high water table along the coast (4 km east from sea shore). Topography of the site is slanting to west with 1.8° slope. *Eucalyptus camaldulensis* was planted on the silvicultural plot with a combination of treatments, *i.e.*, mulching, clayey materials dressing, and fertilizer amendment. *Stylosanthes hamata* was grown in a plot as a cover crop for grazing cattle. On agricultural plot, cassava and pineapple were cultivated to examine the effect of organic or inorganic fertilizer and mulching.

Ratchaburi (Ratchaburi province, Central Thailand) The site were situated on the lateritic gravelly materials at the former river terrace after clearing the forest to obtain fuel wood for local limestone mining and ceramic production. Very high temperature and long dry period accelerated the hardening of surface soil materials, which make it possible to regenerate only thorny scrub. During 5 years, the rain fall ranged from 844 to 1322 mm per annum, and 4 to 6 months of drought were observed. The highest monthly mean temperature was found in April (30.4 to 31.4°C), and the lowest was in December or January (22.5 to 24.5°C). Original vegetation was dry dipterocarp forest. Experimental site is located on the foot slope to small valley bottom with a maximum slope of 4° and average of 3°. As for the silvicultural species, *Eucalyptus camaldulensis* and *Pterocarpus macrocarpus* was used, while for the agricultural trial, cassava, pineapple, and maize were grown with a combination of fertilizer application.

Somdet (Karasin province, Northeast Thailand) The experimental site was established on the abandoned land after low-land shifting cultivation, where grain crops and subsequently cassava had been grown for several years. The fertility of the original soil was very low because of the parent material originated from sand stone. After exhaustion of the original nutrient, *Imperata cylindrica* infested severely preventing from regeneration of dry dipterocarp forest. During 5 years, the mean precipitation ranged from 959 to 1268 mm per annum with a long dry months (5 to 7 months in a year). The monthly mean temperature was highest (28.2 to 30.0°C) in April, and lowest (19.7 to 21.7°C) in December or January. Topography of the site was slanting to south-west with 1.4 ° slope. *Eucalyptus camaldulensis, Pterocarpus macrocarpus*, and *Acacia mangium* were planted for silviculture, while cassava, ground nuts, maize, sorghum, kenaf, and rosel were cultivated as agricultural crop species.

Huey Tung Jaw (Chiang Mai province, North Thailand) The experimental site was settled on the land after highland shifting cultivation for poppy plantation. After giving up the field, *Eupatorium adenophorum* and *Imperata cylindrica* predominated instead of hill evergreen forest composed of *Castanopsis* spp. The weeds often becomes a cause of ground fire which may lead to a complete destruction of forest system around. Annual precipitation was 1490 and 1785 mm in 1986 and 1987, respectively, and the drought period continued for 3 months. The monthly mean temperature was highest in April or May (22.8 to 23.8°C) and lowest in January (16.4 to 16.6¥°C). The site was located on the small valley with a southeast slope (10 °).

Cryptomeria japonica, Chamaecyparis obtusa, Pinus kesiya, Calliandra calothyrsus, Paulownia sp., *Cunninghamia lanceolata* were planted with or without coffee, tea, Lablab bean, and castor bean as intercrop species and with *Desmodium* as cover crop.

Experimental methods

Agricultural and silvicultural experiments started at the beginning of growing or rainy season in 1985. Examination of soil hardness was conducted during 1987 to 1989. Its result is expressed as in Fig. 2. Horizontal axis represents the penetrating depth (cm) per one drop of weigh and vertical axis does the cumulative depth (cm). In short, the smaller the area in the figure, the harder the soil. In this paper, definition of soil hardness is classified using the value plotted on the horizontal axis (termed as one drop penetrability, ODP) as follows; very hard, ODP less than 0.5; hard, ODP between 0.5 and 1.0; moderate, ODP between 1.0 and 2.0; soft, ODP more than 2.0.

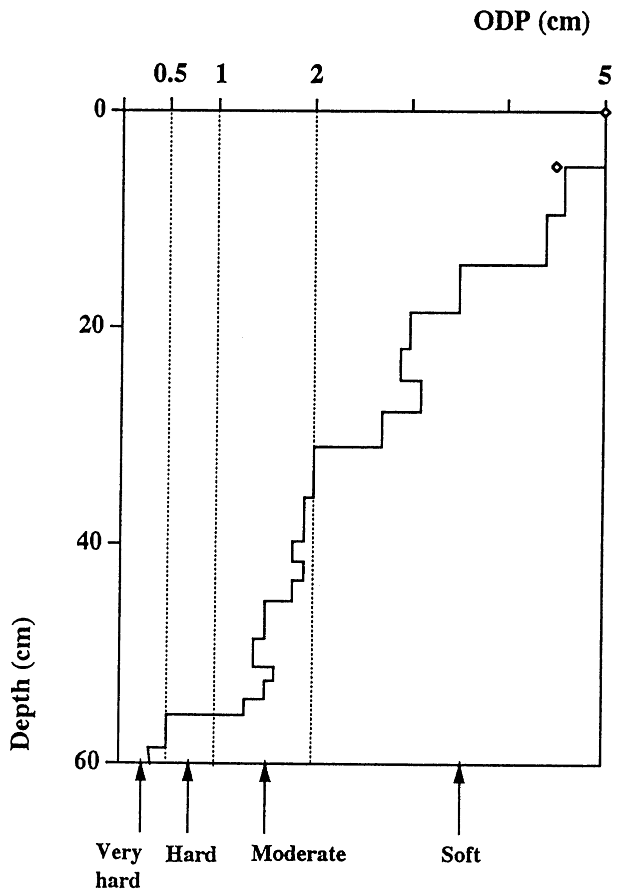


Fig. 2. One drop penetrability (ODP) and definition of soil hardness.

Some of the physical properties of soils are summarized in Table 1 (Sakurai *et al.*, 1989), where the procedure of their determination and their profile description was described in detail.

RESULTS AND DISCUSSION

Takuapa Experimental Site

Soil hardness measurement was conducted at every plot with different treatments. Fig. 3 shows the pattern of the soil hardness, which is quite similar at every point examined. This was because the distribution of soil materials were quite uniform within the whole experimental site, indicating that any treatment could not be significant to modify the soil physical properties. The ODP value was more than 2.0 only at the surface 15 cm at most. Below that depth, it ranges between 0.4 & 0.6, showing very strong resistance against the root penetration. This was confirmed to dig out the tree and crops. *Eucalyptus* root suffered from physical disturbance of gravelly materials. Table 2 showed the ratio of gravel (particles greater than 2 mm in diameter) to the total soil materials in two plots. TE-01 is control plot without any treatment and only mulching treatment was done at TE-02. At the surface 30 cm, gravel

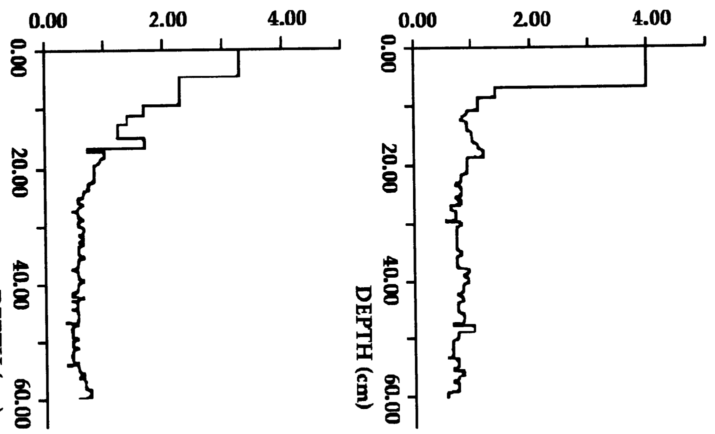


Fig. 3. The pattern of soil hardness in Takuapa.

ratio ranged from 35 to 51%, and it became 14 to 24% below that depth. Sandy materials moved from the surface layer into the subsurface layer, resulting much denser soil in the deeper part of the solum. Even though the root of *Eucalyptus* extended to a depth of 60 cm, its shape looked like zig-zag, indicating the severe disturbance of root elongation by gravels.

Gravel layers and sand layers appeared alternately throughout the profile, but in the limited parts, thin clay layers (less than 1 mm in thickness) were also observed. Without clayey dressing, root distribution appeared to be limited only in the thin clay layer above the gravel layer and/or below the sand layer. No roots could elongate into the dense sand layers. When clayey materials were applied down to the depth of 50 cm at the initial plot preparation, tree roots reached down to a depth of 94 cm. These are in good agreement with the description by Payne (1988). He emphasized the spatial room as an essential factor for the root growth as well as the clay accumulation for water and nutrient retention during the dry season. Dense sand layer was harder than the gravel layer for the root to penetrate into. Soil penetrometer, however, could not tell this fact.

Ratchaburi Experimental Site

Soil layer was composed of the surface plow layer with 10 to 30 cm depth and the subsurface layer below that depth. The subsurface layer have quite different characteristics from site to site, and at least 4 different layers were recognized; laterite, gravel layer mixed with clay, thick clay layer and fragmented rock layer derived from sandstone bed rock. Judging from the soil profile description down to 200 cm in depth and the topography of this site, clay layers are overlaid by the other three members mentioned above (Sakurai *et al.*, 1989).

Soil hardness was examined at 48 points along the 3 transects on October in 1988. In Fig. 4, total count of the penetrometer is depicted schematically. The upper figure in a plot is the result obtained in October 1988 and the lower figure in December 1988. Dry season began after October measurement and continued until the beginning of April 1989. Differences of total count between two measurements showed clearly the degree of hardening in the dry season. The measuring point at the serial numbers of 4 to 12 is located on the lower part, and that at 14 and 15 is located on the pathway of rain water. At these points, soils were very soft in October 1988 because of a rain just before measurement. After this measurement, there

Table 1. Physical properties of the selected soils in and near the sites.

Plot No.	Depth or horizon(cm)	Three phase distribution Solid	Liquid %	Air	Bulk density	Moisture content (%)	Hydraulic conductivity (cm/sec)
TE-4	0- 5	59.4	2.9	33.7	1.56	1.9	2.5×10^{-2}
	20-25	58.2	2.8	39.0	1.55	1.8	2.4×10^{-2}
	40-45	59.2	3.8	37.0	1.57	2.3	2.9×10^{-2}
TG	A2	55.5	35.1	9.4	1.38	20.2	5.3×10^{-2}
	BA	43.6	31.1	25.3	1.21	20.5	5.8×10^{-2}
	B1	52.7	25.7	21.6	1.46	15.0	8.4×10^{-3}
	B2	59.8	29.6	10.6	1.59	15.7	8.5×10^{-3}
RE-01	C	68.2	23.9	7.9	1.97	20.1	1.7×10^{-2}
RE-1	C1	51.7	10.7	37.6	1.48	6.1	3.3×10^{-3}
RE-5	C	67.2	29.4	3.4	1.64	17.7	4.3×10^{-5}
RE-5	IIC	60.0	33.5	6.5	1.51	16.9	4.1×10^{-7}
SE-4	0- 5	44.5	7.7	47.8	1.22	6.2	1.2×10^{-2}
	20-25	42.6	11.3	46.1	1.19	9.0	1.9×10^{-2}
	40-45	53.6	16.0	30.4	1.48	10.0	2.9×10^{-3}
	60-65	57.7	16.7	25.6	1.54	10.0	4.0×10^{-3}
	80-85	51.1	18.3	30.6	1.41	11.7	3.9×10^{-3}
SS	A	49.8	9.7	40.5	1.35	7.0	2.5×10^{-3}
	AB	54.9	12.0	33.1	1.47	7.8	5.6×10^{-3}
	BA	51.9	14.7	33.4	1.53	9.0	4.8×10^{-3}
	B1	54.8	14.8	30.4	1.51	9.2	1.3×10^{-3}
	B2	53.9	16.3	29.8	1.49	10.1	2.1×10^{-3}
TJ-3	A	46.9	39.1	14.1	1.23	24.4	1.8×10^{-4}
	B	45.2	34.5	20.3	1.19	22.7	3.7×10^{-3}
	C1	53.6	32.8	13.6	1.37	19.5	1.3×10^{-3}
	C2	53.8	21.8	24.6	1.44	13.3	9.6×10^{-4}
TJ-N	A2	not determined					7.1×10^{-3}
	A12	not determined					6.6×10^{-3}
	B21	not determined					3.4×10^{-4}
	B22	not determined					1.4×10^{-4}

(source: Sakurai *et al.*, 1989)

were almost no rain and the drying proceeded quickly. As a result, soil became very hard to yield a large number of count (Fig. 4).

At the selected 24 points, another 4 times of measurement was carried out on January, February, March, and April in 1989. It started raining on April. Examples of vertical distribution pattern on soil hardness are depicted in Figures 5a and 5b. Except for the measurement on October 1988, the ODP value below 2 cm depth corresponded to very hard in almost all measurements.

In Table 3, the total count needed for a soil penetrometer test was summarized. Reflecting a significant variation of the materials underlying, soil hardness also varied greatly among the measurements in a month.

For the mean value of the total count of each month, Duncan's new multiple range test (Table 4) was carried out. Based on this test, it was found that the soils were softest in

Table 2 . Gravel ratio of the soils around a tree in Takuapa.

	Depth (cm)	Frame	Total Weight (g)	Fine earth (g)	Gravel (g)	Gravel ratio (%)
TE-01	0-10	1	441.6	268.9	172.7	39.1
		2	448.2	262.3	185.9	41.5
		3	447.2	260.8	186.4	41.7
	10-20	1	463.9	266.1	197.8	42.6
		2	449.1	221.4	227.7	50.7
		3	463.4	228.5	234.9	50.7
	20-30	1	431.0	249.4	181.6	42.1
		2	461.3	295.0	166.3	36.1
		3	479.2	283.0	196.2	40.9
	30-40	1	256.6	219.6	37.0	14.4
		2	457.6	373.4	84.2	18.4
		3	471.7	359.8	111.9	23.7
TE-02	0-10	1	395.3	229.8	165.5	41.9
		2	403.4	226.7	176.7	43.8
		3	394.6	240.2	154.4	39.1
	10-20	1	425.3	240.5	84.8	43.5
		2	418.4	269.3	149.1	35.6
		3	440.4	233.7	206.7	46.9
	20-30	1	437.2	240.3	196.9	45.0
		2	400.3	256.3	194.0	43.1
		3	450.6	283.7	156.9	37.0
	50-60	1	455.6	365.9	89.7	19.7
		2	450.3	344.5	105.8	23.5
		3	438.5	351.0	87.5	20.0

Frame 1, 2, and 3 denote the area around a tree, within a square of 0.5 m × 0.5 m, 1.2 m × 1.2 m and outside of Frame 1, and 2.0 m × 2.0 m and outside of Frame 2, respectively.

October and hardest in December. Except these two measurements, there were no statistically significant differences in soil hardness among March, April, January and February. Since there were several points where measurement could not be completed down to the 60cm depth (referred as NC in Fig. 4), those data were excluded from the test. Monthly rainfall was 314 mm, 15 mm, 0 mm, 34 mm, 0 mm, 0 mm, and 11 mm through October 1988 to April 1989. Thus, soil drying proceeded drastically from October to December and continued to April 1989, and that condition would be kept or loosened by the whimsical rain and relatively cool temperature. From another point of view, physical hazard due to hardening of soil together with shortage of soil moisture content may be easily accomplished in the beginning of the dry season. Judging from the moderately good growth even under such a severe soil physical condition in Ratchaburi experimental site, *Eucalyptus* can overcome it, as long as the tree stand is established well.

As shown in the previous paper (Sakurai *et al.*, 1989), three phase distribution of the subsurface soils did not reflect the heterogeneity of the soil materials, because every material here showed a very high solid ratio and its difference in composition of the materials could not be discriminated. On the other hand, in addition to texture determined at the field, the

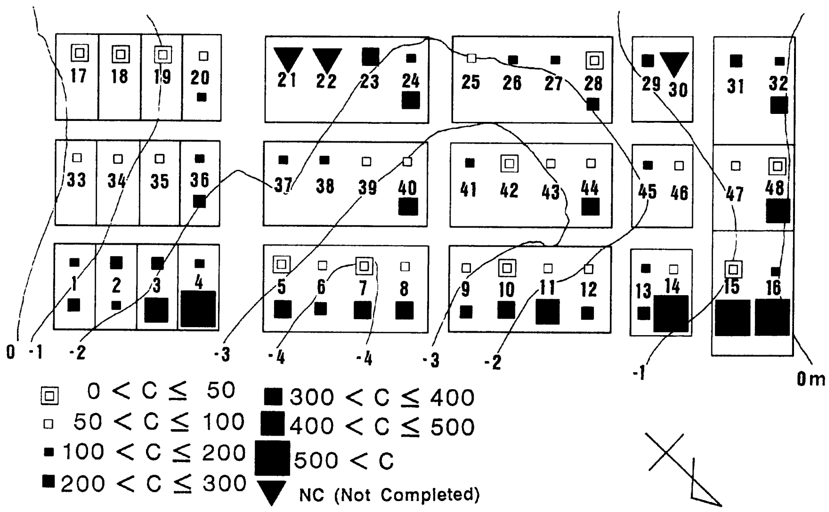


Fig. 4. Changes in soil hardness through soil drying. Upper and lower symbol denote total count in October and December 1988, respectively.

Table 3. Total count of soil penetrometer in Ratchaburi.

Serial	1988		1989				Plot	Serial	1988	
No.	Oct	Dec	Jan	Feb	Mar	Apr		No.	Oct	
1	158	267	392	291	325	255	RC-1	17	25	RM-1
2	280	175	326	253	N.C.	182	RC-2	18	26	RM-2
3	269	406	347	N.C.	N.C.	N.C.	RC-3	19	32	RM-3
4	166	523	N.C.	368	438	447	RC-4	21	N.C.	RE-1
5	50	383	364	318	435	354	RE-5	22	N.C.	RE-1
6	59	287	334	227	273	464	RE-5	23	349	RE-1
7	16	305	215	264	380	327	RE-5	25	54	RE-2
8	59	353	210	226	216	266	RE-5	26	154	RE-2
9	61	226	235	345	244	246	RE-6	27	114	RE-2
10	49	394	218	68	89	N.C.	RE-6	29	249	RE-04A
11	59	425	369	325	273	149	RE-6	30	N.C.	RE-04A
12	52	265	321	250	309	92	RE-6	31	212	RE-01
13	135	238	398	371	1000	379	RE-04C	33	94	RP-1
14	63	518	272	348	370	405	RE-04C	34	51	RP-2
15	26	566	174	252	254	186	RE-03	35	56	RP-3
16	103	706	N.C.	N.C.	N.C.	N.C.	RE-03	37	101	RE-3
20	53	189	193	125	239	308	RM-4	38	135	RE-3
24	176	316	220	406	271	324	RE-1	39	67	RE-3
28	16	236	186	146	232	264	RE-2	41	137	RE-4
32	169	335	N.C.	161	99	157	RE-01	42	36	RE-4
36	115	251	300	191	320	354	RP-4	43	87	RE-4
40	65	374	109	402	449	313	RE-3	45	198	RE-04B
44	73	325	245	255	294	331	RE-4	46	79	RE-04B
48	74	459	213	147	N.C.	225	RE-02	47	78	RE-02

N.C.: Not Completed (impenetrable down to 60 cm) because of the presence of hard laterite pan or stone layer.

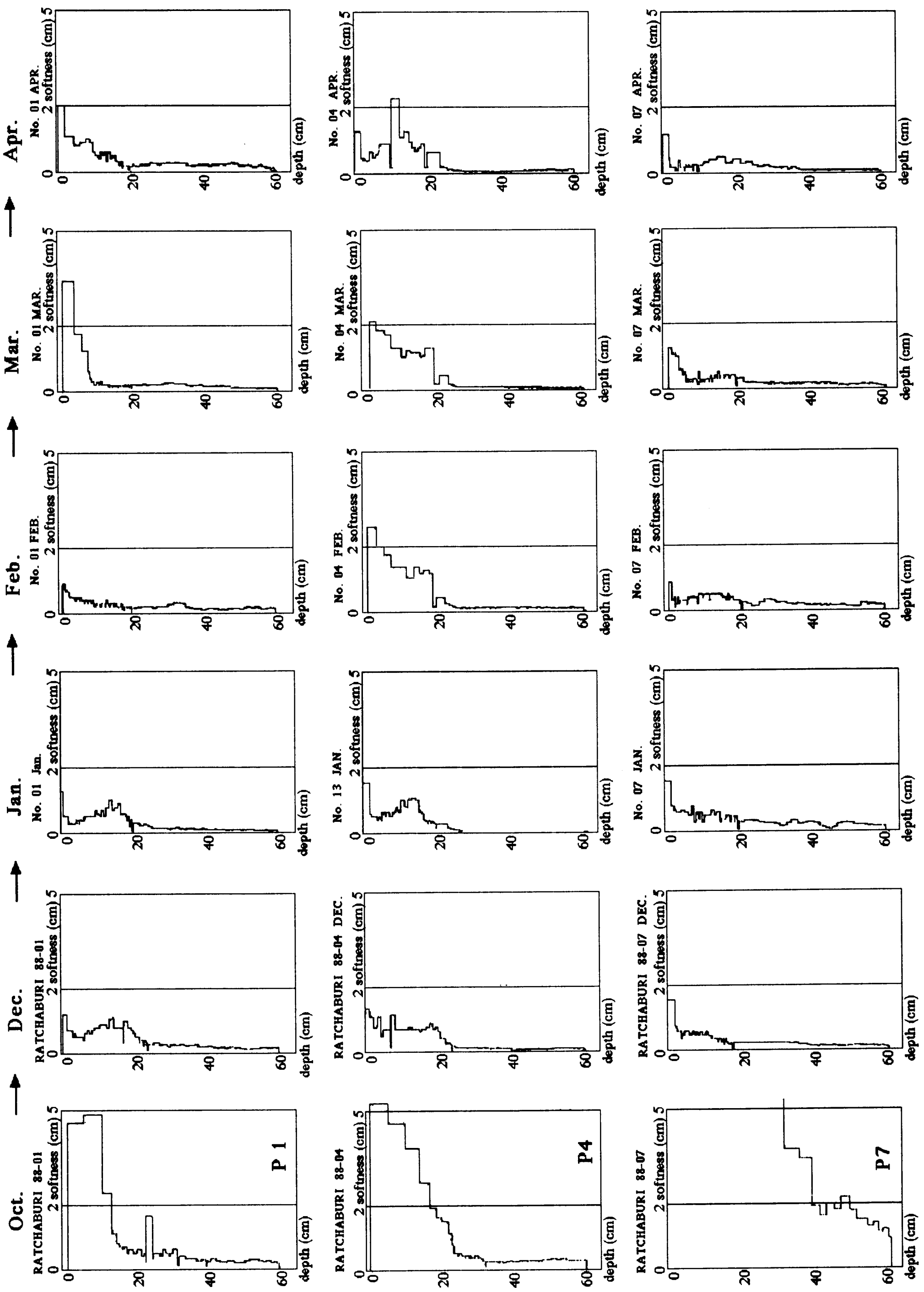


Fig. 5. Changes in the pattern of soil hard-ness in Ratcha-buri from October 1988 to April 1989.

5a. At the measuring point No. of 1, 4, 7.

5b. At the measuring point No. of 10, 13, 16

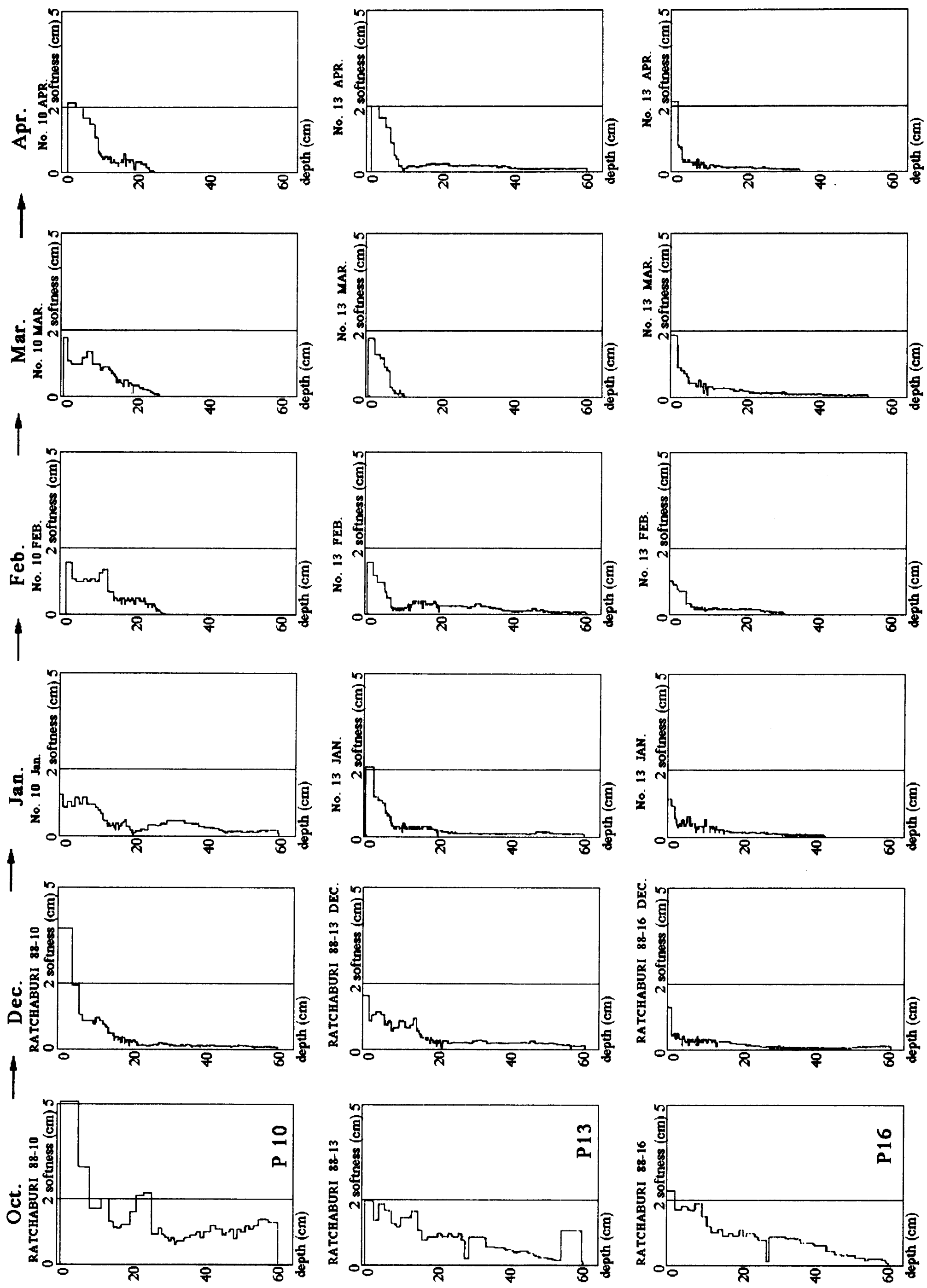


Table 4. Coefficient and result of Duncan's new multiple range test for the soil hardness in Ratchaburi 1988 - 1989.

a) Coefficient

	r=2	3	4	5	6
p=0.05 *	55.50	58.48	60.46	61.85	63.04
p=0.01 **	73.54	76.51	77.90	80.48	81.47

b) Result

		Oct.'88 (104.0)	Feb.'89 (260.9)	Jan.'89 (268.6)	Apr.'89 (287.0)	Mar.'89 (290.0)	Dec.'88 (355.1)	
Dec.'88	(355.1)	251.1**	94.2**	86.5**	68.1*	65.1*	--	c
Mar.'89	(290.0)	186.0**	29.1	21.4	3.0	--		b
Apr.'89	(287.0)	183.0**	26.1	18.4	--			b
Jan.'89	(268.6)	164.6**	7.7	--				b
Feb.'89	(260.9)	156.9**	--					b
Oct.'88	(104.0)	--						a

value of the hydraulic conductivity showed the clear difference in soil materials (Sakurai *et al.*, 1989). Taking various information on physical properties of soils into consideration, the relationship between tree growth and some physical properties is depicted into a map (Fig. 6). From this map, it is clearly understood that gravel layer would not be necessarily a limiting factor for tree growth. A combination of a heavy texture with strong acidity and a moderately high amount of gravel was the most suppressive soil factor for tree growth.

Somdet Experimental Site

Throughout the site, there were similar morphological characteristics of loamy sand or sandy loam textured A horizon and slightly finer textured B horizon. Although the porosity of the soils reached almost 50%, the hydraulic conductivity of these soils was moderate (10^{-3} cm s^{-1}). Termite and ant holes and spots filled with the surface soils were observed in the subsurface horizon, representing high biological activities in soils. Since physical properties of the soils are considered to be moderately well for plant growth, lack of water during dry season or depletion of nutrient by intensive cultivation without appropriate fertilizer application can be a limiting factor. *Pennisetum* grass striving here would be an important source of organic matter.

In Table 5, the mean value and standard deviation of total count by the soil penetrometer are summarized for the results obtained in 1988 and 1989 within and near four experimental sites. Generally, soils in Somdet site were softer than Ratchaburi. On the other hand, they were softer than those in Takuapa and Huey 'Tung Jaw in 1988 but harder in 1989. There was a heavy rain in Somdet one week before measurement in 1988, but not in 1989. Therefore, soil hardness of sandy deposit in Somdet was easily affected by the change in soil moisture content, while those of gravelly deposit in Takuapa and colluvial deposit in Huey Tung Jaw were not significantly affected by it.

When drying, this type of sandy soil becomes very hard, while once getting wet, it becomes much softer than before. This implies that tree roots can penetrate into deeper part when soils are soft enough even though they may suffer from compaction of surface materials in the dry season. Generally, tree roots concentrate in a surface soil (e.g., 10 to 20 cm in depth). As drying proceeds gradually from the surface into the deeper part of the solum, tree roots can elongate into much deeper part because the soil in Somdet is very deep (at least 4 m

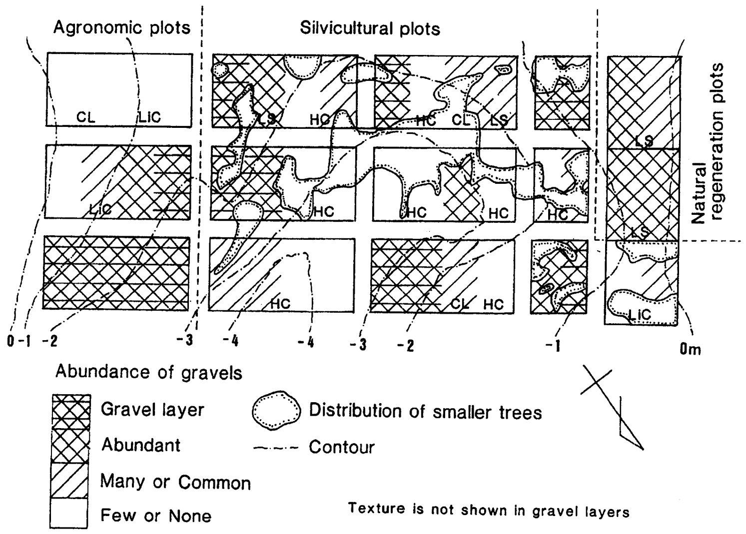


Fig. 6. Map of the tree growth and soil physical properties along with topography in Ratchaburi Experimental Site.

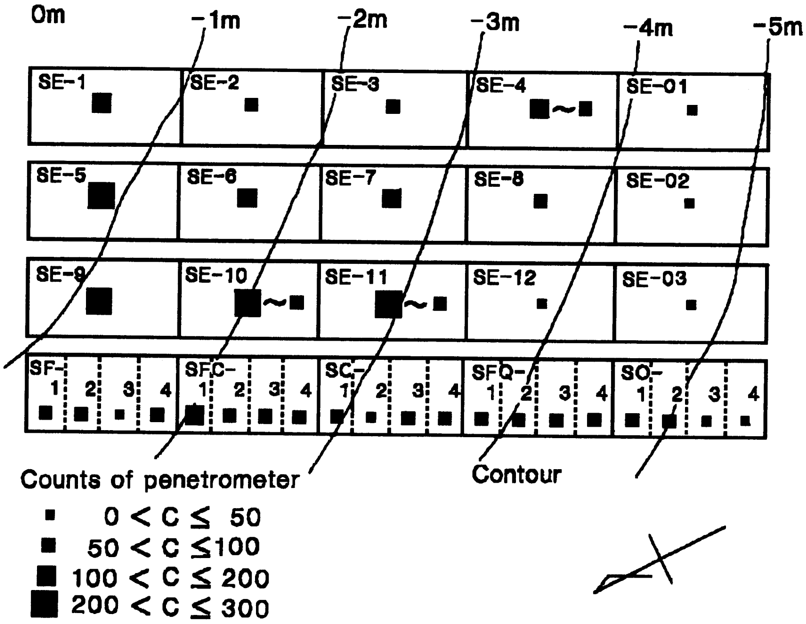


Fig. 7. Soil hardness in Somdet Experimental Site.

in depth). Furthermore, since the ground water level is found to be very low (at least lower than 4 m), tree roots do not have any constraints because of over wetness. Thus, soil hardness can be used for the evaluation for the physical hazard of root growth depending on the soil moisture status in Somdet.

Eucalyptus camaldulensis (Ec) is said to be water consuming tree. If this is true, soils under Ec plantation should be harder than those under the other plantations and also under natural vegetation. As stated before, the distribution of soil materials seems homogeneous

Table 5. Summary of soil hardness measurement.

Site and plot	Repli-cation	Mean total count	SD	Remarks (tree species, treatment)
Somdet 1988				(After heavy rain)
Shrine forest	6	45. 0	12.62	Natural forest
Exp. site				
SE-01	4	43.0	6.06	Natural regeneration plot
SE-02	4	31.3	6.95	ditto (weeded but not removed)
SE-03	4	29.5	11.50	ditto (weeded and removed)
SE-4(1)	6	51.0	16.53	Ec
(2)	6	111.8	20.07	
SE-10(1)	6	252.2	56.99	Pm
(2)	6	55.3	9.05	
SE-12(1)	6	25.3	6.09	Am
(2)	6	23.5	4.76	
(3)	6	29.0	2.61	
Somdet 1989				(After moderate rain)
Secondary forest	8	69.0	11.65	
Exp. site				(since 1985)
SE-03	8	51.5	9.17	see above
SE-4	8	154.5	59.80	Ec (Chemical Fertilizer, CF)
SE-I0	8	229.6	88.65	Pm (CF+Compost)
SE-II	8	87.4	13.37	Ec (Compost)
SE-12	8	70.5	31.87	Am
SFC	8	62.0	20.26	Cassava
FIO plantation				
Cassava	5	82.6	26.09	Cassava (since 1977)
Pm	5	127.4	18.57	Pm (since 1976)
Ec	5	120.6	39.73	Ec (since 1980)
Ma	5	65.0	23.36	Ma (since 1978)
Da	5	91.2	18.70	Da (since 1977)
Takuapa 1988				
TE-2	8	62.1	7.14	Ec
TE-3	8	62.8	3.85	Ec
TC-0,TP-0	8	72.5	8.90	Cassava, Pineapple
Ratchaburi 1988-1989				(Not completed/examined)
Oct'88	45	104.0	76.91	3/48
Dec'88	24	355.1	129.31	0/24
Jan'89	21	268.6	81.11	3/24
Feb'89	22	260.9	94.33	2/24
Mar'89	19	290.0	99.41	5/24
Apr'89	21	287.0	99.26	3/24
Huey Tung Jaw 1988				
TJ-3	45	63.0	28.37	*Pinus kesiya* 25/70

throughout the experimental site. However, soil hardness was different significantly from place to place (Table 5).

In Fig. 7, the count of penetrometer test in 1987 is shown together with the contour line. It is clear that the harder soils mostly distributed in the relatively higher position of silvicultural

Table 6 . Coefficient and result of Duncan's new multiple range test for the soil hardness in Somdet 1988 and 1989.

a) Coefficient

	r=2	3	4	5	6	7
Exp. 1988						
p=0.05 *	61.21	64.42	66.35	67.85	68.92	69.99
p=0.01 **	81.76	85.40	87.75	89.25	90.75	92.04
Exp. 1989						
p=0.05 *	44.01	46.32	47.70	48.78	49.55	50.32
p=0.01 **	58.78	61.39	63.09	64.16	65.24	66.16
FIO 1989						
p=0.05 *	34.90	36.68	37.62	38.45		
p=0.01 **	47.56	49.93	51.23	52.06		

b) Result

Experimental site 1988							
	SE-12	SE-03	SE-02	SE-01	Shrine	SE-4	SE-10
	25.9[a]	29.5[a]	31.3[a]	43.0[a]	45.0[a]	81.4[a]	153.8[b]
Experimental site 1989							
	SE-03	SFC-2	Secondary	SE-12	SE-11	SE-4	SE-10
	51.5[a]	62.0[a]	69.0[a]	70.5[a]	87.4[a]	154.5[b]	229.6[c]
FIO plantation 1989							
	Ma	Cassava	Da	Ec	Pm		
	65.0[a]	82.6[a]	91.2[a]	120.6[ab]	127.4[ab]		

plots (SE-1 to SE-12) in this site. In the natural regeneration plots (SE-01 to SE-03) and the agricultural plots (SF-1 to SO-4), soils were softer. Examples of soil hardness were shown in Fig. 8. Soils under single plantation of Ec with or without intercropping (SE-4, 7, 8, 9, 11) were not always harder than the other tree species.

To evaluate the soil hardness in more detail, intensive measurement was carried out in 1988 and 1989. In Table 5, replications, mean total count, standard deviation, and coefficient of variation (CV, expressed in %) are summarized. Based on these data, Duncan's new multiple range test was conducted (Table 6). In 1988, only SE-4 (Ec plantation) was differentiated from the others as the hardest soil. There were no plots significantly discriminated among mixed plantation of *Pterocarpus macrocarpus* (Pm) and Ec (SE-10), *Acacia mangium* (Am) plantation, natural regeneration plots (SE-01, SE-02, and SE-03), and also natural forest in the shrine. On the other hand, SE-10 was hardest in 1989, followed by SE-4. The others, SE-11 (Ec with compost application), SE-12 (A.m.), secondary forest close to our plot, SFC-2 (cassava cultivation with chemical fertilizer and compost), and SE-03 showed no significant differences with each other.

Soil hardness among different tree species in Forest Industry Organization (FIO) plantation (adjacent to our site) was also examined in 1989. Soils under Pm and Ec were harder than those under *Dipterocarpus alatus*, cassava and *Melia azedarach* (Ma).

Soil hardness in 1989 was in good accordance with the pF value measured *in situ* (Fig. 9), only in SE-4 (Ec plantation) and SE-10 (Pm plantation) showed very high pF values compared with the other plots.

Soil moisture content was monitored by the gypsum block during 1987 to 1989 as the

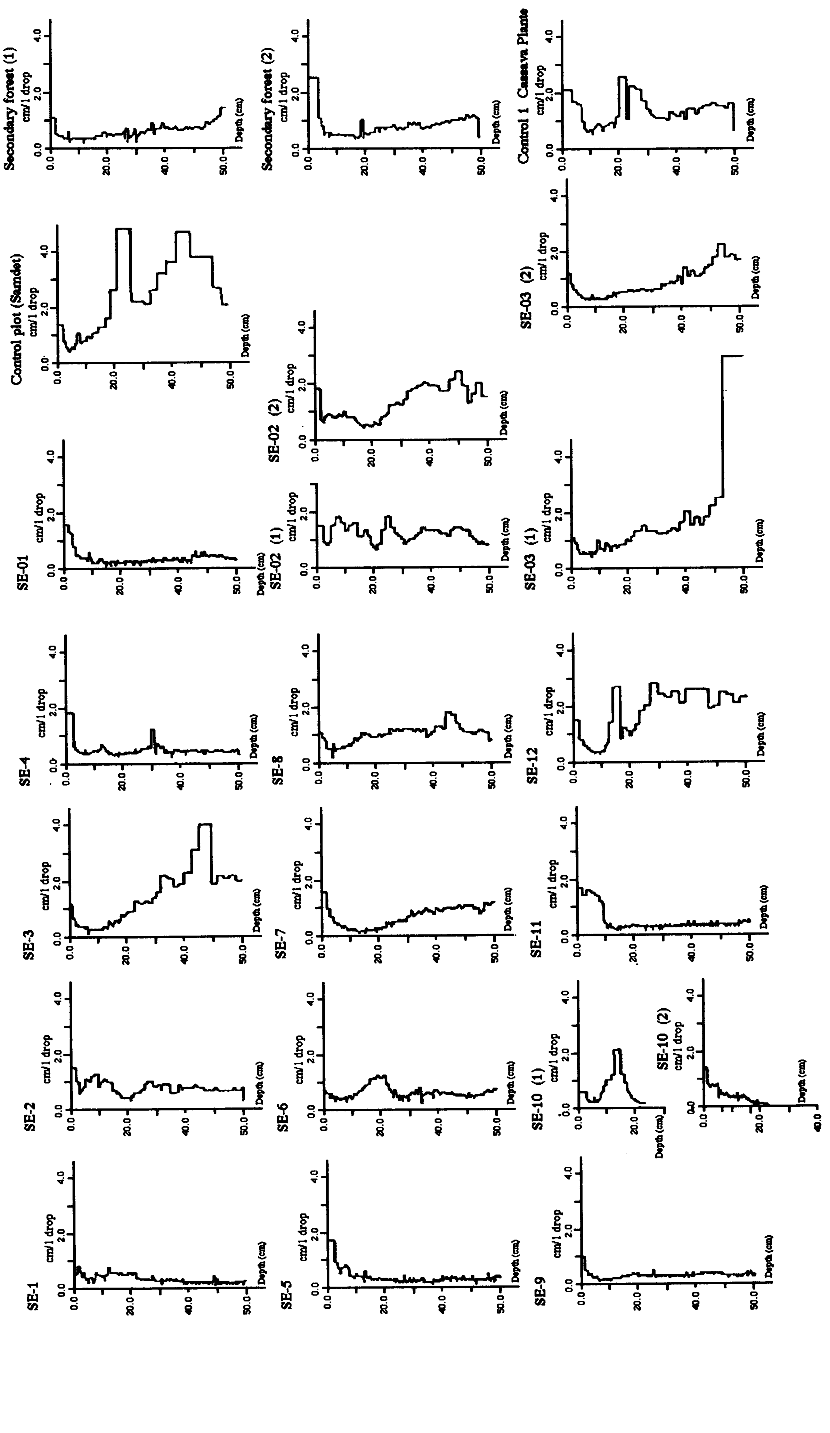


Fig. 8. The pattern of soil hardness in Somdet

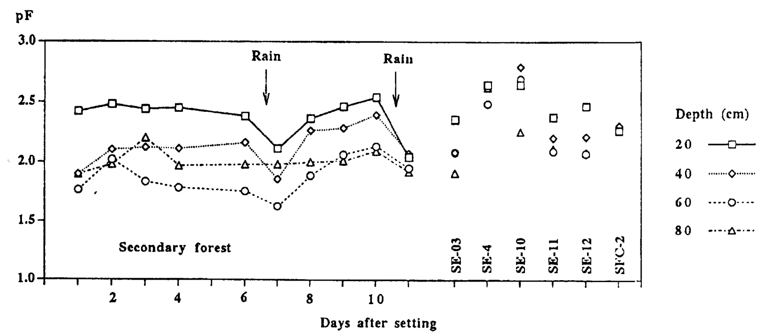


Fig. 9. Soil moisture condition measured by the tensiometer in Somdet 1989.

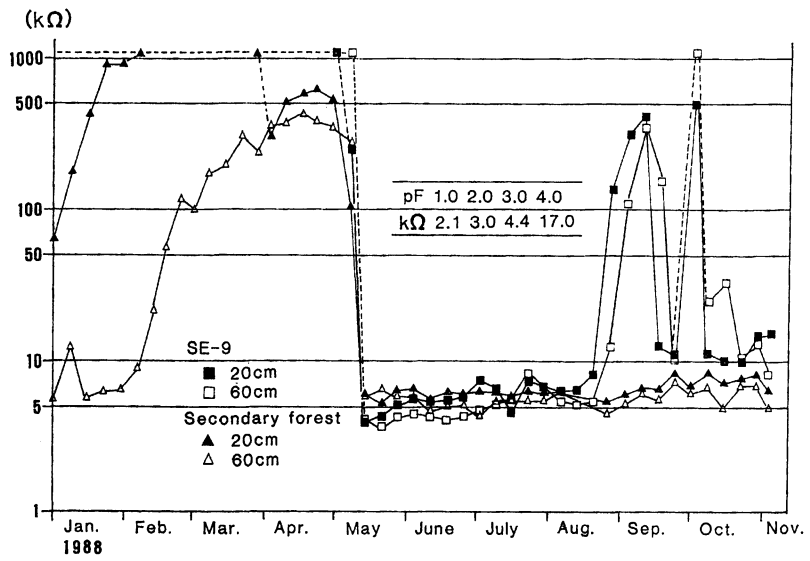


Fig. 10. Soil moisture condition monitored by gypsum blocks in Somdet. SE-9: *Eucalyptus camldulensis* plantation secondary forest:located near experimental site

same procedure described in Sakurai *et al.* (1991). Fig. 10. is the example of the results in 1988. In SE-9 (Ec with chemical fertilizer application), during the dry season (January to April), the soil at both 20 and 60 cm depth was severely dry throughout, whereas, under the secondary forest, the soil at 20 cm depth dried quickly but, that at 60 cm depth kept some moisture. During the rainy season, both soils showed similar resistance values. Again, once the second drying season proceeded in the mid August, the resistance value of the soil under Ec plantation (SE-9) fluctuated quickly depending on the rainfall pattern. This observation may give an indication of the effect of plant biomass on the soil moisture content.

If comparing the leaf biomass, it was 2.87 ton ha^{-1} for the secondary forest near our experimental site and 6.07 and 5.01 ton ha^{-1} for Ec (SE-4) and Am (SE-12), respectively (Table 7-10, Kanzaki *et al.*, 1991a). Pm was grown together with Ec in SE-2 and SE-10 and the leaf biomass of Pm and Ec was 0.00186 and 3.53 ha^{-1} in SE-2 and 0.0717 and 4.09 ton ha^{-1} in SE-10, respectively (Tables 4-(2) and 4-9(8), Kanzaki *et al.*, 1991b). Secondary forest had a smaller leaf biomass than the single plantation of Ec and Am and also the mixed plantation of Ec and Pm. Provided that the water consumption roughly depends on the biomass, both the single plantation of Ec and Am may reduce the water greatly in soils. As shown in Fig. 10, soil moisture content in the Ec plantation was very low during dry season. In Fig. 9., the pF value was the highest in SE-4 (Ec plantation) and SE-10 (Ec and Pm mixed plantation), indicating that the strongly dried condition of soils. Since the leaf biomass of these plantation was much higher than that of secondary forest, soil moisture content was lower than that under the secondary forest.

The mixed plantation of Ec and Pm showed less biomass than the single plantation of Ec and Am, but harder. Taking these results into consideration, soils under the mixed plantation of Pm and Ec seemed to be harder than those under the natural vegetations, reflecting water consumption in soils. we need more work to draw a definite conclusion on the relationship between moisture content of soils and plantation species.

Huey Tung Jaw Experimental Site

An experimental site was made on a straight slope of a gentle to hilly valley bottom, southeastern slope of 10.4 ° in mean inclination, about 1,400 m in altitude. Soil materials in this experimental site are colluvial deposit of deep weathering crust of granite. The soil color of the subsurface horizon is dark throughout the profile, indicating a relative accumulation of organic matter. Since charcoals and a lot of slightly weathered rock fragment were found down to 1 m depth, a big mass movement might have occurred in the past. The texture of the soil was light clay. When comparing the profile of the undisturbed ridge, it can be estimated

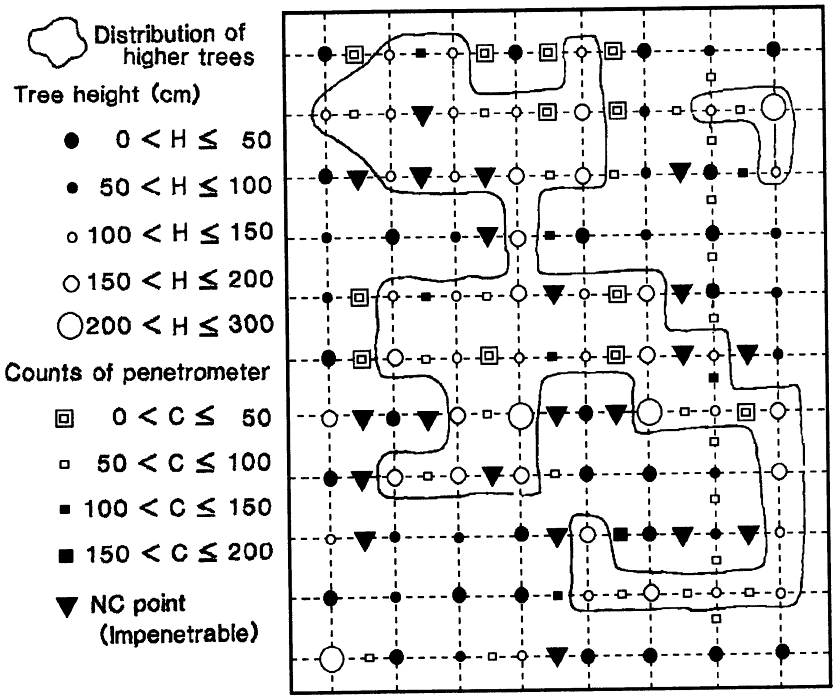


Fig. 11. Distribution of the higher trees and soil hardness in TJ-3 at Huey Tung Jaw Experimental Site.

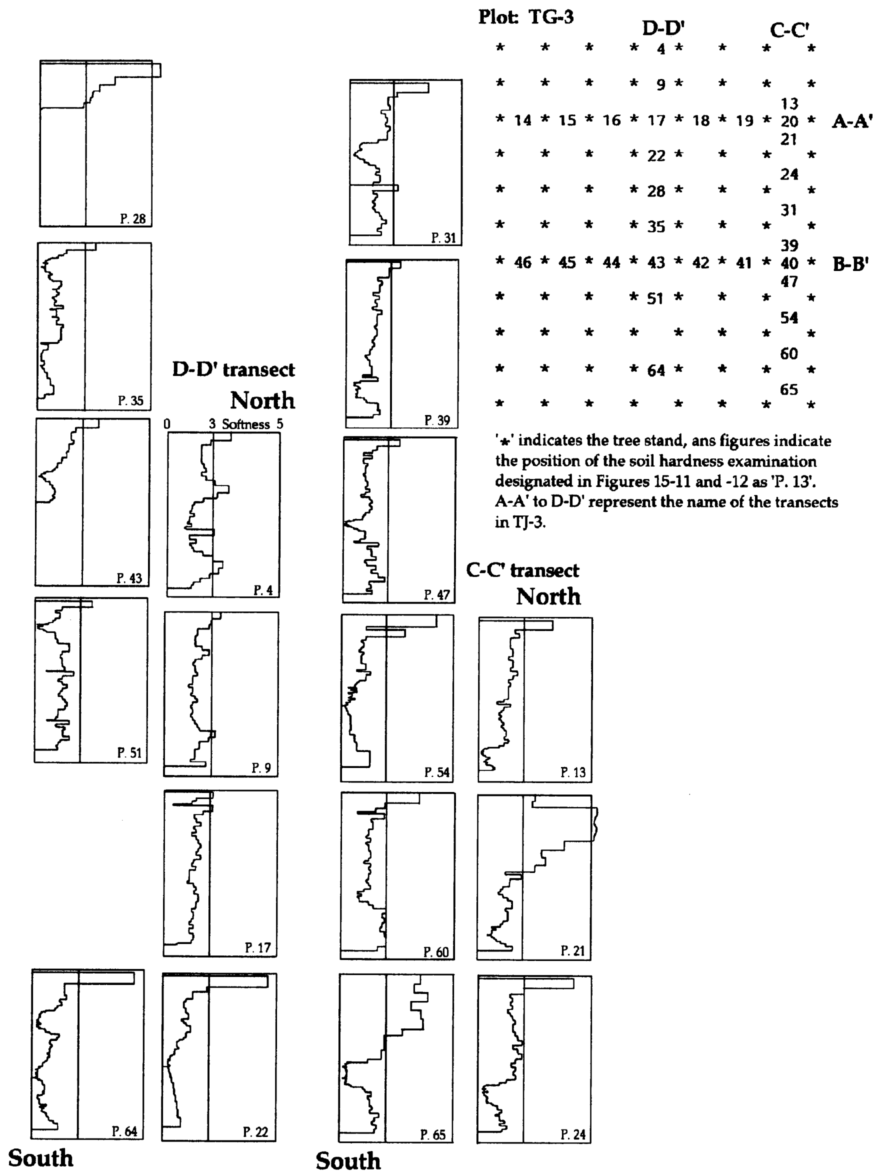
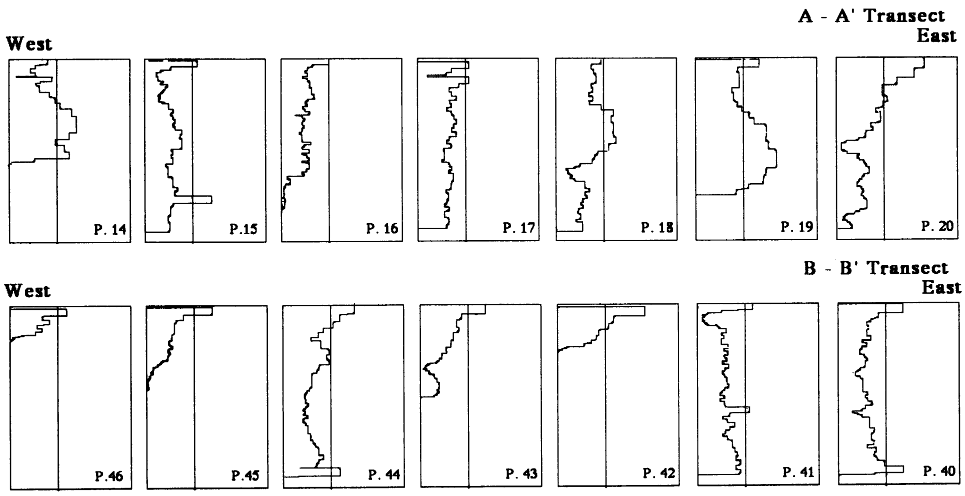


Fig. 12. Distribution pattern of soil hardness in Hey Tung Jaw.
12a. North-south transects

that clayey materials would have been lost during transportation of the materials from the hill ridge and through erosion during flower cultivation. Since soil chemical property may not be a limiting factor for tree growth (though data were not shown here), soil physical property should be paid more significant attention, such as texture, hydraulic conductivity in relation to drainage, water retention, and especially, soil hardness.

The hydraulic conductivity was not significantly slow (10^{-3} cm s^{-1}, Table 1) even in the heavy textured subsurface horizons. On the other hand, a bad drainage condition during rainy season at the valley bottom may interrupt the sound elongation of tree roots.

Fig. 11 is the map showing tree height of *Pinus kesiya* on July in 1988 and the count of soil penetrometer measured on December, 1988. Tree height is expressed by the solid and



12b. East-west transects

blank circles with different size, while count of penetrometer is indicated in solid and blank squares. Triangle means the point where measurement could not be completed due to the presence of rocks. This point is referred as a NC point, thereafter.

Altogether 50 points at the space between two trees were examined. Examples of soil hardness are shown along the north- south transect in Fig. 12a and along the east-west transect in Fig. 12b. At 19 points, the NC point was found due to the presence of some rocks within 60cm-depth. Without rocks, soils seemed rather soft because of heavy rain during October to December in 1988. Judging from Fig. 11, tree growth seemed to be well corresponding to the distribution of rocks. Out of 19 NC points, 5 points were situated in the midst of good trees in growth, and 13 points were close to these trees. Mostly, at one side of the NC point, there was a good tree and at the other side, a bad tree. Though distribution pattern of the rocks in the solum was irregular, it could be expected that tree roots would have a benefit of good drainage condition along the rocks to get enough amount of oxygen. Without rocks, drainage seemed to be bad for sound growth of trees.

Moisture content on November in 1989 is shown in Fig. 13, together with the pF value (expressed in closed circle with solid line) of three plots. Soil moisture content was highest in TJ-12 at the lowest part of the site and it was lowest in TJ-4 at the middle part. On the contrary, as a result of field survey, moisture condition seemed to be higher in the highest part then gradually decreased toward the lower part.

The pF value was lowest in TJ-13, while it was highest in TJ-7 though their moisture content was not greatly different. Generally, organic matter can retain lower tension water than the clayey materials. Considering these results, there might be more amounts of the materials, such as organic matter, which could retain low tension water. On the other hand, in TJ- 7, they were more clayey materials, although the texture is not different greatly. Another possibility was that in TJ-7, planted tree (*Calliandra*) grew up significantly and it absorbed more water in soils and then few grass grew on the ground, whereas, in TJ-13, tree growth (*Cunninghamia*) was extremely bad and grass growth was vigorous, which kept soil moisture content higher.

The most urgent demand of this area is reforestation, and therefore, soil conservation and

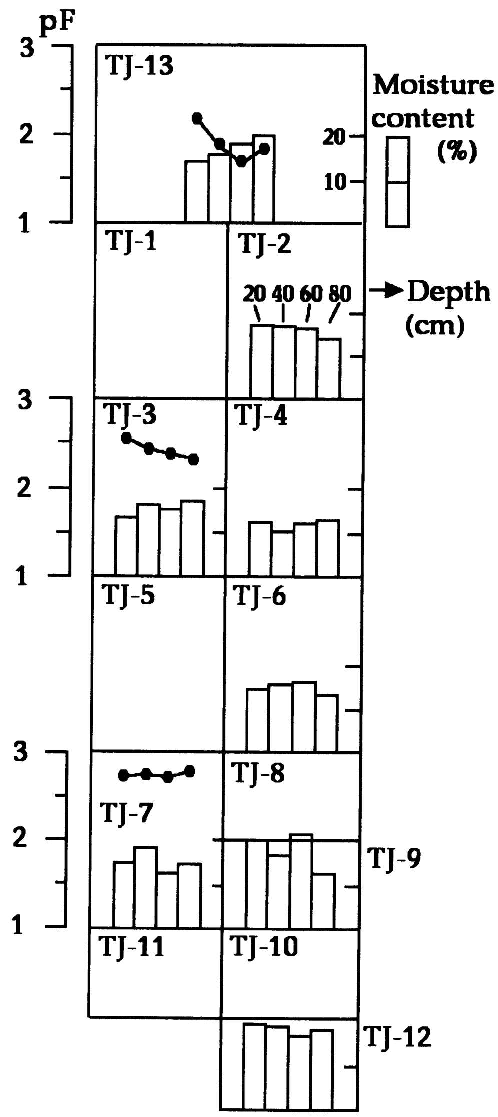


Fig. 13. Moisture content and the tension of the soil water at the different depths in Huey Tung Jaw Experimental Site.

control of weeds which often compete with planted trees are needed. We can not conclude which one is a more dominant factor in this site. However, tree species selection in such a position as valley bottom should be done more carefully at the onset of the experimental design because the soil moisture condition in relation to the topography and the materials underlying will yield many unknown effects that is difficult to be clarified systematically.

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タイの土壌劣化地における生物生産力の回復III. 野外での土壌硬度の測定

タイ国では，この30年間にきびしい森林面積の減少が進んだため，劣化し放棄された土地での植生回復は緊急に解決すべき課題の一つである。この報告は，一連のこの仕事"Weste Land Project (WLP)"の一部であり，タイ国に設けられた4つの異なるタイプの荒廃地のより良い管理策を土壌硬度の測定によって見つけようとするものである。

特に，母材の不均質なラチャブリの場合，土壌硬度の季節変化は水分欠乏や植物根の土の硬さに対するストレスを見分けるのに適していた。ソムデットの砂質土壌の場合，乾期に生じた表層土壌の硬化を，雨水が容易に軟化させた。フエイトゥンジョウでは，土壌断面内の岩の存在が土壌硬度の測定から推定でき，雨季の排水性を良くし，酸素の供給をとおして，根の生育を健全にしていた。

国外での研究には，野外で容易におこなえて，土壌の貴重な情報を手近に得られる手法が必要である。土壌硬度の測定は，それが可能であり，植物の生育に対する物理的障害を予測できることが判った。