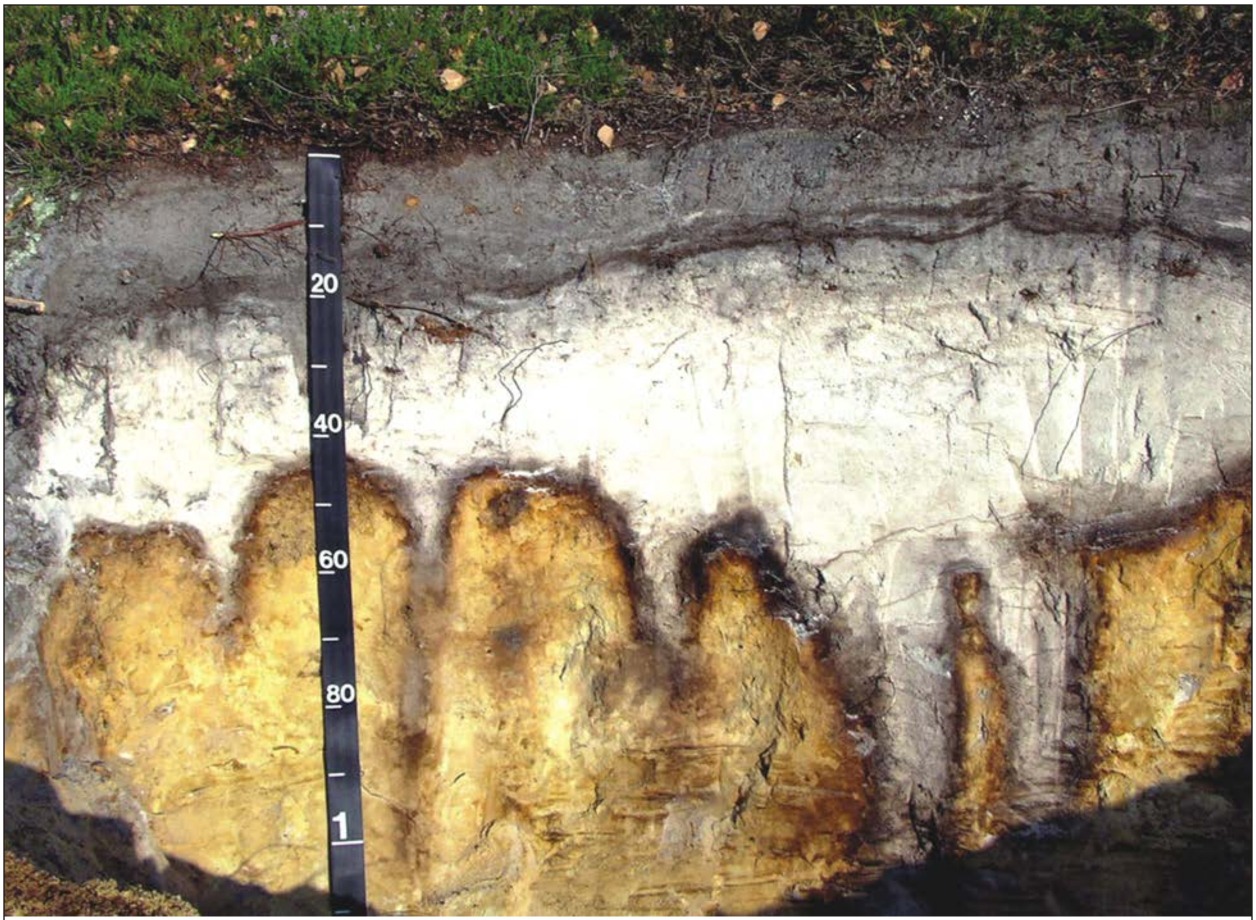

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Characterizing Soil Properties of Lowland and Hill Dipterocarp Forests at Peninsular Malaysia

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Abstract: A study was conducted to characterize soil properties of a rehabilitated-degraded forestland and an adjacent natural forest in two major forest types, representing the lowland and hill-dipterocarp forests at Bidor and Kinta Forest Reserves, respectively. Twelve soil profiles were dug at both sites. At Bidor site, the soil profiles were under rehabilitated secondary forests (B1 and B2), an abandoned *Acacia mangium* plantation (B3 and B4) and natural forests (B5 and B6) of lowland dipterocarp. However, at Kinta site, the soil profiles were located in differing topography: rehabilitated secondary forests at 450 m (K1 and K2), rehabilitated secondary forests at 550 m (K3 and K4) and natural forests at 650 m (K5 and K6) above sea level. The effect of rehabilitating the forests could be seen by the accumulation of organic matter in the uppermost layer, which was assumed to be at an intermediate stage of mineralization. The soil morphology in natural forests of Bidor site exhibited a thicker and darker upper horizon than that of the rehabilitated sites, whereas, those at Kinta site had pronounced soil color in the upper horizon, though to come from decomposition of organic matter. The soils were very acid (pH <5.5), having low activity clay resulting in low (<16 $\text{cmol}_c\ \text{kg}^{-1}$) Cation Exchange Capacity (CEC), available P (Av. P), total nitrogen and exchangeable bases, but high in exchangeable Al. High exchangeable Al was the main cause of soil acidity. The main source of negative charge was the organic matter which affected the CEC, Points Zero Salt Effect (PZSE) and σp values. The soils were considered as strongly weathered, devoid of 2:1 type clay minerals. Kaolinite and gibbsite dominated the clay fraction of the soils at both sites. It is recommended that soil characteristics be taken into consideration prior and during the rehabilitation of degraded forestland in tropical rainforests.

Key words: Clay minerals, lowland and hill dipterocarp forests, rehabilitation, soil properties, tropical rainforests

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INTRODUCTION

Tropical rainforest is one of the most complex ecosystems existing among the earth ecosystems (Whitmore, 1998; FAO, 2001). However, the tropical rainforests are prevailed at unprecedented rate by human activities due to overexploitation of forest areas through deforestation, excessive logging and shifting cultivation, leading to degradation of forestland. Degradation of forestland commonly refers to the intensity of deterioration of physical and chemical of the areas. Physical degradation involves with an increase the compaction and erosion of the soils while chemical degradation reflects to decrease in soil fertility (ITTO, 2002; Arifin *et al.*, 2008b). Forest rehabilitation process of degraded forestland in tropical regions in particular Peninsular Malaysia commonly involves with the plantation of high quality indigenous species from diptrocarpaceae family or exotic species such as *Khaya ivorensis, Azadirachta excelsa*, *Acacia mangium* and *Pinus carribae* (Appanah and Weinland, 1993).

In Peninsular Malaysia, lowland and hill dipterocarp forests are well known as the most enormous forest types due to high biological diversity and many valuable high quality timber trees (Appanah and Weinland, 1993; Manokaran and Swaine, 1994). The characterization of lowland and hill dipterocarp forests are based on the altitude of above sea level (a.s.l) of which the former ranged from 0 to 300 m.a.s.l. while the later ranged from 300 to 700 m.a.s.l. However, such forests have been deteriorating due to anthropogenic activities such as the conversion of natural forest to large scale commercial plantation (oil palm and rubber) and extensive logging operation resulting in degraded forestland. These degraded lands are characterized by the deterioration of soil properties and damage of residual trees (ITTO, 2002). Most of the scientists agreed that when natural forest is cleared, the vegetation is unable to regenerate easily even in humid tropical region with high rainfall. This because the nutrient stocks in the soils are depleted (Moran *et al.*, 2000; Lu *et al.*, 2002; Arifin *et al.*, 2008a).

Rehabilitation of degraded forestland becomes very important in order to curtail the loss of soil nutrients and improve vegetation stand or composition as well as for environmental concern. In Malaysia, rehabilitation of degraded forestland due to abandoned shifting cultivation has been successfully implemented under the ecosystem rehabilitation in Sarawak (Kendawang *et al.*, 2004) and degraded forestland due to excessive harvesting has been rehabilitated by the enrichment planting technique in Peninsular Malaysia (Appanah and Weinland, 1993; Arifin *et al.*, 2008b; Affendy *et al.*, 2009; Hamzah *et al.*, 2009). Rehabilitation of tropical rainforest on severely degraded land requires knowledge on soil science for better understanding of the effective soil conservation and management. However, most of the previous studies have emphasized the growth performance of planted species along with the planting technique with less attention on soil morphological, physico-chemical and charge characteristics and clay mineralogical properties. The empirical data of soil properties of degraded forestland under rehabilitation are still lacking. Such information is important in order to characterize the soil properties in relation to the soil development, weathering and fertility status for an accurate measures soil conservation and management.

The present study was conducted in the Multi-Storied Forest Management System, a technical cooperation project between the Forestry Department Peninsular Malaysia (FDPM) and Japan International Cooperation Agency (JICA) in Perak, Peninsular Malaysia. Through this project, various valuable dipterocarp tree species have been planted with different rehabilitation techniques. However, such rehabilitation efforts on degraded forestland require an understanding and assessment on the ecosystem involved, such as soils (Ohta, 1990a;

Ishizuka *et al*., 2000), species selection or site suitability (Appanah and Weinland, 1993) and tree planting technique (Arifin *et al*., 2008b). Thus, this study aims to elucidate the soil properties of degraded forestland under rehabilitation forest in comparison to an adjacent natural forest at lowland and hill dipterocarp forests in Perak, Peninsular Malaysia. The soil's morphological, physico-chemical, charge and mineralogical properties at the study sites were emphasized and the soils at both sites were classified in terms of weathering process and nutrient status which mainly influenced by the parent materials.

MATERIALS AND METHODS

Description of Study Sites

This study was conducted at the Multi-Storied Forest Management System (MSFS), a joint collaborative project between the Governments of Malaysia and Japan. It was cooperatively initiated in 1991 in order to promote forest plantation activities for sustainable forest development and management in the tropics. Under these project, two sites were selected namely Bidor and Kinta Forest Reserves, Perak, Peninsular Malaysia. The Bidor Forest Reserve, located at 4° 07' N and 101° 37' E, is classified as lowland dipterocarp forest. It is located at 30 km south of Ipoh, the business city of Perak. The Kinta Forest Reserve, located at 4° 40' N and 101° 60' E, consists of approximately 150 ha of rehabilitated logged-over forest and is classified as hill dipterocarp forest. The altitude at the former site is ranging from 10 to 30 m above sea level (asl) with slight undulations, whereas the later site is situated on a steep mountainous region having 35 to 45° with an elevation ranging from 400 to 700 m.a.s.l.

The climate of Peninsular Malaysia is typically humid tropical or wet equatorial, which is characterized by high temperature and high rainfall throughout the year. Thus, both sites are classified as tropical rainforest under Koppen's meteorological classification. The relative humidity at the Bidor site varies from 70 to 98% and less than 50% during wet and dry period, respectively. The average annual precipitation is 3,050 mm and the mean temperature is approximately 29.8°C (1990 to 2002) at the Bidor weather station about 5 km North-East of Bidor site and that of Kinta site the average annual precipitation, temperature and humidity from (1990 to 2002) are 2500 mm, 25.5°C and 92.4%, respectively at the Tapah weather station approximately 20 km South of the Kinta site (Mustafa *et al*., 2002).

The Bidor Forest Reserve consists of two distinct areas namely sites A and B. Site A, located at the Northeast part of Bidor, is on sedimentary and metamorphic rocks of Silurian to Devonian periods, while site B, situated at the Southwest, is on unconsolidated materials of Tertiary periods. However, both areas have been subjected to forestland degradation by the excessive logging and abandoned plantation of *Acacia mangium*, which is consequently regenerated into a secondary forest. The soil at Kinta Forest Reseve is derived from granite, which has undergone considerable clay formation. The geology of Kinta site is characterized by acid intrusive rock. The native tree species at both sites are dominated by dipterocarp and non dipterocarp species. The map and site history of both sites including tree species, planting density and distance are described in details by Arifin *et al.* (2008a, b).

Soil Sampling

Soil survey and sampling were carried out from August to October 2009 at Bidor and Kinta sites. A total of twelve soil pits were dug; there were six profiles at each Bidor and Kinta sites. The soil profiles were described accordingly, followed by soil sampling to the following depths: 0-20, 20-40, 40-60, 60-80, 80-100, 100-120 and 120-150 cm. In addition, the soil profiles were also characterized based on the soil horizon. The B1 and B2 profiles located at the northeast part at a relatively high area (upper slope) of the forest reserve which formerly dominated by regenerated pioneer secondary forests and other shrubs and herbs species prior to forest plantation with various dipterocarp species in 1995. The B3 and B4 profiles located at a relatively low or flat area (lower slope) of Southwest part of Bidor was an area of fast growing tree plantations (*Acacia mangium*) in the late 1980s for the Compensatory Forest Plantation Project (CFPP). In addition, B5 and B6 profiles were situated at a relatively flat area of adjacent natural forest.

The Kinta site was logged-over using selective logged-over natural forest system in 1990s. The logging activities significantly resulted in large and small gaps left in the forest with dense shrubs including ferns, palms and other tree species regenerated within 2 to 3 years (Mustafa *et al*., 2002). In 1995, the area was subjected to forest rehabilitation under the Multi-Storied Forest Management System through the plantation of various dipterocarp species such as *Shorea* sp., *Hopea* sp. and *Dipterocarpus* sp. which were implemented under various spacing of line and gap planting techniques. Soil profiles hereafter designated as K1 and K2 at the line planting (lower slope) and soil profiles at gap planting of K3 and K4 (upper slope) and K5 and K6 at adjacent natural forest were dug. The K1 and K2 profiles were located an elevation of 450 m.a.s.l. with a relatively stable lower slope of less than 10°, whereas the K3 and K4 profiles were situated at the upper slope with an elevation of 550 m.a.s.l., respectively and slope of less than 40°. The adjacent natural forest (K5 and K6 profiles) was dominated by dipterocarp species, such as *Shorea curtisii*, *S. leprosula*, *S. pauciflora*, *S. parvifolia*, *S. roxburgii*, *S. acuminata*, *S. macrophylla*, *S. macroptera* and other non dipterocarp species. The slope and elevation at the adjacent natural forest were 35° and 650 m above sea level, respectively.

Soil Analysis

The samples were air-dried and passed through a 2 mm mesh-sieve for physico-chemical properties, characteristics and clay mineral composition. All plant materials such as fine roots, twigs and leaves were removed carefully. In addition, core samples (100 mL) were collected in triplicate for determination of bulk density. Particle-size distribution was determined by pipette method. Soil pH was measured with a glass electrode using a soil to solution (H_2O and 1 M KCl) ratio of 1:5 after reciprocal shaking for 1 h (denoted as pH_w and pH_k, respectively). Electrical Conductivity (EC) was measured using the supernatant solution after reciprocal shaking 1 h at soil to water ratio of 1:5. Total Carbon (TC) and Total Nitrogen (TN) contents were determined by a dry combustion method using NC analyzer (Sumito Chemical, Sumigraph model NC-80). Available P (here after denoted as Av. P) was determined by the Bray II method (Bray and Kurts, 1945).

The contents of exchangeable bases were extracted twice with 1 M ammonium acetate at pH 7.0 for determination of Ca, Mg, K and Na, by reciprocal shaking and centrifugation at a soil to solution of 1:5. The contents of exchangeable bases were determined by atomic absorption spectrophotometry for Ca, Mg and K and by flame photometry for Na (AA-6800; Shimadzu; Kyoto, Japan). After the extraction of exchangeable bases, the residue was washed once with 20 mL of water and twice with 20 mL of 99% of Ethanol to remove the excess salt. Then, the ammonium ion was extracted with 30 mL of 10% of NaCl twice by reciprocal shaking for 1 h, followed by centrifugation for 10 min at 179 G. The amount of NH_4 ion replaced by Na was determined as Cation Exchange Capacity (CEC) by the steam distillation and titration method. Exchangeable Al, H and NH_4 were extracted with 1 M KCl. Exchangeable acidity (Al and H) was determined by titration method with 0.01 M NaOH and the content of exchangeable Al was determined with 0.01 M HCl. The content of exchangeable H was calculated as the difference between the values of the exchange acidity and exchangeable Al. The amount of NH_4 was measured using the indophenols blue Bray II method (Mulvaney, 1996). The Point of Zero Salt Effect (PZSE) and the residual charge at PZSE (σp) were measured by the modified salt titration method of STPT (Sakurai *et al*., 1988). The amounts of Al and Fe soluble in ammonium oxalate (Alo and Feo) were extracted by the method of McKeague and Day (1966). The amounts of Al and Fe soluble in dithionate-citrate system buffered with sodium bicarbonate (designated as Ald and Fed, respectively) were extracted by the method of Mehra and Jackson (1960). The concentration of extracted Fe and Al were determined by sequential plasma spectrometry (Shimadzu, ICP-1000IV). Clay mineral composition was identified by X-ray diffraction analysis using CuKα radiation.

Statistical Analysis

In order to detect any significant relationship among physico-chemical properties, a linear regression analysis was performed. All statistical tests were performed in SPSS version 16.0 for windows.

RESULTS AND DISCUSSION

Soil Morphological Characteristics

The soil of these sites was highly weathered, with deep solum. The most significant morphological difference between the soils at Bidor and Kinta sites was soil texture, presumably related to the parent materials. At Bidor site, there were two different soil types. In this location, at sites B1 and B2, the soil is very deep and highly weathered. It was developed from sandstone and the texture was sandy clay loam throughout the profile and the color of the soil became redder with depth. It had an argillic horizon and thus qualifies as an Ultisols. The soils at B3 and B4 sites were both loamy while the B5 and B6 sites were sandy throughout the horizon which developed from granite wash. From the morphological features in the field, this soil was clearly an Inceptisol. Soils at B5 and B6 site were characterized as sandy loam topsoil, overlying coarse sand. Clearly, the sandy materials appearing at about 60 cm below the surface and that above it were of different period of sedimentation. This soil can also be classified as an inceptisol from the standpoint of field investigation.

The soil morphology was greatly different within a small area in the lowland of dipterocarp forest of Bidor where soil morphological properties between the B1, B2 and B3 to B6 profiles were relatively different even though there was a very small difference in slope gradient. The soil texture was the sandy clay to clay throughout the profile with abundant amount of quartz, following the development of patchy cutans on the ped surfaces in the deeper part of the B1 and B2 profiles. Meanwhile, the B3 to B6 profiles were accumulated with fine clayey fraction at the B-horizon without the development of patchy cutans, suggesting a discontinuity of sedimentation in parent materials. This phenomenon was probably due to the difference in weathering process of parent materials of sedimentary rocks in B1 and B2 profiles and unconsolidated or alluvial sediments at B3 to B6 profiles. The outwash materials (alluvium materials) were assumed to be transported and deposited by water from the surroundings areas during the Silurian to Devonian periods and its characteristics were chemically reduced due to high moisture content.

The soils at Kinta site were situated on a hill covered by planted dipterocarp forest which developed from granite, which is the most important rock type in Malaysia. The soils were present at high elevation. Sandy clay was dominant in the uppermost layer (A-horizon), but the subsoils were clayey in nature. The soil structures were well developed associated with the presence of patchy cutans. The formation of patchy cutan in the horizon was probably due to the continuity of clay sedimentation throughout the profiles. The soils can be classified as Ultisols due to the presence of cutans. At the deeper part of K4, a large amount of stoney gravels (weathered granite) was found. This confirmed that the soils were derived from the granite. During the soil sampling, soil fauna activity was observed at B2, B3, B4, B5 and B6 profiles. They were mainly earthworms and small mammals. There was no evidence of soil fauna activity at the B1 site. The organic layer at the B3 was thicker (more than 10 cm thick) than that of the B1 and B2 sites. This could be attributed to the supply of raw materials and the different types of fauna present. The evidence of soil fauna activity could be seen under a thick litter above the ground of the plantation site (Fisher, 1995). No soil fauna activity at the B1 site was probably due to the canopy, which was not closed and dominated by undergrowth shrub even after more than 10 years of rehabilitation.

At the Kinta site, the influence of rehabilitation by means of the contribution of raw materials to the uppermost layer could be seen based on the similar depth of 5 cm (natural forest). This phenomenon is due to the decomposition of plant debris, which was more frequent in the high altitude, associated with the soil fauna activity and high precipitation. Numerous studies found that high soil fauna activity, organic matter and rainfall (Ohta, 1990a, b) and topographical position (Montesur *et al*., 1997) would lead to rapid decomposition of plant debris and stronger development of soil structure beneath the forest stand.

At the Bidor site, the most significant difference among the soils were color (10YR 2/1)and the thickness of A-horizon, which was at the depth of 10 cm at the B5 and B6 sites as compared to 5 cm depth at B1 to B4 sites. A thicker A-horizon and the darker soil color (10YR 5/6) in the former than the latter sites could be ascribed due to high amounts of peaty materials. This reflects the contribution of organic matter from the mature vegetation at B5 and B6 sites. On the other hand, the establishment of forest plantation (*A. mangium*) had resulted in the thinner organic layer and lighter soil color. Such a result is in agreement with the findings of Kadir *et al*. (2001), who reported that delayed fire influenced soil color and organic matter content at the surface layers. Similar finding on the accumulation of organic matter in the topsoil had been reported by Ishizuka *et al*. (1998, 2000). Hattori *et al*. (2005) found that the accumulation of organic materials is higher in the surface horizon at remnant forest than other degraded land in Sarawak, Malaysia.

The thin O-layer at the B1 and B2 sites (rehabilitation forest) was probably due to the supply of raw materials since the trees were considered as immature stage (at 15 year-old) in comparison to a continuous supply of organic matter from mature vegetation in the natural forest. Thus, the O-horizon of soils in natural forest at both Bidor and Kinta sites tended to have lower hue, value and chroma as compared to those at the planting sites, reflecting the significant contribution of organic matter to soil color. A large amount of fine roots was present in the uppermost layer of the soils across the study areas. However, the occurrence of fine roots was restricted only to the argillic horizon of the soils at the K4, K5 and K6 sites. At the B1, B2 and B3 sites, fine roots could be found from the upper layer through to deeper part of the solum, except at the lower part of soil at B5 and B6 sites. This was due to good soil structures and friable consistence, resulting from the loam to sandy loam texture at Bidor site. This reflects that soil compaction did not occur and was not a limiting factor for the tree growth because fine root penetrated the deeper part of the soil. At the B3 and B4 sites of abundant *A. mangium* plantation, it seems like plant species influenced the growth of fine roots, which was also associated with the soil fauna activity in the soil.

Accumulation of thick litter of about 10 cm above the ground was observed in the field during the soil sampling at Bidor site. This litter, a potential source of organic matter for the soils, mainly consisted of undecomposed *Acacia* and *Shorea* sp. leaves, which were not found at the other planting site. However, this does not necessary means that the other planting site was not effective in producing litter. A study by Fisher (1995) stated that degraded land could be improved by planting fast growing tree species such as *Acacia mangium* that grew rapidly and returned large amounts of organic matter 3 years after establishment in tropical rain forest of Costa Rica. The advantage of *A. mangium* is that it is able to fix nitrogen in the atmosphere and provide large root systems, which allow them to accumulate nutrients from a very large volume of soil and subsequently increase the soil fertility (Fisher, 1995). These results reveal that the initial changes of soil morphology as a result of the rehabilitation of degraded land were restricted to the uppermost layer and were more pronounced under the *A. mangium* stand by developing a large quantity of roots and litter fall that subsequently enriched soil fauna activities (Ohta, 1990a).

Soil Physico-Chemical Properties

The textural composition of the soils at the study sites was affected by the weathering processes of the parent materials. Apparently, soils at both sites can be divided into two textural classes based on the clay and sand contents. The clay content of the soils at Bidor site was less than 25% and sand content more than 70% (Table 1). In comparison, in the Kinta site, clay content was more pronounced, attaining a value of more than 30%, while sand content was less than 62% (Table 2). The relatively low values of silt and clay contents of the soils at the Bidor site were probably due to the weathering process, reflected by low silt to clay ratios, which are the characteristics of humid soils (Kauffman *et al.*, 1998). The B1 to B6 profiles could be considered as sandy soils because the sand content was more than 75% throughout the profiles. The high sand content in these two soils is related to sandy parent material, which is granite wash deposited a long time ago. Reflecting their sandy materials, the soils had very low clay and silt contents that exhibited inconsistent increase with depth. The inconsistent increase of clay and silt contents could be explained by a minimal translocation of finer clay particles throughout the profiles.

In the case of Kinta profiles, the clay contents significantly increased with depth, while the sand contents decreased. Since patchy cutans were found in the subsoil at these sites, a significant increase of clay contents with depth could be ascribed to the downward movement of clay by eluviation, accompanied by illuviation promoted by rain water (Hattori *et al.*, 2005). Stronger clay migrations are more pronounced in the fine soil than in the coarse soils, corresponding to the high level of development of soil structure (Ohta and Effendi, 1992). The pHw and pHk values both in Bidor and Kinta soils ranged from 4.15 to 5.89 and 3.42 to 5.28, respectively, indicating that the soils were strongly to moderately acid. The pH values tended to increase with depth. It seems that the soil acidity of the area undergoing rehabilitation (B1, B2, B3, B4, K1, K2, K3 and K4) is not much different from that of the natural forest (B5, B6, K5 and K6). The lower pH values at the surface layer across the study sites correspond to the larger amounts of organic matter in the topsoil, reflecting that organic matter is responsible for acidity through litter decomposition. The higher acidity in the surface layer is probably due to the contribution of organic matter supplied from the vegetation since all the sites were covered with trees and the decomposition of organic matter lead to the acidification of surface soil (Sakurai *et al.*, 1998). Ishizuka *et al.* (1998, 2000) and Hattori *et al.* (2005) found that organic matter and exchangeable Al contributed to the soil acidity of degraded land under rehabilitation in Sarawak, Malaysia.

Table 1: Physico-chemical properties of the soils at lowland dipterocarp forest (Bidor)

								Exchangeable cations												
				T-C	T-N	C/N	CEC[a]	Ca	Mg	K	Na	Al	H	ECEC[b]		Av.P	Bd[d]	Clay	Silt	Sand
Plot	Depth (cm)	pH$_w$	pH$_k$	(g kg^{-1})		ratio	(cmol$_c$ kg^{-1})								Al.S[c]	(mg P kg^{-1})	(gcm^{-3})	(%)		
B1	0-20	4.55	3.99	21.7	1.53	14.2	4.81	0.22	0.12	0.08	0.06	1.57	0.43	2.05	76.59	11.9	1.3	10.5	2.9	86.6
	20-40	4.65	4.41	10.8	1.17	9.2	3.41	0.06	0.04	0.05	0.05	1.31	0.39	1.51	86.75	8.6	1.3	12.9	3.3	83.9
	40-60	4.85	4.52	5.0	0.54	9.3	2.48	0.09	0.03	0.06	0.05	1.43	0.34	1.66	86.14	7.6	1.4	20.5	3.8	75.8
	60-80	4.86	4.61	2.8	0.21	13.3	2.31	0.07	0.06	0.04	0.02	1.33	0.08	1.52	87.50	5.1	1.5	20.5	3.9	75.7
	80-100	4.89	4.64	2.7	0.20	13.5	2.21	0.04	0.03	0.05	0.02	1.23	0.05	1.37	89.78	5.2	1.6	17.2	2.3	80.5
	100-120	4.90	4.67	2.6	0.19	13.7	2.19	0.05	0.02	0.05	0.01	1.10	0.12	1.23	89.43	5.6	1.8	12.0	2.4	85.6
	120-150	4.90	4.69	2.6	0.18	14.4	2.00	0.03	0.04	0.02	0.01	1.23	0.24	1.33	92.48	4.3	2.2	14.0	2.0	84.0
B2	0-20	4.45	3.56	25.3	1.65	15.3	5.20	0.25	0.11	0.09	0.10	1.34	0.32	1.89	70.90	13.2	1.2	19.2	4.5	76.3
	20-40	4.53	3.61	15.4	1.34	11.5	3.54	0.21	0.12	0.09	0.05	1.32	0.21	1.79	73.74	10.4	1.2	17.1	4.9	78.0
	40-60	4.40	3.50	10.2	1.21	8.4	4.90	0.19	0.09	0.07	0.04	1.12	0.20	1.51	74.17	12.1	1.4	12.6	5.4	82.0
	60-80	4.54	3.67	4.5	0.67	6.7	3.10	0.23	0.06	0.05	0.03	1.00	0.17	1.37	72.99	6.5	1.5	10.8	5.8	83.4
	80-100	4.80	3.98	5.6	0.90	6.2	2.89	0.13	0.04	0.05	0.03	0.87	0.16	1.12	77.68	7.0	1.8	13.0	6.8	80.2
	100-120	4.67	4.43	3.5	0.40	8.8	2.90	0.09	0.04	0.03	0.01	0.98	0.15	1.15	85.22	5.6	2.0	7.8	6.7	85.5
	120-150	4.90	4.70	3.0	0.20	15.0	2.79	0.08	0.03	0.02	0.01	1.00	0.10	1.14	87.72	3.0	2.3	4.1	9.0	86.9
B3	0-20	4.45	3.97	39.8	3.86	10.3	12.10	0.29	0.15	0.12	0.09	2.31	0.58	2.96	78.04	23.1	1.5	10.2	4.6	85.2
	20-40	4.58	4.45	21.3	2.43	8.8	13.50	0.26	0.11	0.10	0.06	2.11	0.39	2.64	79.92	21.0	1.6	8.9	3.6	87.5
	40-60	4.57	4.49	40.2	3.54	11.4	11.80	0.23	0.12	0.07	0.04	1.86	0.26	2.32	80.17	25.6	1.7	15.4	4.5	80.1
	60-80	4.93	4.41	25.6	1.67	15.3	6.58	0.17	0.10	0.03	0.04	1.39	0.31	1.73	80.35	19.7	1.7	14.5	6.8	78.7
	80-100	4.83	4.69	24.2	1.56	15.5	6.10	0.16	0.06	0.03	0.03	1.36	0.26	1.64	82.93	10.4	1.9	18.2	8.1	73.7
	100-120	4.98	4.70	19.8	1.43	13.8	5.40	0.10	0.06	0.03	0.02	1.21	0.21	1.42	85.21	8.9	2.2	19.0	10.2	70.8
	120-150	5.12	4.91	14.5	1.26	11.5	5.00	0.13	0.04	0.02	0.02	1.00	0.15	1.21	82.64	6.5	2.5	21.0	11.6	67.4
B4	0-20	4.76	4.45	35.5	2.34	15.2	12.80	0.23	0.18	0.15	0.12	2.22	0.35	2.90	76.55	25.4	1.7	15.0	6.5	78.5
	20-40	4.80	4.20	34.2	2.12	16.1	10.30	0.21	0.17	0.08	0.06	1.81	0.21	2.33	77.68	20.3	1.6	12.8	7.5	79.7
	40-60	4.90	4.60	28.0	2.09	13.4	9.98	0.19	0.16	0.07	0.07	1.34	0.33	1.83	73.22	22.1	1.8	9.0	7.8	83.2
	60-80	5.43	4.90	25.3	1.67	15.1	8.76	0.15	0.08	0.09	0.04	1.38	0.19	1.74	79.31	17.4	2.1	8.8	5.6	85.6
	80-100	5.39	5.00	23.1	1.71	13.5	5.65	0.09	0.05	0.05	0.04	1.23	0.07	1.46	84.25	13.2	2.3	2.7	10.1	87.2
	100-120	5.45	5.10	18.8	1.45	13.0	5.12	0.08	0.06	0.04	0.05	0.85	0.06	1.08	78.70	9.8	2.5	5.3	5.9	88.8
	120-150	5.50	5.10	16.7	1.29	12.9	5.11	0.08	0.08	0.04	0.03	0.81	0.03	1.04	77.88	7.9	2.8	6.1	5.6	88.3
B5	0-20	4.23	3.82	47.7	5.18	9.2	15.60	0.29	0.21	0.15	0.10	4.13	0.56	4.88	84.63	29.4	1.0	4.5	5.5	90.0
	20-40	4.50	4.42	36.5	4.71	7.7	14.32	0.25	0.19	0.12	0.09	3.39	0.42	4.04	83.91	25.6	1.1	8.6	11.5	79.9
	40-60	5.07	5.01	32.3	3.15	10.3	12.12	0.14	0.18	0.09	0.07	2.18	0.28	2.66	81.95	20.5	1.3	9.8	12.3	77.9
	60-80	5.01	5.07	28.7	2.88	10.0	9.30	0.11	0.10	0.06	0.05	2.01	0.26	2.33	86.27	16.1	1.3	6.2	7.4	86.4
	80-100	5.12	5.10	24.1	2.43	9.9	5.60	0.08	0.08	0.04	0.04	1.89	0.17	2.13	88.73	10.3	1.5	5.3	6.5	88.2
	100-120	5.45	5.14	22.5	2.30	9.8	5.20	0.10	0.03	0.05	0.03	1.31	0.15	1.52	86.18	6.5	1.6	6.7	5.3	88.0
	120-150	5.46	5.19	19.8	3.22	6.1	3.80	0.05	0.03	0.06	0.03	1.00	0.10	1.17	85.47	5.4	1.6	5.1	6.5	88.4
B6	0-20	4.30	3.65	44.8	4.23	10.6	14.20	0.31	0.24	0.19	0.12	3.68	0.32	4.54	81.06	26.5	1.1	14.0	6.2	79.8
	20-40	4.42	3.92	30.6	3.40	9.0	12.10	0.26	0.20	0.17	0.08	3.30	0.24	4.01	82.29	21.0	1.2	18.8	6.0	75.2
	40-60	4.56	4.32	21.6	2.34	9.2	10.50	0.19	0.18	0.16	0.07	3.45	0.19	4.05	85.19	18.9	1.1	7.0	7.6	85.4
	60-80	4.98	4.60	25.8	2.45	10.5	11.31	0.15	0.14	0.10	0.09	2.81	0.23	3.29	85.41	16.4	1.3	7.4	7.8	84.8
	80-100	4.80	4.59	20.7	2.87	7.2	8.70	0.10	0.09	0.05	0.04	2.67	0.15	2.95	90.51	10.9	1.5	5.8	8.2	86.0
	100-120	5.21	4.80	18.5	2.11	8.8	6.80	0.08	0.09	0.05	0.04	2.10	0.09	2.36	88.98	8.6	1.6	2.9	9.0	88.1
	120-150	5.43	5.28	17.0	2.00	8.5	5.20	0.10	0.06	0.04	0.01	1.89	0.10	2.10	90.00	8.1	1.6	11.5	7.0	81.5

[a]Cation exchange capacity. [b]Sum of exchangeable Ca + Mg + K + Na. [c] Al saturation; exchangeable Al/ECECx100. [d]Bulk density

Table 2: Physico-chemical properties of the soils at hill dipterocarp forest (Kinta)

								Exchangeable cations												
				T-C	T-N	C/N	CEC[a]	Ca	Mg	K	Na	Al	H	ECEC[b]		Av.P	Bd[d]	Clay	Silt	Sand
Plot	Depth (cm)	pH_w	pH_k	(g kg^{-1})		ratio	(cmol$_c$ kg^{-1})								Al.S[c]	(mg P kg^{-1})	g cm^{-3}	(%)		
K1	0-20	4.21	3.54	26.5	3.45	7.7	12.50	0.32	0.15	0.10	0.06	4.12	0.89	4.75	86.74	12.5	1.3	35.8	8.9	55.3
	20-40	4.31	3.71	21.0	2.89	7.3	9.60	0.12	0.10	0.08	0.05	3.87	0.75	4.22	91.71	11.2	1.4	35.8	8.9	55.3
	40-60	4.70	3.93	6.7	2.16	6.5	6.61	0.09	0.07	0.05	0.04	3.58	0.60	3.83	93.47	9.0	1.5	35.8	8.9	55.3
	60-80	4.29	4.15	6.6	2.15	4.5	5.50	0.07	0.04	0.03	0.03	3.45	0.54	3.62	95.30	8.2	1.6	35.8	8.9	55.3
	80-100	4.33	4.21	6.5	2.10	3.1	6.98	0.08	0.06	0.03	0.02	3.25	0.47	3.44	94.48	6.5	1.6	35.8	8.9	55.3
	100-120	4.45	4.28	5.4	2.00	2.7	4.52	0.05	0.04	0.01	0.02	3.10	0.35	3.22	96.27	6.0	2.3	35.8	8.9	55.3
	120-150	4.60	4.40	5.1	1.78	2.9	4.00	0.02	0.01	0.01	0.01	2.50	0.21	2.55	98.04	5.2	2.5	35.8	8.9	55.3
K2	0-20	4.35	3.42	22.4	3.12	7.2	14.20	0.28	0.18	0.15	0.08	5.23	1.10	5.92	88.34	11.3	1.4	35.8	8.9	55.3
	20-40	4.52	3.58	18.5	3.05	6.1	10.10	0.26	0.14	0.11	0.06	5.12	0.96	5.69	89.98	10.4	1.3	35.8	8.9	55.3
	40-60	4.69	3.80	10.6	2.85	3.7	11.20	0.21	0.12	0.11	0.05	4.56	0.89	5.05	90.30	10.1	1.6	35.8	8.9	55.3
	60-80	4.98	3.65	7.5	2.52	3.0	8.40	0.18	0.09	0.07	0.04	3.54	0.65	3.92	90.31	8.67	1.8	35.8	8.9	55.3
	80-100	4.90	3.70	6.0	2.45	2.4	6.50	0.18	0.08	0.05	0.03	3.24	0.45	3.58	90.50	7.21	2.2	35.8	8.9	55.3
	100-120	5.12	4.12	5.5	2.25	2.4	6.20	0.11	0.05	0.05	0.03	3.12	0.32	3.36	92.86	5.6	2.5	50.9	20.1	29
	120-150	5.10	4.40	5.4	2.10	2.6	5.80	0.10	0.04	0.03	0.02	2.4	0.29	2.59	92.66	4.8	2.8	51.1	20.8	28.1
K3	0-20	4.23	3.86	36.0	2.70	13.3	10.62	0.17	0.13	0.11	0.05	2.62	0.33	3.07	85.24	10.9	1.6	31.0	8.3	60.8
	20-40	4.30	4.12	14.8	2.45	6.0	6.01	0.16	0.08	0.04	0.03	2.53	0.42	2.84	89.08	6.6	1.8	35.4	9.0	55.6
	40-60	4.33	4.14	10.7	2.39	4.5	7.81	0.06	0.03	0.06	0.04	2.39	0.23	2.58	92.64	9.0	2.3	36.8	9.6	53.5
	60-80	4.31	4.15	4.9	1.72	2.8	3.41	0.06	0.04	0.04	0.05	2.42	0.42	2.61	92.72	3.8	2.4	38.6	10.2	51.1
	80-100	4.65	4.44	4.3	1.20	3.6	2.60	0.02	0.01	0.01	0.02	1.45	0.18	1.51	96.03	2.5	2.8	44.5	10.1	45.4
	100-120	4.76	4.45	4.1	1.11	3.7	2.56	0.02	0.01	0.01	0.02	0.98	0.15	1.04	94.23	2.2	2.9	49.8	14.5	35.7
	120-150	4.80	4.67	4.0	1.00	4.0	2.10	0.02	0.01	0.01	0.02	0.56	0.11	0.62	90.32	2.1	2.9	52.4	16.7	30.9
K4	0-20	4.34	3.63	30.4	2.54	12.0	16.50	0.21	0.19	0.13	0.10	3.45	0.42	4.08	84.56	16.5	1.5	43.2	10.2	46.6
	20-40	4.50	3.76	28.9	2.21	13.1	7.40	0.19	0.17	0.11	0.09	3.32	0.34	3.88	85.57	13.2	1.6	44.5	14.3	41.2
	40-60	4.55	3.80	19.9	2.01	9.9	6.50	0.17	0.14	0.08	0.12	3.10	0.29	3.61	85.87	10.1	1.7	40.3	9.6	50.1
	60-80	4.62	3.98	15.4	1.90	8.1	7.10	0.09	0.09	0.07	0.05	2.50	0.21	2.80	89.29	8.4	1.8	49.5	18.4	32.1
	80-100	4.70	4.22	4.1	1.76	2.3	3.40	0.07	0.06	0.07	0.04	2.12	0.18	2.36	89.83	5.6	2.5	56.2	20.7	23.1
	100-120	4.89	4.54	4.0	1.20	3.3	2.80	0.08	0.06	0.05	0.02	1.89	0.11	2.10	90.00	3.1	2.6	58.9	20.9	20.2
	120-150	4.89	4.76	3.2	0.59	5.4	1.98	0.08	0.05	0.04	0.01	1.96	0.09	2.14	91.59	2.0	2.9	62.1	24.3	13.6
K5	0-20	4.34	4.20	53.0	3.21	16.5	20.70	0.52	0.32	0.29	0.18	4.23	0.52	5.54	76.35	23.4	1.1	34.4	7.6	58.1
	20-40	4.61	4.21	14.5	2.77	5.2	12.23	0.35	0.23	0.22	0.13	3.76	0.43	4.69	80.17	17.2	1.2	35.1	7.7	57.2
	40-60	4.72	4.37	13.2	1.89	7.0	10.30	0.14	0.20	0.20	0.10	3.42	0.39	4.06	84.24	15.9	1.4	36.9	6.6	56.5
	60-80	5.15	4.52	10.9	1.45	7.5	9.85	0.09	0.16	0.13	0.08	2.32	0.31	2.78	83.45	12.0	1.3	41.2	7.7	51.1
	80-100	4.89	4.22	5.4	0.50	10.8	8.92	0.06	0.10	0.07	0.07	2.18	0.34	2.48	87.90	9.0	1.5	51.9	7.9	40.2
	100-120	5.60	4.65	3.0	0.35	8.6	7.52	0.05	0.07	0.06	0.04	1.56	0.21	1.78	87.64	7.8	1.8	55.6	9.8	34.6
	120-150	5.50	4.69	2.9	0.30	9.7	7.20	0.05	0.06	0.05	0.01	1.21	0.18	1.38	87.68	6.8	2.0	58.7	10.2	31.1
K6	0-20	4.15	4.1	46.9	3.89	12.1	18.30	0.42	0.29	0.19	0.12	4.56	0.65	5.58	81.72	31.3	1.1	39.8	9.6	50.6
	20-40	4.32	4.07	40.8	2.56	15.9	15.40	0.29	0.22	0.14	0.1	4.21	0.43	4.96	84.88	26.5	1.2	43.1	10.3	46.6
	40-60	4.26	4.12	38.7	2.21	17.5	9.70	0.21	0.25	0.11	0.07	3.41	0.30	4.05	84.20	22.7	1.5	44.5	10.9	44.6
	60-80	4.45	4.25	20.8	2.16	9.6	5.40	0.21	0.18	0.16	0.09	3.34	0.36	3.98	83.92	14.6	1.4	47.6	12.3	40.1
	80-100	4.70	4.54	13.1	1.23	10.7	5.54	0.08	0.10	0.09	0.05	3.20	0.28	3.52	90.91	10.2	1.6	51.2	15.4	33.4
	100-120	5.45	4.89	8.7	1.16	7.5	4.80	0.07	0.05	0.09	0.05	2.87	0.21	3.13	91.69	8.6	1.8	53.2	19.8	27.0
	120-150	5.89	4.90	4.3	0.98	4.4	5.35	0.07	0.04	0.03	0.03	2.51	0.18	2.68	93.66	6.7	2.1	56.8	20.6	22.6

[a]Cation exchange capacity. [b]Sum of exchangeable Ca + Mg + K + Na. [c]Al saturation; exchangeable Al/ECECx100. [d]Bulk density

The value of acidity (sum of exchangeable Al and H) decreased with depth, resulting in the higher pH_w at depth. This suggests that the acidification process tended to be higher in the surface horizon than the subsoil. According to Kadir *et al.* (2001), the high acidity in the surface soil was associated with hydrolysis of Al, which was released under strongly leaching conditions and which subsequently lower pH, causing toxicity. On the other hand, the value of Al saturation (percentage of exchangeable Al content in ECEC) of the soils at the Bidor site was more than 70% throughout the profiles. However, the Al saturation of K4, K5 and K6 soils exhibited values of more than 80% throughout the pedon, except for the surface layer of K5 with a value of 76%. It is common knowledge that high value of Al saturation is associated with acidic soils. Thus, Al saturation is correlated with soil acidity.

The CEC value of Bidor soils consistently decreased with depth, except for the B2 soil. The highest CEC value of 15.6 $cmol_c\ kg^{-1}$ soil was found at the surface layer of B5 soil, which was attributed to the high organic matter content (Table 1). Similarly, in Kinta site, the CEC value was also low and tended to decrease with depth. Meanwhile, the high value of exchangeable cation (Ca, Mg, K and Na) surface layer of the K5 and K6 soils was influenced by the CEC. In order to find the relationship between cation exchange capacity with soil attributes, linear regressions were employed. For the Bidor site, the results showed that the CEC was highly correlated with organic matter, exchangeable Al, ECEC, acidity, available P and total N. Among them, organic matter content gave the highest correlation ($r = 0.79^{**}$, $p<0.05$), implying that organic matter plays a decreasing role on CEC from surface to subsurface horizons. This is different from the studies in the lowland dipterocarp forest of Kalimantan, Indonesia (Ohta and Effendi, 1992) and in the former shifting cultivation area of mixed dipterocarp forest in Sarawak, Malaysia (Hattori *et al*., 2005). These researchers found that CEC was highly correlated with clay content, which is not the case in this study. In addition, Kauffman *et al.* (1998) revealed that the low correlation between CEC and clay content can be explained by the extreme leaching of nutrients, especially among the sandy soils of the tropical region.

At the Kinta site, the exchangeable Ca, Mg and K were correlated with clay content. However, the clay content was not correlated with the CEC. Organic matter was probably the main source of CEC. This result is in agreement with the findings of Kadir *et al.* (2001), who stated that high clay content would not necessarily lead to high CEC, which is due to the behavior of kaolinite. The extreme leaching of nutrients under high rainfall in the tropics consequently decreases the CEC. It is commonly accepted that both the amount of clay and organic matter content are closely related to the cation exchange capacity (Ohta, 1990a). However, there was no correlation between CEC and clay contents in this study. This is probably due to minimal translocation of clay particles to deeper part of the profiles. In contrast, fine and total clay contents are usually considered as the soil components contributing most to the exchange capacity of the soils in the tropics (Martel *et al*., 1978; Sakurai *et al*., 1998). Excluding the natural forest at both sites, the CEC of the Bidor soils was slightly lower than Kinta site. This is probably due to the sandy texture in the former.

The content of Av. P was found to be higher in the A-horizon and decreased downward for all soils in accordance with the decrease in total carbon. Furthermore, the Av. P content was relatively higher both in the natural forests as compared to that of the rehabilitating sites. Total bases (sum of exchangeable Mg, Ca, K and Na) in the soils decreased inconsistently with depth. In general, the values of total SUM were higher in the soils at the planting site (B1 to B4) as compared to the natural forest (B5 and B6). In the case of Kinta soils, the total bases was higher in the surface layer than the subsoil and tended to decrease with increasing depth. The total bases in the surface layer of soil at natural forests K5 and

K6 were higher than that of the planting site (K1 to K4). In contrast, high amounts of exchangeable Ca and Mg in the soils at planting site than natural forest at Bidor was assumed to result from clear-felling and burning prior to the establishment of the rehabilitation project. Such results are in agreement with the findings of Hattori *et al.* (2005), who reported that a large amount of these cations were present in the surface layer of soils in the grassland after burning.

The total carbon, total nitrogen, Av. P, aluminum saturation, CEC and ECEC were higher in the uppermost layer of the natural forest as compared to that of others planted forest. It can be concluded that the nutrient status of the soils at the rehabilitation sites, which were formed from different parent materials and grown with different vegetations can be classified as an intermediate status when compared to the soils in the natural forests due to the capability of forest soils to accumulate large amount of organic matter, mainly supplied by the mature vegetation.

Soil Mineralogical and Sesquioxides Properties

The clay mineralogical compositions of the Bidor and Kinta soils were appreciably different due to differences in the mineralogy of the parent materials undergoing weathering under high rainfall environment. The parent materials of the soils at Bidor site were sedimentary (B1 and B2) and unconsolidated sediments (B3 to B6). The parent materials of soils would influence the removal of silica in the soils. There was a high amount of gibbsite in the sandy soils, with values exceeded that of kaolinite in some cases. Hydroxy-interlayered vermiculite (denoted as HIV) was only found as minor constituent in the B3 to B6 profiles. The soils at Kinta site were developed from igneous rock (granite). The soils were dominated by kaolin clay minerals, with a significant amount of gibbsite, quartz, HIV and illite. It is known that kaolinite and gibbsite mostly occur in soils at the advanced stage of weathering. Thus, the presence of kaolinite and gibbsite in the soils at Kinta site indicate that the soil had undergone advanced weathering under acidic conditions. This result is in agreement with the findings of Hattori *et al.* (2005) who studied the degraded tropical soils in Sarawak, Malaysia and Sakurai *et al.* (1996) who studied the evergreen and deciduous forest in Thailand. These researchers found that kaolinite was more abundant clay mineral than the others. High kaolin mineral in the soils at Kinta site was due to dissolution of the weathering products such as aluminum and silicon under suitable conditions under humid tropical climate. As weathering process proceed under high rainfall, rapid removal of bases through intensive leaching lead to the formation of kaolinite (Sakurai *et al.*, 1996). He further illustrated that the formation of various silicate clays and oxides of Fe and Al under the event of weathering process was in the following order: primary minerals>chlorite>illite>vermiculite >montmorillonite>kaolinite>oxides of Fe and Al.

Sakurai *et al.* (1996) and Ishizuka *et al.* (1998) reported that soils in tropical Southeast Asia were mostly dominated by variable charge minerals such as kaolinite. It is uncommon that gibbsite is more dominant than kaolinite in the soils of subtropical and tropical region, except for the strongly weathered soils (Chen *et al.*, 2001) or in the Inceptisols derived from volcanic ash in Taiwan and the Ultisols derived soils from feldspar parent materials in the mountainous area of South Carolina (Norfleet and Smith, 1989). Gibbsite occurred more abundantly than kaolinite in the Bidor soils. This is thought to be due to the alteration of primary minerals as the weathering process starts, releasing silicon faster than aluminum and subsequently accumulate amorphous aluminum, which is converted to crystalline gibbsite under suitable conditions.

The most important factor for the removal of silica is rainfall. This would result in the formation of gibbsite. Gibbsite was the dominant mineral in the Bidor soils and thus they can be considered as highly weathered soils. This result is in agreement with the clay mineral sequence of Jackson (1962), who stated that the gibbsite is the end product of silicate mineral weathering. Furthermore, gibbsite represents as indicator of most advanced stages of weathering and more commonly associated with highly weathered soils of the tropical and subtropical climates (Calvert *et al*., 1980; Chen *et al*., 2001). The constant amount of gibbsite throughout the pedon suggests that it occurs under a quite stable environment due to the presence of minor amount of HIV, which is antigibbsite (Jackson, 1963).

Chlorite was not found and the 2:1 type of clay minerals was almost absent in the soils of Bidor and Kinta sites, indicating that the soils were highly weathered. Therefore, further weathering of the soil associated with high rainfall would lead to the soil leaching and acidity, which subsequently increased the retention of aluminum. This consequently leads to the formation of soil with low nutrient capacity and the availability to the plants would be restricted. The rehabilitation by means of tree plantation would prevent further weathering but enhanced the soil fertility through the organic matter decomposition as well as soil restoration. The values of aluminum and iron extracted by dithionate-citrate-bicarbonate (Ald and Fed) were consistently higher than those extracted by acid oxalate (Alo and Feo) for both Bidor and Kinta soils. For the soil at Bidor site, the B1 and B2 soil showed very low value of amorphous oxides of iron and aluminum (Table 3). Slightly higher values of Ald and Fed may indicate a strongly weathered soil. These results were in agreement with the findings of Sakurai *et al*. (1989) and Kadir *et al*. (2001); they stated that high Ald and Fed were due to large accumulation of oxidized Al and Fe, which was accompanied by strong weathering. This phenomenon would be ascribed to the clay content, since the clay in these profiles was relatively higher, while the organic matter content was considerably low as compared to other two profiles (B3 to B6) in the Bidor site.

On the other hand, the B3 to B6 soils exhibited higher amorphous and crystalline oxides, associated with high activity ratio of Fe and Al contents throughout the profile. A substantially higher organic matter contents both at B3 to B6 soils would be the possible source of high Alo, Ald, Feo and Fed since the clay content was very low as compared that in the B1 and B2 soils (Sakurai *et al*., 1989). Although the values of both amorphous and crystalline oxides were not much different, we could conclude that the weathering status of the soils was similar. This is in agreement with the results from morphological study. The lower value of the amorphous and crystalline oxides in the deeper horizon of more than 60 cm would be attributed to the lower clay and organic matter contents indicating that the oxide of the former failed to bind the humus with clay. The highest value of Alo, Ald, Feo, Fed and Sid for both extraction with DCB and acid-oxalate was found at the 40-60 cm depth of B3 soil, corresponding to the high organic matter and clay contents. These results suggest that humus and clay particles would be responsible for stabilization of amorphous and crystalline oxides, consequently lead to higher value of free oxides in that layer than other layers.

In the case of Kinta soils, there was no conspicuous difference between both amorphous and crystalline oxides among the profiles except for the uppermost layer of the natural forest soil (K5 and K6), which was slightly higher than the K1 to K4 soils. Thus, the surface layer of the natural forest with high organic matter exhibited higher content of crystalline and amorphous aluminum oxides than those of the planting sites. Such results were already reported by Sakurai *et al*. (1989, 1996). They found that the continuous supply of organic matter from the mature vegetation associated with the decomposition processes would

Table 3: Mineralogical, sesquioxides properties and charge characteristics of the soils at lowland dipterocarp forest (Bidor)

		Oxalate extr.[a]			DCB extr.[b]							Clay mineral composition				
Plot	Depth (cm)	Alo (g kg^{-1})	Sio (g kg^{-1})	Feo (g kg^{-1})	Ald (g kg^{-1})	Sid (g kg^{-1})	Fed (g kg^{-1})	Alo/Ald	Feo/Fed	PZSE[c]	δp[d] ($cmol_c\ kg^{-1}$)	HIV	It	Kt	Gb	Qz
B1	0-20	1.39	1.65	1.47	2.04	2.28	4.62	0.68	0.32	3.70	0.80	-	-	+++	++++	±
	20-40	1.06	1.76	1.74	2.58	2.13	6.42	0.41	0.27	4.02	0.51	-	-	+++	++++	±
	40-60	1.26	1.72	0.91	3.46	2.14	8.60	0.36	0.11	4.02	0.40	-	-	+++	++++	±
	60-80	2.31	2.06	2.39	2.45	3.16	10.32	0.23	0.10	4.54	0.36	-	-	++	++++	±
	80-100	2.19	0.97	2.98	3.23	2.89	7.65	0.31	0.09	4.32	0.32	-	-	++	++++	±
	100-120	2.56	1.92	3.81	4.32	2.98	6.50	0.21	0.08	4.65	0.29	-	-	++	++++	±
	120-150	3.43	1.76	2.21	4.12	2.10	4.56	0.13	0.07	4.87	0.21	-	-	+++	++++	±
B2	0-20	2.34	1.30	1.23	2.76	1.87	2.12	0.45	0.87	3.54	1.12	-	±	+++	++++	±
	20-40	1.23	2.12	1.45	1.54	2.76	2.54	0.67	0.65	3.45	0.98	-	-	+++	++++	±
	40-60	3.45	1.19	1.89	4.32	2.12	2.80	0.32	0.43	4.12	0.67	-	-	++	++++	±
	60-80	2.19	1.09	0.43	3.21	1.67	1.89	0.28	0.56	4.10	0.45	-	-	++	++++	±
	80-100	3.89	2.56	1.80	4.76	2.90	3.23	0.19	0.76	4.46	0.23	±	-	+++	++++	±
	100-120	4.32	2.89	2.45	4.90	3.25	3.60	0.19	0.23	4.87	0.22	-	-	++	++++	±
	120-150	1.20	1.90	2.23	1.42	2.91	2.14	0.10	0.15	4.80	0.19	-	-	++	++++	±
B3	0-20	1.65	1.77	1.35	2.04	1.98	2.80	0.81	0.48	3.15	1.20	-	-	+++	+++	±
	20-40	1.23	2.07	1.74	4.92	2.80	2.08	0.25	0.83	4.08	0.90	±	±	+++	+++	±
	40-60	6.54	1.25	3.30	9.12	2.24	4.09	0.72	0.81	4.49	0.43	±	±	+++	+++	±
	60-80	3.27	1.92	2.68	5.58	3.21	5.16	0.59	0.52	4.15	0.75	±	±	+++	+++	±
	80-100	4.08	0.96	2.92	4.02	1.29	4.50	1.01	0.65	4.30	0.70	±	±	+++	+++	±
	100-120	4.54	0.78	2.40	4.00	1.90	4.67	1.14	0.51	4.80	0.54	±	±	+++	+++	±
	120-150	5.32	0.54	3.60	4.50	2.00	4.80	1.18	0.75	4.75	0.50	±	±	+++	+++	±
B4	0-20	2.10	1.87	1.56	2.43	2.23	2.78	0.98	0.70	3.23	1.65	±	-	+++	+++	±
	20-40	1.54	2.13	1.65	1.98	3.12	2.30	0.65	0.65	3.56	1.23	-	-	+++	+++	±
	40-60	3.45	1.20	2.56	4.32	2.76	3.23	0.70	0.60	4.32	0.98	±	±	+++	+++	±
	60-80	2.43	2.10	1.09	3.24	3.21	3.20	1.34	0.45	4.80	0.87	±	±	+++	+++	±
	80-100	2.80	2.50	3.21	3.87	4.10	3.90	1.32	0.82	3.88	0.50	±	±	+++	+++	±
	100-120	3.20	0.80	2.65	3.90	2.12	3.40	1.40	0.92	3.89	0.45	-	±	+++	+++	±
	120-150	4.12	0.40	3.80	4.56	1.78	4.80	1.23	0.40	4.65	0.40	±	±	+++	+++	±
B5	0-20	3.21	1.90	1.21	3.76	2.65	2.65	0.98	0.89	3.54	1.87	-	±	++	+++	+
	20-40	4.54	1.65	0.67	5.65	2.43	2.98	0.45	0.56	4.54	1.34	-	-	+++	++++	+
	40-60	4.87	1.20	1.45	6.54	2.65	2.90	1.32	0.50	4.40	1.09	-	-	+++	++++	+
	60-80	3.98	1.98	1.50	4.87	2.10	3.45	1.20	0.34	5.40	1.50	±	-	++	++++	++
	80-100	2.34	2.43	1.90	3.56	3.65	3.87	1.87	0.40	5.34	1.20	±	-	+	++++	+
	100-120	0.98	1.98	2.10	3.54	2.43	3.81	2.10	0.21	nd	nd	±	±	+	++++	+
	120-150	1.34	0.67	2.30	5.45	2.10	3.76	2.54	0.20	nd	nd	±	±	+	+++	++
B6	0-20	2.27	1.61	0.86	4.93	0.63	1.59	0.46	0.54	3.25	2.76	±	±	++	++++	+
	20-40	4.89	1.75	1.35	7.22	0.80	1.92	0.68	0.70	4.08	1.85	±	±	+++	++++	+
	40-60	4.29	1.29	1.93	6.74	0.57	2.59	0.64	0.74	4.15	1.60	±	±	+	++++	+
	60-80	3.97	1.69	1.10	5.63	0.31	2.79	0.71	0.39	4.30	1.32	±	±	++	+++	++
	80-100	4.56	2.12	1.87	5.73	0.34	2.98	0.80	0.63	4.39	1.20	±	±	++	++++	+
	100-120	4.56	2.34	2.34	5.80	0.23	3.45	0.79	0.68	4.80	0.96	±	-	+	++++	+
	120-150	4.90	2.87	2.45	5.80	0.60	2.90	0.84	0.84	nd	nd	-	-	+	++++	++

[a] Amounts of Al and Fe extracted by ammonium oxalate. [b] Amounts of Al and Fe extracted by a dithionate citrate system buffered with sodium bicarbonate. [c] Point of zero salt effect. [d] Residual charge at PZSE. [e] HIV: hydroxy-interlayered vermiculite, It: Illite, Kt: Kaolin minerals, Gb: Gibbsite, Qz: Quartz. -: Not determined, ±: 1-5%, +:5-20%, ++: 20-40%, +++: 40-60%, ++++: >60%. nd: could not be determined

prevent weathering and maintained both amorphous and crystalline aluminum in the form of oxide. The activity ratio of Al and Fe tended to be higher in the deeper part of K1 to K6 soils with respect to the increased clay content with increasing depth (Table 4). These results were in agreement with those reported by Eswaran and Bin (1978) and Ohta *et al.* (1993), who stated that the finer particles of silt and clay were transported together with Alo and Ald by eluviations into the deeper part of the soil profile. Among the oxides, Fed was found to be at more than 40 cm downwards of the profiles. This would be ascribed by the accumulation of oxidized Fe associated with clay content under highly leaching environment and weathering. On the other hand, low value of Feo/Fed ratio for B1 to B4 and K1 and K6 soils and the values ranged from 0.11 to 0.92 as compared to B5 and B6 soils (Table 3). This indicates that the former soil was in more stable conditions during the weathering processes than the latter (Hattori *et al.*, 2005). Ultisols are strongly weathered soils (Ohta *et al.*, 1993), while inceptisols are in the early stage of soil formation (Chen *et al.*, 2001).

Charge Characteristics

At the rehabilitation sites (B1 to B4 profiles), the values of ZPC tended to increase towards the deeper layers, while the σp decreased (Table 3). This phenomenon could be related to the content of both organic matter and exchangeable Al, which exhibited higher values in the surface soil. Sakurai *et al.* (1989) stated that the content of organic matter, exchangeable Al and 2:1 type clay minerals are the main factors that responsible to shift ZPC to lower value. Since the 2:1 type clay minerals were not found in the soils at Bidor site (except for minor amount of illite in the surface layer of B3 soil), the lower ZPC value in the surface than the subsurface layers was due organic matter, which decreased downwards. However, the ZPC value at the depth of 40-60 cm at B3 profile was high with a value of 4.50 although organic matter was high. Since the exchangeable Al was also very low in this layer, a significantly high content of both amorphous and crystalline oxides presumably contributed to a high ZPC and low σp values. This happened due to the characteristics of Al and Fe oxides, which have positive charge that was thought to block and reduced the permanent negative charge of the clay surface and consequently increased the ZPC value. Moreover, the Al oxide was also known to have a high ZPC at the neutral pH value (Sakurai *et al.*, 1989, 1996).

On the other hand, the low ZPC and high of σp values were found at the uppermost layer of the natural forests (B5 and B6). This was attributed to the negative charge generated by organic matter, which was relatively high compared to other soils. Numerous other studies (Sakurai *et al.*, 1989, 1990; Kadir *et al.*, 2001) have shown that the negative charge produced by organic matter was responsible for shifting the ZPC and σp into lower and higher values, respectively. However, the values of both ZPC and σp values were too low at the deeper layers of B6 profile. Since the amount of organic matter and exchangeable Al were extremely low, it was thought they were unable to influence the ZPC value. Thus, the abundance of quartz in the sand (>80%) fraction (Table 1) was presumably influencing the ZPC and σp values in that layer (Hendershot *et al.*, 1978).

In the case of Kinta soils, the ZPC value was lower than 4.0, except for the deeper part of the horizon, while the σp did not exceed 2.0 $\text{cmol}_c\ \text{kg}^{-1}$ (Table 4). In general, the ZPC values for all soils at the Kinta sites tended to be increased downward, while the σp values were vice versa. This trend was, however, similar to the Bidor soils. Clay minerals in the soils of both sites presumably influenced the ZPC values. As a result, excluding the surface layer of each horizon, the ZPC value of Kinta soils was slightly lower as compared to that of the Bidor soils, corresponding to the abundance of kaolinite in the former and abundance of

Table 4: Mineralogical, sesquioxides properties and charge characteristics of the soils at hill dipterocarp forest (Kinta)

		Oxalate extr.[a]			DCB extr.[b]							Clay mineral composition				
	Depth	Alo	Sio	Feo	Ald	Sid	Fed				δp[d]					
Plot	(cm)	(g kg⁻¹)						Alo/Ald	Feo/Fed	PZSE[c]	(cmol$_c$ kg^{-1})	HIV	It	Kt	Gb	Qz
K1	0-20	0.65	1.98	0.62	1.45	1.88	1.64	0.45	0.38	3.30	1.60	±	±	++++	++	+
	20-40	0.96	1.67	1.17	1.41	1.74	2.30	0.68	0.51	3.65	0.80	±	±	++++	++	+
	40-60	0.95	1.78	1.27	1.72	1.32	3.62	0.55	0.35	3.78	0.60	±	±	++++	+++	+
	60-80	0.99	1.54	1.14	1.28	0.80	3.31	0.77	0.34	3.75	0.51	±	±	++++	+	+
	80-100	1.28	1.63	1.39	1.46	0.59	3.26	0.88	0.43	3.80	0.40	±	±	++++	+	+
	100-120	1.26	1.45	1.45	1.36	0.60	3.42	0.93	0.42	4.12	0.34	±	±	++++	+	+
	120-150	1.34	1.60	1.57	1.40	0.73	3.65	0.96	0.43	4.40	0.29	±	±	++++	+	+
K2	0-20	0.82	1.87	0.89	1.65	2.10	1.67	0.50	0.53	3.25	1.89	-	-	++++	+	±
	20-40	0.99	1.54	1.21	1.54	1.76	1.80	0.64	0.67	3.43	1.45	±	-	++++	++	+
	40-60	0.87	1.40	1.25	1.45	1.65	2.10	0.60	0.60	3.67	1.32	-	±	++++	+	+
	60-80	1.12	1.50	1.45	1.32	1.70	2.30	0.85	0.63	3.87	0.89	±	±	++++	+	+
	80-100	1.34	1.56	1.56	1.41	1.60	3.45	0.95	0.45	3.80	0.67	±	±	++++	++	-
	100-120	1.65	1.32	1.34	1.98	1.54	3.87	0.83	0.35	4.23	0.54	±	±	++++	++	-
	120-150	1.80	1.12	1.67	2.12	1.40	3.98	0.85	0.42	4.54	0.50	±	±	++++	+	-
K3	0-20	1.21	1.82	1.25	2.38	2.54	3.45	0.51	0.36	3.40	2.00	±	±	++++	++	±
	20-40	1.08	1.56	2.13	2.36	2.23	3.32	0.46	0.64	3.70	0.75	±	±	++++	++	±
	40-60	1.46	1.43	2.46	2.92	1.78	2.58	0.50	0.95	3.92	0.60	±	±	++++	++	+
	60-80	1.57	1.38	2.65	2.89	1.65	2.72	0.54	0.97	3.97	0.30	±	±	++++	+++	+
	80-100	2.40	1.23	2.76	3.12	1.54	3.21	0.77	0.86	4.25	0.20	±	±	++++	++	+
	100-120	2.22	1.12	2.98	3.45	1.34	3.54	0.64	0.84	4.54	0.21	±	±	++++	++	+
	120-150	2.50	1.00	3.23	3.50	1.45	3.67	0.71	0.88	4.87	0.15	±	±	++++	++	+
K4	0-20	1.34	1.76	1.32	1.65	2.31	2.54	0.89	0.42	3.70	1.76	+	+	++++	++	±
	20-40	1.20	2.31	1.40	1.43	1.67	2.10	0.43	0.45	3.65	1.31	+	+	++++	++	±
	40-60	1.32	1.43	1.65	1.54	1.60	3.45	0.78	0.23	3.98	1.21	±	±	++++	++	+
	60-80	1.45	1.31	1.87	1.65	1.40	2.34	1.32	0.53	4.20	0.72	±	±	++++	++	+
	80-100	1.65	1.20	2.32	2.34	1.54	3.56	0.80	0.65	4.40	0.30	±	±	++++	++	+
	100-120	2.31	1.16	2.54	2.80	1.23	3.98	1.78	0.90	4.60	0.30	±	±	++++	++	+
	120-150	2.43	1.21	2.87	2.98	1.98	3.50	2.21	1.30	4.21	0.24	±	±	++++	++	+
K5	0-20	2.49	1.58	1.28	5.48	2.98	4.28	0.45	0.30	3.92	1.70	+	+	++++	++	±
	20-40	1.49	1.63	1.23	1.82	0.37	2.44	0.82	0.50	3.98	0.65	+	-	++++	+	±
	40-60	1.49	1.98	0.90	2.84	0.20	1.21	0.52	0.74	4.00	0.30	+	-	++++	++	±
	60-80	2.55	2.45	0.73	1.22	0.30	1.52	2.09	0.48	4.08	0.20	+	-	++++	+	+
	80-100	3.20	1.30	0.93	1.06	0.30	1.36	3.01	0.68	4.14	0.18	±	-	++++	+	+
	100-120	4.50	1.80	0.56	1.67	0.23	2.10	2.69	0.27	4.65	0.12	±	-	++++	+	±
	120-150	4.87	1.10	0.87	2.9	0.21	1.20	1.68	0.73	4.80	0.13	+	-	++++	+	±
K6	0-20	2.31	2.12	1.42	2.34	3.21	2.31	0.54	0.56	3.45	1.45	+	+	++++	±	±
	20-40	2.00	2.00	1.30	2.31	2.87	2.20	0.32	0.32	3.87	1.34	+	+	++++	±	±
	40-60	1.89	1.87	1.65	2.54	3.05	2.10	0.67	0.65	3.90	1.05	+	+	++++	±	±
	60-80	3.42	1.90	2.12	1.87	2.76	1.78	0.80	0.30	4.32	0.65	+	±	++++	+	+
	80-100	3.80	2.10	2.57	1.32	2.32	1.65	0.23	0.89	4.54	0.50	±	±	++++	+	+
	100-120	4.30	1.50	3.21	1.21	2.10	1.34	0.32	0.70	4.80	0.50	±	±	++++	+	±
	120-150	4.30	1.45	2.09	1.34	2.00	1.80	0.30	0.90	4.89	0.34	+	-	++++	+	±

[a]Amounts of Al and Fe extracted by ammonium oxalate. [b]Amounts of Al and Fe extracted by a dithionate citrate system buffered with sodium bicarbonate. [c]Point of zero salt effect. [d]Residual charge at PZSE. [e]HIV: hydroxy-interlayered vermiculite, It: Illite, Kt: Kaolin minerals, Gb: Gibbsite, Qz: Quartz. -: Not determined, ±: 1-5%, +:5-20%, ++: 20-40%, +++: 40-60%, ++++: >60%. nd: could not be determined

gibbsite in the latter. Kaolinite has both permanent negative and variable charge and therefore the ZPC value is zero. As a result the surface layer would carry negative charge at normal soil pH values (Sakurai *et al.*, 1990). Since the soil pH at these sites was considerably low, more protons would be added onto the surface clay and thus the crossover point of the titration curves was shifted to a lower pH range.

Soil Classification in the Study Area

The soils at Bidor and Kinta sites have udic soil moisture regime and isohyperthermic climatic regime, typical of soils in the well drained areas of tropical region. They can be categorized into various soil orders (and soil series) based on the morphological and physico-chemical properties. Soil profiles at B1 and B2 which was derived from sedimentary and metamorphic rocks have clay content in the depth of 40-120 cm which greater than 4% than the surface horizon and has an apparent CEC and ECEC per clay were lower than 16 and 12 $\text{cmol}_c\ \text{kg}^{-1}$, respectively thus satisfying the requirements for kandic properties. Moreover the base saturation of these soils is less than 35% while the ECEC value (>1.5 $\text{cmol}_c\ \text{kg}^{-1}$) throughout the profile could be classified as Typic Kandiudult (Soil Survey Staff, 1999). The soils at B5 and B6 were formed on unconsolidated parent materials. They are in the early stage of soil formation, having an umbric epipedon and cambic horizons. Both soils have a base saturation of less than 60% in all sub horizons between a depth of 20 to 150 cm satisfying for the dystrudepts properties. These soils can be classified as Inceptisols (Soil Survey Staff, 1999). From the morphological features in the field, this soil was clearly an Inceptisol. The underlying horizon of Kinta soils (K1 to K6) was described as an argilic horizon in the field as clayskin on the ped surface. Thus the K1, K2, K5 and K6 soils have an apparent CEC and ECEC per clay of <16 $\text{cmol}_c\ \text{kg}^{-1}$, respectively satisfying for the argilic horizon. The base saturation is less than 35% may be classified as Typic Paleudult (Soil Survey Staff, 1999). However, the soil at K3 and K4 cannot be classified as an argilic horizon as the CEC and ECEC per clay is less than 16 and 12 $\text{cmol}_c\ \text{kg}^{-1}$, respectively. Since, the clay increased from a depth of 40 to 120 cm and the total carbon decreased with depth may be suited into kandic properties. The base saturation is <35% and the ECEC value of more than 1.5 $\text{cmol}_c\ \text{kg}^{-1}$ could be classified as Typic Kandiudult.

The soils at Bidor (B1 to B4) and Kinta (K1 to K6) sites, which were derived from sedimentary, unconsolidated sediment and granite, respectively are classified as Red Yellow Podzolic by the Malaysia Soil Taxonomy (Paramananthan, 2000). The soils can be considered as low activity clay as the CEC values is less than 24 $\text{cmol}_c\ \text{kg}^{-1}$ clay. In terms of soil series, the soils at Kinta sites are classified as Rengam Series. At the Bidor site, the B1 and B2 soils are classified as Serdang Series. The other four soil profiles at the Bidor site do not fit into any of the soils currently classified under the Malaysian Soil Classification System. For the time being, the B3 to B6 soils are called Bidor Series.

CONCLUSIONS

Rehabilitating degraded tropical rainforest such as in the present study requires sufficient information on soils for a better soil and forest management. High level of Al. saturation was the main cause of soil acidity, associated with high rainfall in the humid tropical region. The cations were absorbed tightly and consequently their availability to plant was restricted. The main source of negative charge was the organic matter, which affected the cation exchange complex capacity. It is imperative to note that high level of Al saturation with predominated of kaolin minerals and gibbsite were the main cause of low fertility status both in rehabilitated and natural forests. Since the soils were highly weathered and concomitantly resulting in low fertility status, input of fresh organic matter from the trees by means of forest rehabilitation is an imperative effort on degraded tropical rainforests. Characterizing the soil properties in terms of morphology, physico-chemical, charge characteristics and clay minerals composition need to be taken into consideration prior to establishment of forest rehabilitation.

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