Development of Soils Derived from Weathered Sedimentary, Granitic and Ultrabasic Rocks in South Kalimantan Province: I. Mineralogical Composition and Chemical Properties

Perkembangan Tanah dari Lapukan Batuan Sedimen, Granit dan Ultrabasis di Propinsi Kalimantan Selatan: I. Komposisi Mineral dan Berbagai Sifat Kimia

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ABSTRACT

Limited information is available on chemical properties and mineralogical composition of soils in South Kalimantan Province. The objective of this study is to assess the development, chemical properties and mineralogical composition of soils derived from weathered sedimentary, granitic and ultrabasic rocks with respect to soil management. Field investigations and laboratory analyses were performed to compare morphological properties, particle sizes, mineralogical compositions of sand and clay fractions, organic C, N, pH, extractable acidity, P retention, exchangeable cations, cation exchange capacity, and oxides of iron and aluminium. The results. show the AY-14 pedon has a higher degree of development followed by MA-86 and SW-89, respectively as indicated by mineralogical composition and chemical properties. Although the three pedons are dominated by kaolinite, the AY-14 pedon (developed from an ultrabasic rock) has no weatherable minerals and vermiculite but has high opaques, low quartz and colloid surfaces bearing positive charge. On the other hand, weatherable minerals are only found in SW-89. The MA-86 and SW-89 (developed from granitic and sedimentary rocks, respectively) have low opaques, high quartz, a minor proportion of vermiculite, and colloid surfaces bearing negative charges. These findings suggest that the AY-14 has a higher degree of development than MA-86 and SW-89. Comparison between MA-86 and SW-89 indicated that the former has lower clay cation exchange capacity (CEC) and contains no weatherable minerals indicating that the MA-86 has a higher degree of development than the SW-89. The values of exchangeable cations, CEC of soil and clay, and ECEC were low in all three pedons. The magnitude of each value was lower in the AY-14 followed by MA-86 and SW-89, respectively. In contrast, P retention and iron oxides were the highest in the AY- 14 pedon followed by MA-86 and SW-89, respectively. The three pedons have very acid to acid pH, and low C and N contents. Based on chemical properties and mineralogical composition, the three pedons need different management practices. The soil derived from ultrabasic rock (AY-14) needs higher phosphate fertilizer due to its high P retention, higher organic matter and lime than soils derived from granitic rock (MA-86) and sedimentary rock (SW-89) in order to increase CEC, nutrient availability and soil pH.

ABSTRAK

Ketersediaan informasi mengenai komposisi mineral dan sifat-sifat kimia tanah di Propinsi Kalimantan Selatan masih sangat terbatas. Tujuan penelitian ini adalah mengkaji per kembangan, sifat-sifat kimia dan komposisi mineral tanah yang berkembang dari pelapukan batuan sedimen, granit dan ultrabasis dalam kaitannya dengan pengelolaan tanah. Penelitian lapang dan analisis laboratorium dilakukan untuk membandingkan sifat morfologi, ukuran butir, komposisi mineral dari fraksi pasir dan liat, C-organik, N, pH, kemasaman dapat terekstrak, retensi P, kation dapat tukar, kapasitas tukar kation, dan oksida besi dan aluminium. Hasil penelitian menunjukkan bahwa pedon AY-14 mempunyai tingkat perkembangan lebih lanjut, diikuti berturut-turut oleh pedon MA-86 dan SW-89 seperti vang ditunjukkan oleh komposisi mineral dan sifat kimia tanahnya. Walaupun ketiga pedon didominasi oleh mineral kaolinit, pedon AY-14 (berasal dan batuan ultrabasis) tidak mengandung mineral mudah lapuk dan vermikulit tetapi mempunyai kandungan opak tinggi dan permukaan koloidnya sudah bermuatan positif. Mineral mudah lapuk hanya terdapat pada pedon SW-89. Dibanding dengan pedon AY-14 maka pedon MA-86 dan SW-89 (masing- masing berasal dari batuan granit dan sedimen) mengandung opak lebih rendah, kuarsa lebih tinggi, sedikit vermikulit dan permukaan koloid masih bermuatan negatif. Hal tersebut menunjukkan pedon AY-14 mempunyai tingkat perkembangan lebih lanjut dari pedon MA-86 dan SW-89. Selanjutnya perbandingan antara pedon MA-86 dan SW-89 menunjukkan pedon pertama mempunyai kapasitas tukar kation (KTK) liat lebih rendah dan tidak mengandung mineral mudah lapuk mengindikasikan pedon MA-86 lebih berkembang lanjut dan pedon SW-89. Jumlah kation dapat tukar, kapasitas tukar kation tanah dan liat, dan KTK efektif termasuk rendah pada semua pedon. Besarnya tiap nilai tersebut adalah paling rendah pada pedon AY-14 diikuti oleh pedon MA-B6 dan SW-B9. Secara kontras retensi P dan besi bebas sangat tinggi pada AY-14 dikuti oleh MA-86 dan SW-89. Ketiga pedon mempunyai nilai pH masam sampai sangat masam, C dan N rendah sampai sangat rendah. Berdasarkan sifat-sifat kimia dan komposisi mineral liat maka ketiga pedon memerlukan pengelolaan yang berbeda. Tanah yang berkembang dari ultrabasis (AY-14) secara kualitatif memerlukan pemupukan P, bahan organik dan kapur yang lebih tinggi dibandingkan oleh tanah dari batuan granit (MA-86) dan batuan sedimen (SW-89) untuk meningkatkan KTK, ketersediaan hara dan pH tanah.

Keywords : Minerals, Soil chemical properties, Colloid charge, Management practice.

INTRODUCTION

Agricultural development has proceeded rapidly over the last decade in South Kalimantan Province. From a topographical standpoint, most of

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the area in the province has potential for agricultural crop development because the soils are distributed on a landscape of plain to rolling relief. Although some areas have been intensively used, little information is available on soil properties and mineralogical composition of soils derived from weathered sedimentary, granitic and ultrabasic rocks in this area. Efforts to improve soil quality and productivity are merely based on traditional experience. Consequently, limited success is obtained in improving soil quality and productivity. Hence, information on the degree of soil development, detailed chemical properties and mineralogical composition is a prerequisite to formulate proper management strategies to obtain optimal soil productivity.

Limited studies have been carried out on soil development, chemical properties and mineralogical composition of Oxisols. Buurman and Soepraptohardjo (1980) reported Oxisols developing on ultramafic rocks in South East Sulawesi and South Kalimantan and on felsic volcanic rocks in West Sumatra. In South East Sulawesi, the mineral of ultramafic rock was mainly peridotite (Buurman and Soepraptohardjo, 1980; Prasetyo *et a*l., 1988; Sudihardjo and Dai, 1989), Buurman and Soepraptohardjo (1980) and Sudihardjo and Dai (1989) found that Oxisols occurred on a lower footslope position. They reported that Oxisols in South East Sulawesi had high clay content, very low exchangeable cations (< 1 cmol/kg), low CEC and almost undetected Al content. Similar results were reported for Oxisols developed from serpentinite in South Kalimantan with the exception of the lower clay content (Buurman and Soepraptohardjo, 1980). In comparison to chemical properties of Oxisols developed from felsic volcanic rocks (feldspar, mica and quartz) in West Sumatera, the CEC values and Al contents were considerably lower in Oxisols from South East Sulawesi and South Kalimantan. This was probably due to the differences in parent materials. However, the sum of cations from all locations was similar.

Data reported by Buurman and Soepraptohardjo (1980) indicated that mineralogical composition of clay fractions of Oxisols was different between locations. The mineralogical composition of clay fractions was mainly kaolinite and goethite with minor gibbsite and quartz for Oxisols from South East Sulawesi, goethite, hematite and gibbsite with minor amount of kaolinite for Oxisols from South Kalimantan and mainly kaolinite with minor amounts of gibbsite, chlorite, goethite and quartz for Oxisols from West Sumatera. Goenadi and Tan (1989) studied clay fractions of Oxisols from Cibinong and Sitiung using XRD and DTA and reported that kaolinite was the dominant mineral accompanied by minor goethite and gibbsite.

On the other hand, Bonifacio *et al.* (1997) found that Haplustalfs and Haplustolls derived from serpentinite occurred at footslope and toeslope positions in Italy. They observed that the main clay minerals of Haplustalfs were serpentine, goethite, chlorite and pyroxene and those of Haplustolls were vermiculite, serpentine and chlorite. In addition, Istok and Harward (1982) studied the soils in a national forest of the Klamath Mountains, USA and reported that Haplustalfs contained smectite, chlorite and serpentine. The difference in clay mineral composition of soils derived from similar parent materials (i.e. serpentinite) found in Indonesia, Italy, and USA is probably due to the udic soil moisture regime in Indonesia and ustic soil moisture regime in Italy and USA.

In the present study, we report the development, chemical properties and mineralogical composition of soils derived from weathered sedimentary, granitic and ultrabasic rocks in South Kalimantan with respect to management practices.

MATERIALS AND METHODS

Location of the study

Three pedons were selected to represent soils formed over different materials in South

Kalimantan, Indonesia. The AY-14 pedon located in Tebing Siring (Pelaihari district) represents soils with a parent material weathered from ultra basic rocks, the MA-86 in Pabaan village (Batu Benawa district) represents soils from granitic rocks, and the SW-89 pedon in Mandurian village (Bungur district) represents soils from sedimentary rocks. The AY-14 pedon occurs on a lower slope of an old volcanic hill with 6% slope gradient and good drainage. The MA-86 is located on a lower slope of a tectonic hill with 10% slope gradient and good drainage. The AY-14 and MA-86 pedons are currently used for bamboo and rubber plantations, respectively. The SW-89 pedon occurs on an alluvial fan landform with nearly flat terrain which intermittently dries each year and is used as a rice field.

Annual rainfall in the three sites studied was 2,173 mm for AY-14 site, 2,244 mm for MA-86 site and 3362 mm for SW-89 site. The mean annual temperature near site AY-14 was 26.5°C with a range of 26.3°C to 27.7°C. In site MA-86 and SW-89, the mean annual temperature was 22.0°C with a range of 19.4°C to 24.4°C.

Field and laboratory studies

Soil was sampled from all horizons of each pedon. Samples were air dried and gently crushed prior to being passed through a 2 mm sieve. Particle size analysis was determined by a pipette method. Soil pH in water and 1 M KCl was measured using 1:2.5 volumetric soil/solution ratio. The Walkley and Black wet oxidation method was used to determine organic C content (Soil Survey Staff, 1972). The N content was measured by the Kjeldahl method. Exchangeable Al was extracted with 1 M KCl and exchangeable bases with 1 M NH_4OAc at pH 7.0, and the solutions were analyzed using atomic absorption spectrophotometry. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases plus aluminum. The ECEC clay was calculated as 100x ECEC soil/percent clay. The cation exchange capacity (CEC) was determined by saturation with the 1 M NH_4OAc at pH 7.0 and + measurement of NH_4 after displacement with 1 N NaCl. The CEC clay was calculated as 100xCEC pH 7.0/percent clay. Free Fe and Al oxides were determined using dithionite citrate sodium bicarbonate (CDB) as described by Mehra and Jackson (1960).

The mineralogical composition of the clay fraction (<2 μm) was determined by x-ray diffraction (XRD). Potassium saturated and Mg saturated, glycerol solvated samples were prepared and run at air dry conditioner. The K-saturated samples were also heated at 550°C to confirm a type of clay mineral present. The sample was examined with a Philips PW 3710 and XRD with a Co Kα radiation target operated at 40kV and 25mA. Amounts of clay minerals present were qualitatively estimated from the area of the XRD peak height and the peak width at half height. Mineralogical composition of the sand fraction (20-200 μm) was determined by polarisation microscope by line counts of 300 grains mounted on a glass slide.

RESUL TS AND DISCUSSION

Morphological and physical properties

Morphological and physical properties varied between pedons (Table 1). The AY-14 pedon showed uniform dusky red colour (10R 3/3-4) and fine granular structure in all horizons, whereas the MA-86 exhibited yellowish red to red colour with very fine subangular blocky structure and the SW-89 showed yellowish brown matrices with light gray mottles in all B horizons.

The soil texture was loam for the AY-14 pedon, light clay (42-46%) for the MA-86 and medium clay (58-61%) for the SW-89. The increase in clay content with depth was insufficient to satisfy argillic horizons for the AY-14 and the MA-86 pedons, therefore the subsurface horizons of two pedons met the oxic

Table 1. Selected morphological and physical properties of three pedons studied in South Kalimantan

Pedon/ Horizon	Depth	Colour¦		Structure	Consistency		Remark	Texture		
		Matrix	Mottle#		Moist	Wet		Sand	Silt	Clay
	cm							——— % ———		
AY-14										
Ap	0- 22	10R 3/3	-	1 g f	fr	so, po		36	53	11
Bo1	22- 66	10R 3/3	-	1 g vf	vfr	so, po	few gravel	52	37	11
Bo2	66- 85	10R 3/3	-	1 g f	vfr	so, sp	few gravel	47	36	17
Bo3	85-108	10R ¾	-	1 g f	fr	ss, sp		33	47	20
B04	108-140	10R ¾	-	1 g f	vfr	ss, sp		33	44	23
MA-86										
A	0- 16	7.5YR 4/3	-	1 sb vf	fr	s, p		35	21	44
Bw	16- 40	5YR 4/4	-	1 sb vf	fr	s, p		38	20	42
Bo1	40- 71	5YR 4/6	-	2 sb vf	fm	s, p		35	19	46
Bo2	71-110	2.5YR 5/6	-	2 sb vf	fm	s, p	few quartz	36	22	42
B03	110-152	2.5YR 5/6	-	2 sb vf	fm	ss, sp	few quartz	38	28	34
SW-89										
Apg1	0- 18	10YR 7/1	5YR 5/6	m		s, p		15	38	47
Bg2	18- 50	10YR 5/6	10YR 7/1	2 sb f		s, p		7	33	60
Bg3	50- 89	10YR 5/6	10YR 7/1	2 sb c		s, p		9	33	58
Bg4	89-120	10YR 5/6	10YR 7/1	2 sb c		s, p		4	38	58
BCg5	120-150	10YR 5/6	10YR 7/1	1 sb c		s, p		4	35	61

1 = weak; 2 = moderate; g = granular; sb = subangular blocky; vf = very fine; f = fine; fr = friable; vfr = very friable; fm = firm; m = massive; s = sticky; so = nonsticky; ss = slightly sticky; po = nonplastic; sp = slightly plastic; p = plastic; ¦ = moist; # = 15-20%.

horizon. In the case of the SW-89, the increase of total clay in B horizons qualified as an argillic horizon. However, the increase in clay was not considered as an argillic horizon since the fine clay (data not shown) was relatively uniform from soil surface to B horizons. Field observation indicated the absence of a clay film or clay skin in B horizons and confirmed the exclusion of clay illuviation from an eluvial horizon as a condition for the formation of clay skin.

Mineralogical composition of sand and clay fractions

Mineralogical composition of sand fractions varied between pedons (Table 2). The AY-14 pedon contained mainly opaque minerals (e.g. hematite, goethite, magnetite) with quartz in minor proportion. In contrast, the MA-86 and SW-89 pedons had quartz as predominant minerals with opaque in trace proportion only. Unexpectedly, the SW-89 contained weatherable minerals such as orthoclase, sanidine and green hornblende in trace proportions. These minerals were absent in MA-86 and AY-14 pedons. The differences in mineralogical composition between pedons were due to differences in parent materials from which the present day soils have been formed. The AY-14 pedon developed from ultrabasic rocks containing pyroxene and serpentine minerals (Sikumbang and Heryanto, 1994) that weather more rapidly, whereas the parent material of pedon MA-86 was granitic rock containing orthoclase, quartz with little plagioclase (albite) and the SW-89 pedon was derived from sedimentary rock containing gravel, sand, silt and clay (Heryanto and Sanyoto, 1994). In addition, the absence of weatherable minerals in the AY-14 pedon was due to its parent material derived ultra basic rocks which weather more rapidly than granitic and sedimentary rocks.

The MA-86 and AY-14 pedons exhibited the absence of weatherable minerals and the trends of opaque and quartz mineral distribution with depth were relatively uniform suggesting that these soils have undergone highly intensive weathering due to the high precipitation and temperature which

Table 2. Mineralogical composition of sand and clay fractions of three pedons studied in South Kalimantan

Pedon/ horizon	Depth	Sand fraction									Clay fraction						
											Clay mineral			Accessory mineral			
		O	Qd	Qt	Cfe	Wm	Rf	Or	Sn	Hb	Ka	Vm	Il	Gb	Hm	Gt	Qz
	Cm	%															
AY-14																	
Ap	0- 22	83	16	1	no	no	<1	no	no	no	78	no	no	10	5	5	2
Bo1	22- 66	85	15	<1	no	no	<1	no	no	no	83	no	no	3	5	5	2
Bo2	66- 86	79	18	1	no	no	1	no	no	no	nd	nd	nd	nd	nd	nd	nd
Bo3	85-108	89	11	<1	no	no	<1	no	no	no	83	no	no	3	5	5	2
Bo4	108-140	89	10	<1	no	no	<1	no	no	no	nd	nd	nd	nd	nd	nd	nd
MA-86																	
A	0- 16	2	90	5	<1	1	2	no	no	no	83	9	no	4	no	2	2
Bw	16- 40	3	87	7	<1	1	2	no	no	no	nd	nd	nd	nd	nd	nd	nd
Bo1	40- 71	3	85	9	<1	1	2	no	no	no	79	8	No	5	no	2	2
Bo2	71-110	5	82	11	<1	1	1	no	no	no	nd	nd	nd	nd	nd	nd	nd
Bo3	110-152	5	84	8	<1	3	<1	no	no	no	48	nd	10	19	no	no	14
SW-89																	
Ap	0- 18	1	80	9	<1	1	4	2	2	1	76	10	no	11	no	no	3
Bg1	18- 50	1	81	9	1	<1	4	2	1	1	nd	nd	nd	nd	nd	nd	nd
Bg2	50- 89	1	80	10	1	<1	5	1	1	1	80	3	no	3	no	14	no
Bg3	89-120	1	78	10	1	<1	6	3	1	<1	nd	nd	nd	nd	nd	nd	nd
BCg4	120-150	1	81	8	<1	<1	6	2	<1	1	81	3	no	3	no	11	2

O = opaque; Qd = turbid quartz; Qt = transparent quartz; CFe = iron concretion; Wm = weathered minerals; Or = orthoclase; Sn = sanidine; Hb = hornblende; Ka = kaolinite; Vm = vermiculite; Il = illite; Gb = gibbsite; Hm = hematite; Gt = goethite; Qz = quartz; nd = not determined; no = not observed.

characterise humid tropical soils. On the other hand, although the SW-89 is pedon dominated by quartz minerals, the presence of weatherable minerals (orthoclase, sanidine, and green hornblende) in minor proportion (<6%) may suggest that this pedon is less weathered than MA-86 and AY-14. The weatherable minerals in the SW-89 pedon may have been transported from the upper hinterland where the soils are derived from granitic rock and volcanic rock (Andesite). These weatherable minerals could provide a particular benefit with respect to plant nutrients especially K, Mg and Fe.

The clay mineral composition of the three soils is given in Table 2. There was a considerable difference in clay minerals between pedons. Although the three pedons were dominated by kaolinite with minor proportions of goethite and gibbsite, the MA-86 and SW-89 pedons possessed vermiculites in minor proportions, which were not detected in the AY-14 pedon. The absence of vermiculite in the AY-14 suggests that this 2:1 phyllosilicate has been weathered, resulting in high kaolinite and accumulation of Fe and Al oxides. This evidence, again, could indicate the higher weathering degree of the AY-14 pedon compared to MA-86 and SW-89 pedons.

Chemical properties

Soil reactions and exchangeable acidity

Soil reactions and exchangeable acidity varied between pedons (Table 3). The MA-86 pedon has a very acid reaction whereas the AY-14 and SW-89 pedons are acid to slightly acid. The AY-14, with the highest degree of development among the three pedons, unexpectedly had pH-H_2O higher than MA-86 but relatively similar to corresponding horizons of the SW-89 pedon. Interestingly, the pH values of the AY-14 measured in 1 M KCl were three units higher in B horizons compared to corresponding horizons of the MA-86 and about 2.7 units higher compared to SW-89. In

Table 3. Chemical properties of three pedons studied in South Kalimantan

Pedon/ horizon	Depth	pH		ΔpH	C	N	P_2O_5	Exchangeable cations				Sum of cation	CEC	Al^{+3}	H^+	ECECl	CECα	Al sat	BS
		H_2O	KCl				HCl	Ca	Mg	K	Na								
	cm				— % —		mg/100 g	—				cmol(+)kg^{-1}soil	—					— % —	
AY-14																			
Ap	0- 22	5.7	5.9	0.2	1.5	0.17	10	0.39	0.28	0.04	0.16	0.87	3.0	nd	nd	7.9	27.3	0.0	29.0
Bo1	22- 66	5.6	6.6	1.0	0.7	0.07	4	0.11	0.15	<0.01	<0.01	0.26	2.6	nd	nd	2.4	23.6	0.0	10.0
Bo2	66- 85	5.8	6.9	1.1	0.3	0.06	2	0.11	0.13	<0.01	<0.01	0.24	1.5	nd	nd	1.4	8.8	0.0	16.0
Bo3	85-108	5.8	6.9	1.1	0.3	0.03	4	0.11	0.15	<0.01	<0.01	0.26	1.1	nd	nd	1.3	5.5	0.0	23.6
B04	108-140	5.9	6.9	1.1	0.3	0.06	6	0.11	0.12	<0.01	<0.01	0.23	0.8	nd	nd	1.0	3.5	0.0	28.8
MA-86																			
A	0- 16	3.8	3.6	-0.2	2.3	0.23	20	0.47	0.33	0.16	0.05	1.01	8.0	5.0	0.9	13.7	18.2	83.2	12.6
Bw	16- 40	3.9	3.7	-0.2	1.0	0.12	12	0.36	0.09	0.08	0.00	0.53	6.5	4.9	0.7	12.9	15.5	90.2	8.2
Bo1	40- 71	4.2	3.8	-0.4	0.8	0.10	10	0.31	0.07	0.06	0.05	0.49	5.8	5.0	0.9	11.9	12.6	91.1	8.4
Bo2	71-110	4.5	3.8	-0.7	0.5	0.08	12	0.36	0.07	0.06	0.02	0.51	6.7	5.0	0.9	13.1	16.0	90.7	7.6
B03	110-152	4.3	3.8	-0.5	0.2	0.04	14	0.26	0.05	0.04	0.03	0.38	6.1	5.3	0.9	16.7	17.9	93.3	6.2
SW-89																			
Apg1	0- 18	4.7	3.6	-1.1	1.0	0.12	10	2.61	1.37	0.04	0.26	4.34	8.2	3.2	0.6	16.0	17.4	42.4	52.9
Bg1	18- 50	5.2	3.9	-1.3	0.6	0.08	64	3.34	2.61	0.08	0.39	6.38	9.6	1.8	0.4	13.6	16.0	22.0	66.5
Bg2	50- 89	5.5	3.9	-1.6	0.4	0.05	64	4.95	5.32	0.06	0.58	10.86	11.6	0.8	0.1	20.1	20.0	6.9	93.6
Bg3	89-120	5.8	4.3	-1.5	0.3	0.04	62	7.29	8.17	0.06	0.78	16.36	14.7	0.1	<0.1	28.4	25.3	0.6	111.3
BCg4	120-150	5.6	4.1	-1.4	0.3	0.03	60	5.69	7.16	0.07	0.56	13.57	13.2	0.0	<0.1	22.2	21.6	0.0	102.8

CEC = cation exchange capacity; ECEC = effective cation exchange capacity; Al sat = Al saturation;BS = base saturation; nd = not detected; ¦ = ECEC clay calculated as 100 %x (Ca + Mg + K + Na+ Al)/% clay; α = CEC clay calculated as 100 x CEC NH_4OAc pH7/% clay addition, the pH-KCl value was one unit higher than pH-H_2O for the AY-14 pedon, whereas in MA-86 and SW-89 pedons the pH-H_2O values were consistently higher than the pH-KCl values. The difference between pH-H_2O and pH-KCl value (ΔpH) was less negative (Δp H = 0.5 unit) in MA-86 than in SW-89 (ΔpH = 1 unit). Higher pH-KCl values than pH-H_20 have been reported in Oxisols (Suharta *et al*., 1995; Hidayat, 1996) and in Andisols (Nanzyo *et al*., 1993).

Nanzyo *et al*. (1993) found the pH-KCl value was higher than pH-H_20 in Andisols due to the adsorption of Cl^{-1} ions to positive charge sites of noncrystalline clays, resulting in the net formation of KOH, which increases the pH in KCl of soil solutions. A similar explanation is adopted in this study, except that Cl^{-1} ions were adsorbed to positive charge sites on oxihydroxyl of Fe and Al, instead of noncrystalline clays, because the soils studied were Oxisols containing mainly kaolinite minerals with higher percentage of crystalline Fe and Al (dithionite). Therefore, the Cl^{-1} ions adsorbed on oxihydroxyl Fe and Al resulted in the release of OH^{-1} ions to the soil solution, which in turn, increased the pH value.

Although the Ap horizon of AY-14 had nearly similar Fe (dithionite) content with subsurface horizons, the pH-KCl value was only a little higher than the pH-H_20, indicating the significant role of organic matter (1.5% organic C) in reducing the amount of positive charge, which in turn, lowered the pH value. However, the B horizons had very low organic C and the pH-KCl value was higher by one unit suggesting that the positive charge was mainly contributed by Fe-oxides.

The implication of the higher pH-KCl value compared to the pH-H_20 of the AY-14 pedon is that soil colloids naturally bear positive charges. Consequently, the soil ability to retain exchangeable cations (i.e. Ca, Mg, K and Na) as plant nutrients will be very limited, if any. This is confirmed by the sum of exchangeable cations within all subhorizons which was extremely low (< 0.3 cmol/kg soil). This small amount of negative charge to retain exchangeable cations should develop from deprotonisation of mainly Fe oxide and to some extend of Al oxide when soil pH is raised to pH 7.0, because the natural pH of the soil was 5.6-5.9. For MA-86 and SW-89 pedons, the pH values were higher in H_20 than KCl, indicating that the colloids bear a negative charge in the natural condition and that the magnitude was higher in the SW-89 than MA-86. This higher negative charge may be due to the presence of vermiculite in these two pedons. Although the type of clay minerals in these two pedons was similar, the high negative charge in the SW-89 pedon was due to the higher content of clay fraction which bears a negative charge.

Exchangeable acidity was highest in MA-86 followed by SW-89 and was not detected in the AY-14 pedon. The absence of exchangeable acidity in AY-14 and its presence in significant amount in MA-86 but low in SW-89 could be explained in a similar manner to the pH values, which were mainly due to the presence of positive charges and negative charges on colloidal surfaces. The presence of a positive charge in the AY-14 pedon could repel the positive charge ions such as Al^{3+} and H^+. On the other hand, the presence of negative charges on colloidal surfaces of MA-86 and SW-89 may be responsible for the adsorption of Al^{3+} and H^+ ions. This is evidenced from the MA-86 pedon which had Al saturation of about 84-94% in all horizons and the SW-89 pedon which had Al saturation of only 22-42% in the two uppermost horizons.

Organic matter

Organic C and N exhibited appreciable differences between surface and subsurface horizons of the three pedons (Table 3). The surface horizons had higher organic C and N contents than the subsurface horizons. The highest organic C and N contents at the surface horizon were found in the MA-86 followed by AY-14 and SW-89. This difference was due to differences in land use and clay content of the three pedons. The MA-86 had high clay content (44%) and is used for bamboo plantation which needs less soil tillage. The higher clay content and less tillage may reduce microorganism accessibility to organic C, thereby preserving organic C in soils. In the AY-14, although less cultivated (under rubber plantation), the organic C and N contents were lower than MA-86 due to the lower clay content (11%) which allows more aggregate to be exposed to microorganism attack than in the former soil.

In contrast, the SW-89 had higher clay content (47%) than MA-86 and AY-14, but organic C and N contents were higher in the latter two. The lower organic matter in SW-89 is due to intensive soil tillage (i.e. the soil is used for rice field) creating more soil aggregates exposed to microorganism decomposers resulting in low organic matter preserved in soil. In addition, there were no major differences in organic C and N contents between pedons in subhorizons of three pedons. All subsurface horizons had low C and N contents due to limited sources of organic matter.

Cation exchange capacity, exchangeable cations and base saturation

Cation exchange capacity (CEC), exchangeable cations (EC) and base saturation (BS) are varied within and between pedons (Table 3). The AY-14 had the lowest CEC values at <3 cmol/kg followed by MA-86 at 5.8-8.0 cmol/kg and SW-89 at 8-15 cmol/kg. These CEC values of three pedons were overestimated since the measurement was performed at pH 7 while natural soil pH values of the three pedons ranged from pH 3.8 to 5.9. For the tropical soils used in this study in which kaolinite is a dominant mineral and free iron is present in high concentrations, the colloid surfaces could develop negative charges of variable charge type as pH is raised, resulting in higher CEC values than under natural conditions. Therefore, the CEC values measured at pH 7 for tropical soils with advanced stage of weathering should be interpreted with caution prior to application for management practices.

The low CEC of AY-14 could be due to the clay surfaces having positive charges. This is confirmed by plotting the CEC clay against clay percentage. As expected, there is a negative exponential relationship between CEC clay and clay percentage (Figure 1). This indicates that the CEC clay decreases exponentially as the proportion of clay increases, suggesting that the clay particle surfaces bear a positive charge. This agrees well with the higher pH-KCl value compared to the pH-H_2O value. However, there are no clear trends in relationship between CEC clay and clay percentage in the MA-86 and SW-89 pedons.

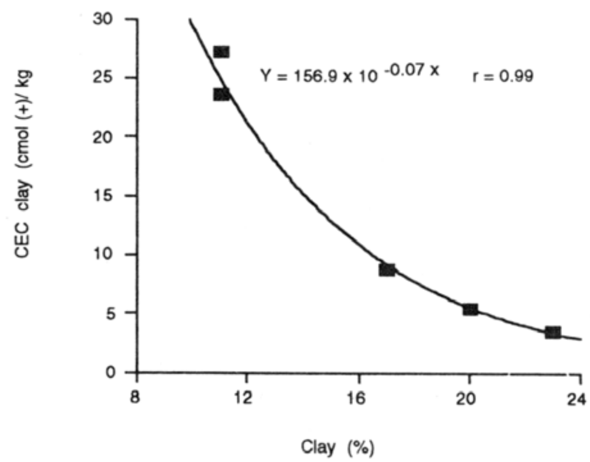

Figure 1. Relationship between CEC clay and clay content of the AY-14 pedon

Furthermore, the positive charge in the AY-14 pedon could be contributed by Fe-oxides. Fe-oxide (dithionite) contents were much higher in the AY-14 pedon (11-13%) followed by SW-89 (1-2.2%) and MA-86 (0.7-1.4%) (Figure 2). The high Fe- oxides in the AY-14 pedon could mask clay surfaces resulting in the blocking of negative charge sites on clay surfaces.

Comparison of exchangeable cations between pedons showed similar trends with CEC values. On the other hand, base saturation was the lowest in MA-86 followed by AY-14 and SW-89.

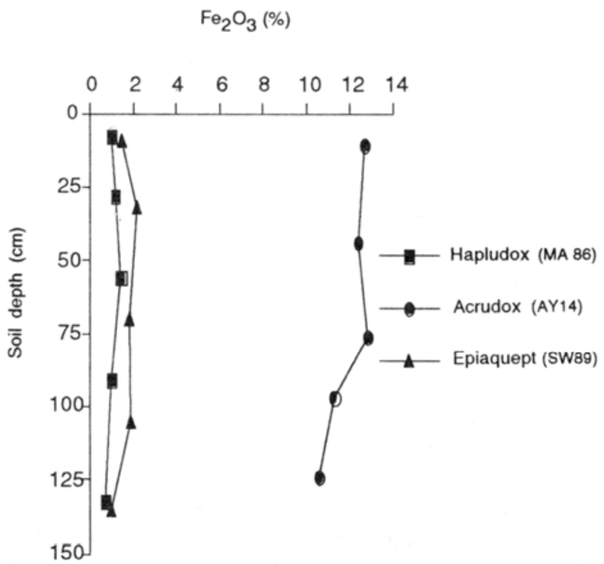

Figure 2. Distribution of Fe dithionite with soil depth within three pedons studied in South Kalimantan

The base saturation of the former two pedons is less than 35% whereas in the latter one it is more than 50%. The low base saturation in the MA-86 pedon was due to the dominance of exchangeable Al on exchange sites as indicated by the high Al saturation (83-93%). The amounts of exchangeable cations in MA-86 and AY-14 were extremely low (< 1 cmol/kg soil) and in SW-89 a little bit higher (4-16 cmol/kg soil). The low CEC values are also exacerbated by high annual precipitation (2,173 mm) which may be responsible for losses of exchangeable cations through leaching processes. In the AY-14 the exchangeable cations were only Ca and Mg and there is a tendency for Mg to be higher probably due to the soil having developed from serpentinite containing high Mg. In the MA-86 pedon, exchangeable cations were dominated by Ca in all horizons and for the SW-89 pedon by Ca at the uppermost two horizons and by Mg in the remaining subsurface horizons.

The differences in CEC, EC and BS between pedons were due to differences in the type of clay minerals, type of charges on clay surfaces and percentage of clay fractions. As mentioned previously, the AY-14 was dominated by kaolinite mineral with a clay fraction of 11-23% and the clay possessed positive charges. For MA-86 and SW-89 on the other hand, the clay fractions contain some vermiculite, although kaolinites are dominant minerals. In addition, these two pedons had high clay content, i.e. 34-44% for the MA-86 and 47- 61% for SW-89.

P retention

P retention was markedly different between pedons (Figure 3). The AY-14 had the highest P retention, followed by MA-86 and SW-89. This suggests the higher the degree of soil development, the greater the P retention. The high P retention of the AY-14 pedon was mainly due to the high content of Fe-oxides that fix P and mask negative charged clay particle surfaces. This is confirmed by a linear correlation between Fe dithionite (expressed as Fe_2O_3) and P retention in which Fe_2O_3 content ranges from 11 to 13% and P retention from 77 of 89% (Figure 4). Suharta *et al*. (1995) reported P retension of 80-94% of Oxisols in Sanggauledo, West Kalimantan. The MA-86 and SW-89 exhibited considerably lower P retention compared to AY-14. However, there was no reason to express the P retention caused by Fe in MA-86 pedon, since there was a tendency for a decrease in P retention as Fe increased. This may indicate that other factors are responsible for the high P retention. Examination of data in Table 3 indicates the Al saturation is high (5 cmol/kg soil). Hence, P retention maybe attributed to Al rather than Fe which is present at a low amount (<2% Fe_2O_3). However, in the SW-89 P retention could be due to both Fe and Al. This pedon has the lowest P retention among the three pedons.

Soil management practices

Based on mineralogical composition and chemical properties, the three pedons need different management practices. The AY-14 has positive charges on colloid surfaces, high P retention,

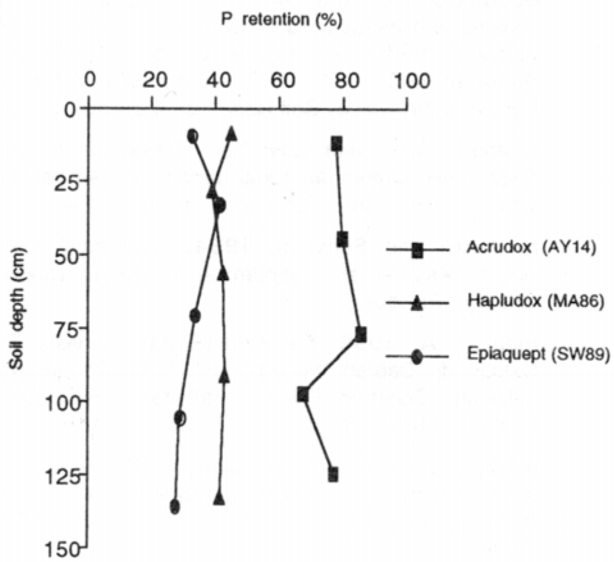

Figure 3. **P retention of three pedons studied in South Kalimantan**

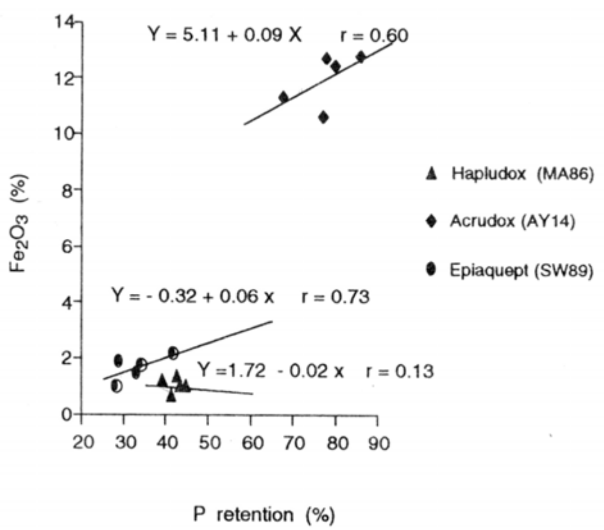

Figure 4. **Relationships between Fe (dithionite) and P retention within three pedons studied in South Kalimantan**

low levels of CEC, exchangeable cations, C and N contents. This indicates the AY-14 needs higher phosphate fertilizer and organic matter to increase CEC, since the main constraint was the presence of the positive charge allowing all cations to be leached out. In addition, lime is necessary to increase soil pH, which in turn may generate the negative charge. The application of lime is mainly directed to increase pH and as a source of Ca. Aluminium content is not a constraint because exchangeable Al was not detected in this soil. The application of fertilizer such as KCl should be carried out periodically, due to the low CEC, in order to prevent/reduce loss of K by leaching.

On the other hand, the MA-86 needs higher lime because it has high exchangeable Al (about 5.0 cmol/kg) and Al saturation of 83-90% at the uppermost two layers. If the amount of lime needed equivalent to 1 cmol/kg Al then 5 t/ha lime is required to improve soil acidity and reduce Al toxicity. In addition, organic matter and phosphate fertilizer are also required to reduce Al toxicity and improve P availability. The P application is lower compared to AY-14 because P retension is lower in the MA-86 than AY-14.

The SW-89 shows better fertility as indicate by 42% Al saturation and exchangeable Al of 3.2 cmol/kg/low to medium rates of P retention, and high exchangeable cations. The better fertililty status of the SW-89 pedon compared to AY-14 and MA-89 pedon is due to fertilizers having been applied such as SP-36, KCl and urea since the soil is used for rice field. Those fertilizers are always needed to keep the fertility status favourable for food crops.

Soil classification

Based on morphological features, physical and chemical properties, and mineralogical composition, the three pedons were classified at a family level as Anionic Acrudox, coarse loamy, kaolinitic, isohyperthermic for the AY-14 pedon; Typic Hapludox, fine, kaolinitic, isohyperthermic for the MA-86 pedon and Typic Epiaquepts, fine, kaolinitic, subactive, isohyperthermic for the SW-89 pedon.

CONCLUSIONS

The AY-14 pedon has a higher degree of development than the MA-86 and SW-89 pedons as indicated by the presence of a positive charge, predominance of kaolinite and disappearence of weatherable minerals in the former. The presence of high weatherable minerals and base saturation of more than 35% in SW-89 suggests that the SW-89 has a lower degree of development than the MA-86 pedon.

In the AY-14 pedon, sand fractions were dominated by opaque minerals with minor quartz as a resistant mineral, whereas the MA-86 and SW-89 pedons were dominated by quartz with traces of opaque minerals. In addition, clay minerals of the AY-14 pedon were mainly kaolinite with minor gibbsite and hematite/goethite and MA-86 and SW-89 pedons were dominated by kaolinite with minor vermiculite, gibbsite, and goethite.

The values of exchangeable cations, CEC of soil and clay, and ECEC of soil and clay were lowest in the AY-14 followed by MA-86 and SW-89, respectively. In contrast, the P retention and iron oxides were high in the AY-14 pedon followed by the MA-86 and SW-89 pedons, respectively.

The clay particle surfaces of the AY-14 bear a positive charge as evidenced from the higher pH-KCl value than the pH-H_2O value and a negative exponential relationship between CEC clay and amount of clay fraction. The MA-86 and SW-89 pedons possess negative charges.

Since the three soils differ in chemical properties and mineralogical composition, different management practices among the three pedons must be considered. The application of high phosphate fertilizer and organic matter is strongly needed for AY-14 and MA-86 pedons, whereas in the SW-89 only P application is needed. In addition, lime application is required to overcome the high Al saturation (83-93%) of MA-86 and to increase the negative charge in the AY-14 pedon.

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