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Full Length Research Paper

Emphasizing the properties of soils occurring in different land use types of tropical rainforest in Sarawak, Malaysia

J. Aiza Shaliha[1], A. Arifin[1,4]*, A. H. Hazandy[1,4], S. Abdul-Latib[1],N.M. Majid[2] and J. Shamshuddin[3]

[1]Department of Forest Production, Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2]Department of Forest Management, Faculty of Forestry, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[3]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[4]Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

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Although, soil properties of tropical rainforest in Southeast Asia have been characterized by several researchers, limited information exists on soil characteristics due to conversion of natural forest into various land use types such as oil palm plantation, rubber plantation, forest plantation and secondary forest. A study was conducted to characterize the soil properties under various land use types of logged-over forest (LF), rehabilitation forest (RF), oil palm (OP) and rubber plantation (RP) at Universiti Putra Malaysia, Bintulu, Sarawak, Malaysia. Soil profiles were dug up to 100 cm depth and 50 cm width and were followed by soil sampling according to soil horizon. Soil morphology was determined in the field while soil physico-chemical properties were determined in the laboratory using standard soil analysis. The soils at RF, LF, OP and RP were derived from sandstone intercalated with shale which gives silty loam and sandy clay loam texture. The soils are acidic to weakly acidic with pH increases with depth. The Cation Exchange Capacity (CEC) and Total Carbon (TC) of soils tend to decrease with depth and it seems to be higher under OP and RP as compared to RF and LF. The Alo, Ald, Feo and Fed increased with depth in all of the profiles. The values of Point Zero of Salt Effect (PZSE) and σp are low in all sites with dominated by kaolin minerals and sesquioxide properties indicating that the soils are highly weathered and low soil fertility status.

Key words: Forest rehabilitation, logged-over forest, oil palm and rubber plantation, charge characteristic.

INTRODUCTION

Tropical rainforests cover about 6% of the earth's land surface and yet provide a habitat for more than 50% of the world's living plant and animal species (Archard et al., 2002; Mayaux et al., 2005). Total land area of Malaysia is approximately 32.8 million ha with 13.1 million ha in Peninsular Malaysia, 7.4 and 12.3 million ha in Sabah and Sarawak, respectively (Shahwahid, 2004). Malaysia's tropical rainforest is well known as one of the most complex ecosystems in the world where it is home to more than 8,000 species of flowering plants of which 2,500 are tree species (Forestry Department of Peninsular Malaysia, 1993).

Land use change encompasses ways in which human use of land have varied through time. Kumar (1986) re-

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*Corresponding author. E-mail: arifin_soil@yahoo.com, arifinabdu@putra.edu.my. Tel: 603-8946 7177/7411, 6019-3338657. Fax: 603-8943 2514.

ported that the changes in land use pattern under forest cover are due to agricultural activities such as rubber, oil palm and cocoa and non-forested land during 1960 to 2005 periods. Oil palm in Malaysia during the past five decades showed a dramatic growth. In Sarawak, the area used for oil palm cultivation expanded from 116,036 in 1995 to 508,307 ha in 2004, while those of other crops stagnated or declined slightly (Tanaka et al., 2009).

Malaysia has to strike a balance between development and conservation of the tropical forest. Degraded forest land in Malaysia due to deforestation is estimated at 4.45 million ha (1970 to 2002) (ITTO, 2002). Degraded forestland is reflected by the increase in soil erosion, decrease in soil fertility and biological degradation of the soils. Moreover, when a natural forest is cleared, the vegetation is unable to regenerate easily even though it is under humid tropical region with high rainfall because the nutrient stocks in the soils are extremely depleted (Ishizuka et al., 2000; Akbar et al., 2010; Saga et al., 2010; Heryati et al., 2011a).

In order to reverse such degraded forest land into more productive areas, plantation forest or rehabilitation activities are important countermeasures from a global perspective in terms of wood resources, environment, and species conservation worldwide. Rehabilitation efforts on degraded forest land require comprehensive understanding and assessment on the ecosystem involved, such as soil condition and fertility towards the establishment and progress of rehabilitation techniques in the future. The progress of rehabilitation program has been reported by several researchers (Nik et al., 1994; Cole et al., 1996; Suhaili et al., 1998; MacNamara et al., 2006; Heryati et al., 2011b).

However, most researchers have focused on species selection for replanting in relation to the growth performance with less concern on soil fertility or forest/soil health. Although, several studies concerned with soil fertility have been conducted on monoculture plantation of fast growing exotic species (Tiki and Fisher, 1998; Norisada et al., 2005; Heryati et al., 2011b). Under the rehabilitation of degraded forest land with high quality of dipterocarp species, limited studies have been conducted to characterize the soil properties, soil fertility (nutrient stock) as well as, the status of forest/soil health comprehensively.

In Malaysia, although the soil properties of rain forest have been characterized by several researchers, limited information exists on soil characteristics due to the conversion of forested area into various land use types for oil palm and rubber plantation, planted forest and subsequently secondary forest.

The objective of this study was to characterize the properties of soils at various land use types (planted/rehabilitated forest, logged-over forest, oil palm and rubber cultivation) in terms of their morphology, physico-chemical properties, sesquioxide contents, charge and mineralogical properties at Nirvana Forest Reserve, Universiti Putra Malaysia Bintulu Campus, Sarawak, Malaysia.

MATERIALS AND METHODS

Study site

This study was carried out at oil palm and rubber plantations rehabilitated forest (UPM-Mitsubishi plot) and logged-over forest (Nirvana Forest Reserve) in Universiti Putra Malaysia, Bintulu Campus, Sarawak, Malaysia on January, 2010. The site is situated about 10 km along Bintulu – Miri road (latitude 3° 12’ N and longitude 113° 05’E). The mean annual rainfall is about 2993 mm and the mean temperature is about 27°C. The mean monthly relative humidity of the area is usually above 80% and slightly lower during rainy season.

The rehabilitated forest is an abandoned shifting cultivation area. Rehabilitation forest (Malaysia Tropical Forest Regeneration Experimental Project) initially, was a join research project between Yokohama National University and Universiti Putra Malaysia sponsored by Mitsubishi Corporation in 1990. It was an attempt to create a native with the indigenous trees. The once deserted 50 ha areas is now becoming home to 350,000 trees and 126 species from the family of Dipterocapaceae and non-dipterocapaceae (Miyawaki, 2011). In contrast, the logged-over forests (Nirvana Reserve Forest) was logged over forest for a period of time and left idle without any forest management.

The oil palm and rubber plantations at Universiti Putra Malaysia (UPM) were opened in 1990. The purpose of the plantations was for student classes and research. UPM manages the farm management, while a private company does the maintenances. Now, the areas are left without maintenance due to low productivity.

Soil sampling and analysis

Soil profiles were dug for each sites and the size of the soil profile was 100 cm depth or more and 50 cm widths. The soil samples were collected according to genetic horizons for each site. Soil morphology properties such as texture, color, soil consistency, structures, boundary and roots were determined based on field observations. The soils were air-dried, homogenized and sieved through a 2 mm sieve for further analysis.

Particle-size distribution was determined using the pipette methods (Gee and Bauder, 1986). Soil pH was determined both in water and in 1 M KCl in a soil to solution ratio of 1: 2.5 using glass electrodes after reciprocal shaking for 1 h. The content of organic matter and total organic carbon were determined using loss on ignition method (Murugayah et al., 2009). Total N was determined using Kjeldahl method (Bremner and Mulvaney, 1982) and total carbon in soil was determined using LECO-412 C analyzer. Available phosphorus was determined using the Bray II method (Kuo, 1996). Al was extracted with 1 M KCl (Barnhisel and Bertsch, 1982) and the Al in the extract was determined by Atomic Absorption Spectrophotometer (AAS). Exchangeable cations were extracted with 1 M NH_4OAc buffered at pH 7. The concentrations of K, Ca, Mg and Na in the solutions were measured by AAS. Cation exchange capacity (CEC) was determined by leaching the ammonium ions from the exchange sites with 0.05 M K_2SO_4 after the soil was leached for the exchangeable cations extraction. Prior to that, the soil was washed with 100 ml of ethanol (95%). The point of zero salt effect (PZSE) and the residual charge at PZSE (σ_p) were elucidated by the modified salt titration method as proposed by Sakurai et al. (1988). The Dithionite-Citrate-Bicarbonate (DCB) method as described by Mehra and Jackson (1960) was used for the determination of Al, Fe and Si oxides and hydroxides (Ald, Fed

Table 1. Morphological characteristics of the soils.

Plot	Depth (cm)	Horizon	Color	Field texture[a]	Structure[b]	Consistency[c]	Roots[d]	Boundary[e]
RF	0-20	A	10YR4/4	L	1fsbk	fri	FeC	c
	20-40	B	10YR7/8	L	2fsbk	fri	FeC	c
	40-90	BC1	10YR6/8	L	2msbk	fri	FeF	c
	90-150	BC2	10YR6/8	L	2mab	fri	FeF	c
LF	0-20	A	7.5YR3/2	SL	fsbk	fri	FeC	cs
	20-46	Bt1	10YR6/6	SCL	2mab with cc	fi	MaC	c
	46-94	Bt2	10YR6/8	SCL	2mab with cc	fi	FeF	d
	94-100	Bt3	10YR7/8	SCL	2mab with cc	fi	FeF	d
OP	0-25	A	10YR 6/8	L	1fsbk	vfri	MaF	cs
	25-50	Bt1	10 YR7/8	L	1fsbk	fri	F.F	c
	50-88	BC	5YR6/8	L	1fab	fri	nf	c
	88-150	C	10YR7/6	L	1fab	fri	nf	d
RP	0-16	A	10YR4/4	SL	1fsbk	fi	FeC	cs
	16-40	Bt1	10YR7/8	SCL	1fsbk with cc	fi	MaF	cs
	40-80	Bt2	7.5YR5/8	CL	1fsbk with cc	fi	FeF	d
	80-126	C	7.5YR6/8	SL	2mab	fi massive	nf	d
	126>	R		SL	2mab	fi massive	nf	c

aTexture: L: loam, CL: clay loam, SC: Sandy clay, SL: Sandy loam, SCL: sandy clay loam; bGrade: 1: weak, 2: moderate, Size: c:coarse, f: fine, m: medium, Type: ab: angular blocky, sbk: subangular blocky, cc: clay cutans; cConsistency: fi: firm, fri: friable, vfri: very friable; dAbundance: Fe:few, Ma: many, nf: not found, Size: C:coarse, F: fine, Me: medium; eBoundary: c: clear, d: defuse, s: smooth.

and Sid). The non- crystalline (amorphous) of Al, Fe and Si oxides and hydroxides (Alo, Feo and Sio) were determined by using auto analyzer (AA) after extracting the soil with 0.2 mol L^{-1} at pH 3.0 by end to end shaker in the dark for 4 h (Mackeague and Day, 1966).XRD analysis was performed to determine the clay mineralogical composition (Markus et al., 2008). The treated clay specimen was then prepared on the glass slide and run on Philip PW 3040/60 X'pert Pro X-ray diffractometer, using CuK-alpha radiation target, operated at 40 kV and 30 mA. The oriented specimens were scanned from 3 to 50° 2θ at 1° min^{-1}. XRD data were collected and stored with connected PC. Semi-quantitative estimation of the mineral proportion was calculated from the height of a first peak.

Soil classification

The soils in the area belong to Berkenu and Nyalau (Ultisols and Inceptisols, respectively) series. The parent material for both soil series is sandstone intercalated with ferrogenous shale. Bekenu series can be classified as fine loamy, mixed, isohyperthermic Typic Paleudult. The topsoil has a light yellowish brown (10YR 6/4), while the rest of the profile has a uniform color of brownish yellow (10YR 6/8). The structures are weak to moderate, medium sub-angular blocky with an increase in consistency with depth (Peli et al., 1984). Paramanathan (2000) considered Bekenu series as a low fertility soil. The Nyalau series can be classified as coarse loamy, kaolinitic, isohyperthermic Typic Dystropept. The topsoil has a yellowish brown (10YR 5/6) color with a brownish yellow (10YR 6/8) to yellow (10YR 7/8) color in the B horizon. The structures are weak to moderate, fine to sub-angular blocky. The soil reaction is medium and well drained. The organic matter content is very high and tends to increase with depth (Peli et al., 1984; Saga et al., 2010).

RESULTS AND DISCUSSION

Soil morphological characteristics

Table 1 shows the main features of the soil morphological properties at the study sites. The soils in the profiles from RF, LF, OP and RP are relatively uniform among the location. The depth of solum at RF, LF, OP and RP ranges from 100 to 150 cm (deep solum). Up to 126 cm, rock fragments and parent materials were found at RP site, while these were absent for the rest of the profiles. Litter layer less than 1 cm was found at RF and LF sites.

Darker A horizon was found in all the pedons. Organic matter appeared to contribute significantly to the darker A horizon. Soil disturbances such as land conversion (rehabilitation forest, oil palm and rubber cultivation) seem to affect the soil color. The color (moist) for soils at RF, LF, OP and RP ranges from dark brown to dark brownish brown (surface) and reddish yellow to brownish yellow for subsurface soils. The soil profiles at RF, LF, OP and RP exhibit the A horizon with darker color, ranging from dark brown (7.5YR 3/2) and dark yellowish brown (10YR 4/4) to brownish yellow (10YR 6/8), probably due to the decomposition of organic matter. The lighter color of soils at OP and RP areas may be due to loss of organic matter caused by tillage and/or subsequent erosion (Kadir et al., 2001; Heshmati et al., 2012).

The texture of the soils at RF and OP is loam in all horizons. The soils at LF is silty loam in the A horizon, but at the deeper horizon the texture was silty clay loam. The A horizon of RP soils was silty loam, but at lower horizon (Bt1, Bt2, C and R) it changes to silty clay loam, clay loam and silty loam, respectively. The soils (RF, LF, OP and RP) are derived from sandstone intercalated with ferrogenous shale. Weak to moderate structures and medium to fine size with sub-angular blocky to angular blocky types throughout horizons in all pedons were observed. Clay cutans were observed on the ped faces in the B horizon of soils at LF, OP and RP, indicating illuvial accumulation of silicate clays. The consistencies of soils for both surface and subsurface at LF and RP pedons are friable to firm. Meanwhile, consistency of soils at RF and OP are friable to very friable. With depth both the stickiness and plasticity increases mainly due to the increasing amount of clay content (Kadir et al., 2001). Roots are abundant in all pedons, ranging from few to many coarse to fine root sizes. The RF and OP profiles show clear boundary, while LF and RP profiles show clear smooth to defuse boundary.

Physico-chemical properties of the soils

The textural composition of the soils at the study sites was related by the weathering processes of the parent materials. The clay content of the soils at rehabilitated forests (RF), logged-over forest (LF), oil palm (OP) and rubber cultivation (RP) area increases with depth, while sand composition is erratically decreased. The inconsistent increase in clay and silt contents can be explained by a minimal translocation of finer clay particles throughout the profiles (Zaidey et al., 2010). Since patchy cutans were found in the subsoil at LF, OP and RP 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 heavy rain (Hattori et al., 2005).

The physico-chemical properties of soils at RF, LF, OP and RP are shown in Table 2. The soil reaction of all profiles is acidic to weakly acidic (pH 3.6 to 5.2). The pH (H_2O and KCl) increases with depth. The soil acidity of the area undergoing rehabilitation (RF) and cultivation (OP and RP) is similar to that of the logged-over forest (LF). The higher acidity in the surface layer is probably due to the contribution of organic matter (OM) from the vegetation since all sites are covered by trees; decomposition of OM leads to the acidification (Arifin et al., 2007, 2008; Sakurai et al., 1998). The increase in pH (H_2O) with depth might be related to the increase in Fe and Al oxides and decrease of organic matter which inhibit high and low pH_0 values, respectively (Sanchez, 1976). Hydrolysis of Al under strong leaching condition produces acidity in these soils because at low pH Al is present in the exchange complex and diffuses into solution where it may lower the pH and cause toxicity (Kadir et al., 2001).

In general, the T-C contents is highest in the A horizon and decreases with depth for all sites. The T-C contents of the soils at oil palm cultivation and logged-over forest are higher than in the planted forest and rubber plantation. On the other hand, the percentage of organic matter (OM) and total organic carbon (TOC) for all sites seems similar, but the values decreased with depth. According to Ishizuka et al. (1998), OM content in the surface horizon was high due to the development of root mats. The OM and TOC percentage of the soils at LF site is the highest among the other sites. The CEC and total carbon (TC) tend to decrease with depth and seems to be higher under OP and RP as compared to those of RF and LF. TOC in soils is affected by the harvesting activities (OP and RP sites). The OM in the soil decreases because no input of OM from the ground covers plant. Similar results were reported by Nye and Greenland (1964), Kedawang et al. (2004) and Ilstedt et al. (2004). Soil organic matter declined rapidly after the soils were exposed to clearing activities.

The CEC of the soils at LF site exhibited higher value than the other areas due to continued supply of organic matter from the vegetation. The CEC of the soils in the RF, LF, OP and RP decreases with depth. These values indicated that the surface soils contain larger amount of variable charge materials due to the higher organic matter contents than the subsoil. Other researchers found that negative charge derived from the clay minerals affects the CEC of clayey soils in the tropics (Ohta and Effendi 1992a; Sakurai et al., 1998; Arifin et al., 2008). Exchangeable bases (K, Ca, Mg and Na) in the soils decrease irregularly with depth. In general, the values of total bases are higher in the soils at the RF, OP and RP sites as compared to LF site. The high amounts of bases at these sites are presumably due to fertilizer application at oil palm and rubber plantations. The higher content of Ca and Mg in the topsoil is assumed to be due to biological accumulation through litter supply and their lower mobility in the soils. Ohta and Effendi (1992b) stated that subsoil may be playing an important role in nutrient storage. They also assumed that some parts of the nutrients in the subsoil are pumped up slowly to the topsoil.

The exchangeable Al increases with depth, whereas, in OP and RP sites, it decreases with depth. Study conducted by Hattori et al. (2005) showed similar results as they also concluded that the Al concentrations were related to exchangeable bases and clay content. The high available P in the soils of oil palm and rubber plantations may be due to chemical fertilizer application, while at rehabilitation forest, it might be because of forest litter decomposition and also coming from the supply of organic matter from the vegetation. The available P was found to be higher in the A horizon and it decreases

Table 2. Physico-chemical properties of the soils.

Plot	Depth (cm)	Horizon	pH$_k$	pH$_w$	OM (%)	TOC (%)	T-C	T-N	CEC	Exchangeable cations					Av. P (ppm)	Granulometric composition				
										K	Ca	Mg	Na	Al		Clay	Silt	Sand	Sand/silt	Silt/clay
							(g kg^{-1})					cmol$_c$ kg^{-1}					(%)			
RF	0-20	A	3.78	4.55	5.40	3.13	1.02	0.15	11.07	0.04	0.26	0.33	0.03	1.98	0.36	20.00	42.46	37.36	0.88	2.12
	20-40	B	3.81	4.45	5.20	3.02	0.43	0.06	7.13	0.02	0.13	0.30	0.02	2.78	0.45	20.46	37.63	41.68	1.11	1.84
	40-90	BC1	3.86	4.70	5.00	2.90	0.31	0.03	7.05	0.02	0.05	0.22	0.02	2.24	0.39	19.37	37.62	42.89	1.14	1.94
	90-150	BC2	3.87	4.53	3.60	2.09	0.36	0.04	5.21	0.02	0.05	0.28	0.02	2.22	0.78	20.61	38.59	40.62	1.05	1.87
LF	0-20	A	3.65	4.28	9.80	5.68	3.23	0.25	16.07	0.05	0.11	0.27	0.02	1.67	0.14	14.53	15.65	69.78	4.46	1.08
	20-46	Bt1	3.98	4.35	7.80	4.52	1.09	0.06	7.86	0.02	0.03	0.25	0.01	2.03	0.28	22.34	16.99	60.60	3.57	0.76
	46-94	Bt2	3.97	5.68	6.60	3.83	0.24	0.05	7.86	0.01	0.03	0.14	0.00	3.39	0.27	28.20	16.32	55.42	3.40	0.58
	94-100	Bt3	3.96	4.79	5.20	3.02	0.25	0.05	4.11	0.01	0.02	0.13	0.01	2.15	0.44	31.03	16.80	52.11	3.10	0.54
OP	0-25	A	3.62	4.21	7.10	4.12	4.24	0.17	11.86	0.10	0.33	0.33	0.09	2.29	0.53	17.10	44.26	38.46	0.87	2.59
	25-50	Bt1	3.75	3.99	7.03	4.05	0.43	0.04	10.50	0.03	0.01	0.10	0.02	2.04	1.02	20.13	41.92	37.82	0.90	2.08
	50-88	BC	3.85	4.63	6.98	4.05	0.31	0.05	8.79	0.03	0.01	0.09	0.02	2.12	0.29	24.02	31.46	44.36	1.41	1.31
	>88	C	3.82	4.58	6.98	4.07	0.26	0.06	6.73	0.01	0.04	0.05	0.02	1.41	0.37	17.53	38.62	43.69	1.13	2.20
RP	0-16	A	3.71	3.87	7.03	4.08	2.27	0.21	10.50	0.11	0.04	0.33	0.04	2.50	0.26	18.28	24.04	57.49	2.39	1.32
	16-40	Bt1	3.80	4.13	7.00	4.06	0.58	0.06	8.86	0.05	0.01	0.15	0.03	2.22	1.08	26.13	24.68	48.98	1.98	0.94
	40-80	Bt2	3.82	4.32	6.99	4.05	0.35	0.06	6.76	0.04	0.02	0.09	0.03	1.95	0.61	30.78	26.90	42.12	1.57	0.87
	80-126	C	3.94	4.51	6.98	4.04	0.24	0.06	4.14	0.01	0.01	0.03	0.02	1.88	0.52	18.57	18.16	63.15	3.48	0.98
	126>	R	4.11	5.23	6.95	4.03	0.16	0.05	3.94	0.04	0.00	0.07	0.04	1.59	1.00	8.80	17.02	73.98	4.35	1.93

Organic matter (OM); Total organic carbon (TOC); Total carbon (T-C); Total nitrogen (T-N); Cation exchange capacity (CEC); Available phosphorus (Av. P).

downward for all soils. Kadir et al. (2001) found a significant relationship between available P and the total C content, because as total C decreased, the available P also declined. Furthermore, the available P is relatively higher in the soils at OP and RP sites as compared to that of the RF and LF sites. The concentration of P in soils depends on a combination of factors, including plant uptake, adsorption-desorption and dissolution-precipitation of inorganic P, the mineralization and fertilizer addition (Perrott et al., 1990; Frossard et al., 2000).

Sesquioxide and charge characteristics

The sesquioxides contents and charge characteristics of the soils at RF, LF, OP and RP sites are shown in Table 3. The values of aluminum and iron oxides extracted by dithionate-citrate-bicarbonate (Ald and Fed) were consistently higher than those extracted by acid oxalate (Alo and Feo) for RF, LF, OP and RP soils. Free oxides values did not change throughout the depth for all soils. The low values of crystalline and amorphous oxides of iron and aluminum at all sites indicated that the soils are yet to reach the ultimate weathered phase. These results are in agreement with the findings of Sakurai et al. (1989) and Kadir et al. (2001); they stated that high Ald and Fed are due to the accumulation of oxidized Al and Fe, which is also accompanied by high weathering.

The Alo and Ald values are similar and tend to be correlated with the clay content, suggesting that these Al-oxides may be translocated in the soils with clay particles. The activity ratio of Al (Alo/Ald) ranged from 0.19 to 1.38, while the Fe

Table 3. Sesquioxide properties, charge characteristic and mineralogical properties of the soils.

Plot	Depth (cm)	Horizon	DCB extr.			Oxalate extr.			Alo/Ald	Feo/Fed	PZSE	σ_p	Clay mineral composition								
			Ald	Fed	Sid	Alo	Feo	Sio					HIV	It	Kt	Qz/Mc	Gb	Gt	Hm	Im	At
			mg/L									$\text{cmol}_c\ \text{kg}^{-1}$									
RF	0-20	A	0.29	2.00	0.25	0.18	0.71	0.01	0.61	0.36	3.34	2.81	±	-	±	++++	-	++	+	-	
	20-40	B	0.32	1.63	0.21	0.19	0.49	0.10	0.61	0.30	3.40	1.10	+	-	+	++++	±	++	+	-	+
	40-90	BC1	0.44	2.20	0.12	0.19	0.37	0.16	0.43	0.17	3.52	1.62	+	-	+	++++	±	++	±	-	±
	90-150	BC2	0.67	2.51	0.09	0.13	0.11	0.05	0.19	0.05	3.29	1.63	+	±	+	++++	±	++	±	±	±
LF	0-20	A	0.36	2.78	0.21	0.11	0.28	0.06	0.30	0.10	3.25	2.88	+	-	+	++++	-	+	+	+	-
	20-46	Bt1	0.39	2.23	0.23	0.13	0.09	0.07	0.33	0.04	3.26	1.22	+	-	+	++++	-	++	+	+	+
	46-94	Bt2	0.43	1.48	0.08	0.13	0.50	0.05	0.30	0.34	3.35	1.08	+++	-	++	++++	-	++	+	±	++
	94-100	Bt3	0.09	2.50	0.11	0.13	0.06	0.08	1.38	0.02	3.48	1.01	+++	-	++	++++	-	+	++	+	++
OP	0-25	A	0.32	1.27	0.25	0.16	0.55	0.16	0.50	0.43	4.01	3.90	±	-	±	++++	++	±	+	-	±
	25-50	Bt1	0.47	1.42	0.12	0.20	1.52	0.06	0.43	1.07	4.08	2.97	-	-	±	++++	+	+	+	-	±
	50-88	BC	0.26	0.59	0.33	0.29	0.04	0.00	1.12	0.07	4.81	1.85	±	±	±	++++	++	+	+	±	±
	>88	C	0.17	2.53	0.07	0.07	0.01	0.09	0.39	0.00	4.60	1.75	±	±	±	++++	++	±	+	±	±
RP	0-16	A	0.38	6.90	0.49	0.17	1.67	0.02	0.45	0.24	3.21	2.60	+++	-	++	++++	++	+	±	++	++
	16-40	Bt1	0.27	4.04	0.50	0.24	0.44	0.23	0.91	0.11	3.52	1.89	+	-	+	++++	++	++	+	±	+
	40-80	Bt2	0.50	1.59	0.05	0.22	0.83	0.00	0.45	0.52	3.62	1.80	+	-	+	++++	++	++	+	±	+
	80-126	C	0.17	1.44	0.17	0.18	0.69	0.06	1.07	0.48	3.63	1.79	+	-	+	++++	+	+	+	-	-
	126>	R	0.36	1.70	0.12	0.13	0.01	0.04	0.36	0.01	4.09	1.10	+	-	++	++++	+	+	±	-	±

Dithionite citrate bicarbonate extraction (DCB); Ammonium oxalate extraction (Oxalate); Point of zero salt effect (PZSE); Residual charge at PZSE (σ_p); Hydroxy-interlayered vermiculite (HIV), Illite (It), kaolinite (Kt), Quartz (Qz), Gibbsite (Gb), Geothite (Gt), Hematite (Hm), Ilmenite (Im), Anatase (At); ±: 0-5%, +: 5-20%, ++: 20-40%, +++: 40-60%, ++++: >60%.

(Feo/Fed) ranges from 0.01 to 1.07. When these values were compared throughout sites, soils at OP and RP showed higher value of Alo, resulting in higher Alo/Ald, than RF and LF sites. These results are in agreement with those previously reported for Thailand soils under rubber plantation (Sakurai et al., 1996). The Feo values and Feo/Fed ratios decreased with depth in soils at RF, LF, OP and RP sites. The Fed values in all soils are higher than that of Feo. Thus, the higher Feo content in the thinner topsoil (OP and RP sites) suggests that they contain larger amount of Fe-humus complexes and/or of ferrihydrite than the subsoil, reflecting their higher content of organic matter which exerts an inhibitory effect on the crystallization of Fe oxides (Schwertmann, 1985). These patterns are similar to those for the clay content. The Fed content is as a whole associated with the clay content, indicating a downward translocation of Fed fraction with concomitant clay illuviation or crystallization of Fe oxides in the argillic horizon (Ohta et al., 1993). Goethite is the main source of Fed in the soils studied.

The values of point zero salt effect (PZSE) ranged from 3.0 to 4.8 for all soils, indicating that the soils are highly weathered. At RF, LF, OP and RP sites, the value of PZSE of the soils tends to towards the deeper horizons. This could be related to increase the content of organic matter, exchangeable Al and both crystalline and amorphous contribution which inhibit higher values in the surface soil. The abundance of kaolinite and the present of gibbsite in the soils influence the PZSE value. Kaolinite has both permanent negative and variable charge (Sakurai et al., 1990). As a result, the surface layer would carry negative charge at normal soil pH value. In this study, soil under natural vegetation (secondary forest) showed a lower zero point of charge (ZPC) values at the surface layer than the subsurface layer due to high negative charge generated by organic matter in the topsoil, which is in agreement with that reported by Sakurai et al. (1996). On the other hand, the σ_p values decreased towards the deeper horizon. The values of σ_p ranged from as low of 1.01 to high 3.90. Similar results had been reported for Thai soils (Sakurai et al., 1989). The exchange site of permanent negative charge is mostly occupied by Al when Al concentration is high, the amount of basic cations retained by the permanent negative charge is low. Since σ_p is defined as a remaining charge at ZPC, the magnitude of σ_p is closely correlated with the amount of exchangeable bases. Thus, the value of σ_p can be an estimate of permanent negative charge in the field condition (Sakurai et al., 1989).

Mineralogical composition

The distribution of clay minerals in the soil profile at rehabilitation forest, secondary forest, oil palm and rubber plantations sites are uniform with depth as shown in Table 3. The surface and sub-surface horizon of the soils at rehabilitation forest (RF), logged-over forest (LF), oil palm (OP) and rubber (RP) sites are dominated by kaolinite. Gibbsite, goethite and hematite are major minerals in the soil profiles, but gibbsite is not present in the soils at LF site. Gibbsite shows abundant distribution in soils at OP and RP sites indicating that the soils are highly weathered. The quantity or composition of gibbsite, goethite and hematite decreases with depth. Quartz, hydroxyl-interlayered vermiculite (HIV) and anatase are present in all profiles in small amount, while ilmenite and illite are present in trace amount. Illite is present in the soils at RF and OP sites which was found in BC and C horizon. Thus, the presence of kaolinite and gibbsite in the soils at RF, LF, OP and RP site indicates that the soils had undergone advanced stage of weathering under acidic conditions.

The clay mineralogical types of the soils at rehabilitation forest, secondary forest, oil palm and rubber plantations are similar probably due to the parent materials undergoing weathering under very high rainfall environment. The mineralogical composition is dominated by 1: 1 type of kaolin minerals. Other minerals are quartz, gibbsite, hematite and goethite, anatase and ilmenite as detected by XRD analysis. High kaolin minerals in the soils at all sites is due to dissolution of the weathering products, such as aluminum and silica, as weathering process proceeds under high rainfall. Rapid removal of bases through leaching leads to the formation of kaolinite (Sakurai et al., 1996). Shamshuddin and Fauziah (2010) have also reported the presence of kaolinite in the soils of the tropics, depending on the degree of weathering and the composition of parent materials of the soils. A large amount of kaolinite exists in the surface and subsurface horizons at all sites, because the weathering intensity has been enhanced due to extreme leaching. Long period of weathering and leaching can result in the formation of minerals such as kaolinite in Ultisols (Sanchez and Buol, 1974).

Goethite and hematite were found to be the most common sesquioxides in all profiles explaining why these soils appear yellowish to reddish color. Hematite may have been formed as a result of dehydration of ferrihydrite and/or goethite (Schwertmann, 1985).

Hydroxyl-interlayered vermiculite (HIV) is present in the B horizons, which could be attributed to conditions favorable to Al-hydroxyl interlayer formation such as active weathering to form Al ions, moderately acidic conditions, low organic matter content, and frequent wetting and drying, which are common in most tropical zone and Ultisols (Rich, 1968). The downward leaching of the Fe and Al from the surface horizons enhances extensive interlayering behavior in the B horizon where organic matter content decreases (Pai et al., 2004). The release of silica from different sized soil particles to the soil solution is one of the important mechanisms for kaolinite formation (Drees et al., 1989).

Conclusion

In general, the soils are acidic, highly weathered and considered poor in soil nutrient content. There are variations in the morphological, physical, chemical, charge characteristic, and mineralogical properties of the soils/profiles, appeared to be influenced by the nature of the parent materials and human activities. Even though, the nutrient content shows no clear differences among the sites, it is shows differences at each horizon. For example, the oil palm site shows highest C/N ratio in the A horizon even though the leaf litter is very thin because the roots distribution of the oil palm is about at 0 to 30 cm (fibrous root). The forest and rubber tree have taproots, so the active roots are in the deeper horizon. Root activities supply carbon and nitrogen to the soils. This shows that different plants give different effects on the soil organic matter activity which is important in nutrient dynamic and carbon emission.

High level of Al saturation is the main cause of acidity associated with heavy rainfall in the tropical region. The exchangeable cations are absorbed tightly and their availability to plant is restricted. Soils under oil palm and rubber cultivation, rehabilitation forest and secondary forest are strongly weathered, consisting of 1: 1 type of kaolin minerals. But the low presence of sesquioxides showed that the soils are yet to reach the ultimate weathered phase. This is supported by high activity ratio of Al (Alo/Ald) and Fe (Feo/Fed). The predominance of kaolin minerals, goethite and gibbsite are the main cause of low fertility status of soils at RF, LF, OP and RP sites.

This study illustrates the actual local impact of forest conversion on soil properties. Our results also indicate the potential of these soils to maintain soil fertility after forest clearing if management practices address the maintenance of organic matter. From the viewpoint of soil fertility management, characterizing soil properties in terms of morphology, physico-chemical, charge, sesquoixide and clay mineral properties should be taken into consideration in sustainable forest management.

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