

CHEMICAL AND MINERALOGICAL PROPERTIES OF ULTISOLS OF SASAMBA AREA, EAST KALIMANTAN

B.H. Prasetyo, N. Suharta, Subagyo H., and Hikmatullah

Center for Soil and Agroclimate Research and Development, Jalan Ir. H. Juanda 98, Bogor 16123, Indonesia

ABSTRACT

Ultisols are a major group of marginal soils extensively found in the upland area of Indonesia. To better understand the potential of the Ultisols developed from claystone and sandstone in the Sasamba Integrated Economical Development Area in East Kalimantan, chemical and mineralogical characteristics of 27 Ultisols pedons consisting of 76 topsoil and 118 subsoil samples were investigated. Besides analysis and interpretation of data, relationships of several soil characteristics were constructed using simple regression. The results indicated that Ultisols showed acid to very acid reaction, had low content of organic matter and low base saturation. Soils generally exhibited net negative charge, and the point of zero charge was reached at pH 3.6. Both potential and available phosphates were low, and there was a trend that amorphous aluminum was responsible for phosphate fixation. The low content of exchangeable potassium in topsoil and subsoil indicated a positive correlation with potential potassium. Clay mineral was composed chiefly of kaolinite, with small amounts of illite, vermiculite, and quartz. The domination of kaolinite and low organic matter content causes the soils to have low cation exchange capacity. Soil management in this area should be focused on building up and maintaining soil fertility, and applying appropriate soil conservation techniques to minimize erosion. To obtain sustained productivity, various soil amendments including the use of farm and/or green manure, liming with agricultural lime, and application of rock phosphate and K fertilizers were highly recommended.

[Keywords: Ultisols; chemical properties; clay; East Kalimantan]

INTRODUCTION

Sasamba, from Samarinda-Sangasanga-Muarajawa-Balikpapan, is the area between the cities of Samarinda and Balikpapan (Fig. 1) and is the integrated economical development area or the *kawasan andalan* of the East Kalimantan province. Sasamba is one of the 13 *kawasan andalan* in Eastern Indonesia established in 1996. *Kawasan andalan* is a "growth pole" that has higher potential economic growth than the surrounding regions, due

to the presence of prime economic sector, sufficient supply of the required component from its hinterlands, and good infrastructure facilities (DK-KTI, 1995). The creation of a *kawasan andalan* is meant to boost economic development of the surrounding regions. Because of these important prospects, a reconnaissance soil survey at the scale of 1:250,000 to inventory soil resources and establish rational guidelines for the future development of Sasamba area was conducted by Center for Soil and Agroclimate Research and Development in 1997 (Suharta *et al.*, 1998).

Sasamba area, covering 319,592 ha, has altitudes between 0 and 240 m above sea level. The area is characterized by a wet tropical climate, with 1,502-2,068 mm annual rainfall, and grouped as having A-rainfall type (Schmidt and Ferguson, 1951) and C1, D1, and E1-agroclimatic zones (Oldeman *et al.*, 1980). Its landform can be divided into five major groups, i.e., alluvial, marine, fluvio-marine, aeolian, and structural/tectonic landform. Geologically, the western part of the area that belongs to structural/tectonic landform is a portion of strongly folded formation that appears as parallel-elongated ridges (van Bemmelen, 1949; Sidarto *et al.*, 1998). In this structural/tectonic landform, the undulating to hilly area is mostly used for upland agriculture, and Ultisols developed from claystone and sandstone are the dominant soils (Hikmatullah *et al.*, 1999).

Ultisols, together with Oxisols, are the dominant upland soils occupying the undulating to rolling terrain in the outer islands (Sumatra, Kalimantan, Irian Jaya) of Indonesia. Ultisols alone cover approximately 45.8 million ha, or about 24.3% of the total Indonesian land surface (Pusat Penelitian Tanah dan Agroklimat, 2000). In general, Ultisols are deep, clayey soils, characterized by the presence of argillic or kandic horizon with low (less than 35%) base saturation (Soil Survey Staff, 1998). These soils are commonly acid and low in natural fertility; therefore they are sometimes grouped as marginal soils.

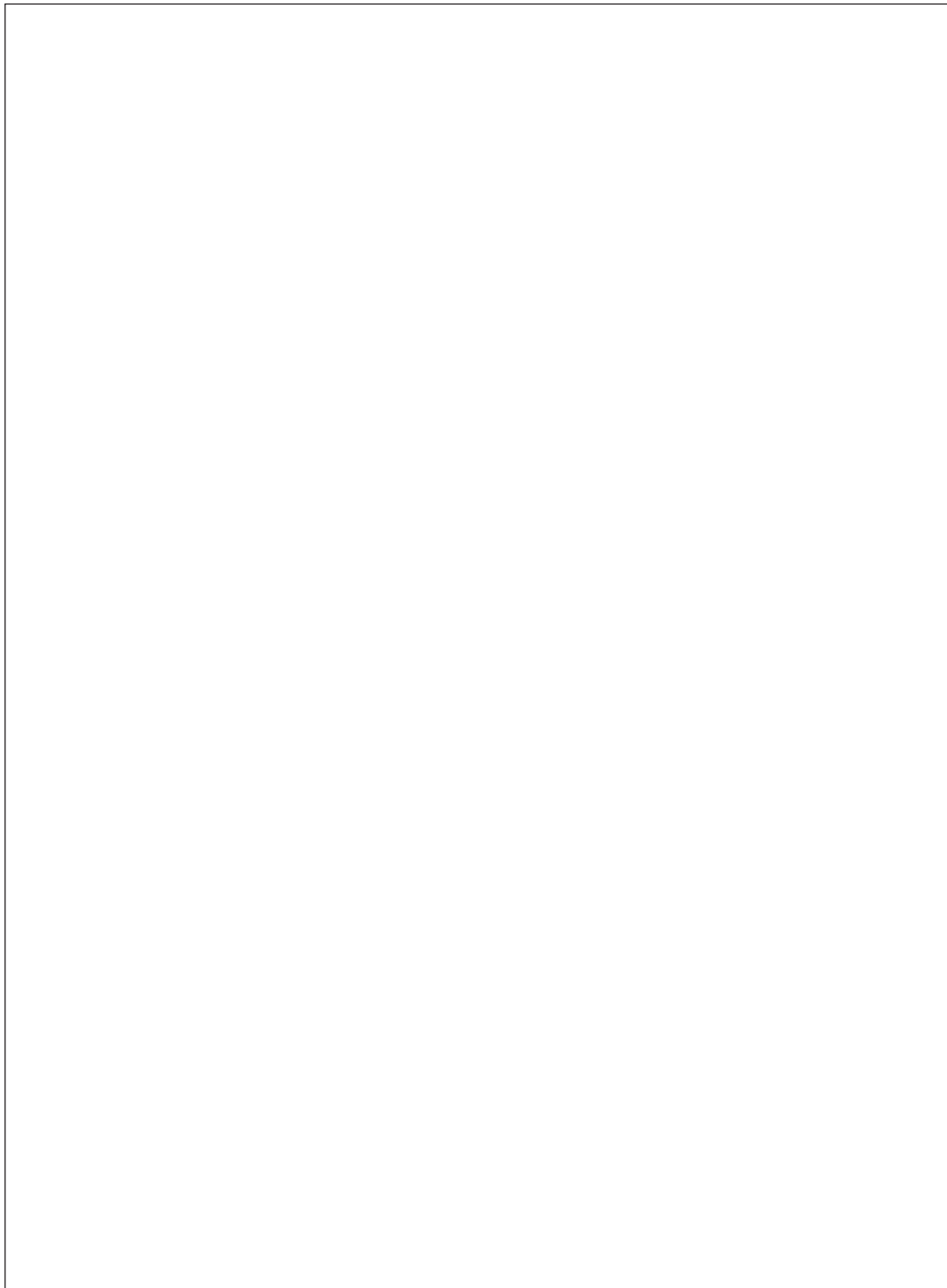


Fig. 1. Map of Sasamba area, East Kalimantan, showing the location of pedons. Insert shows the Sasamba area in Borneo.

Intensive weathering and advanced soil formation have led to a dominance of low-activity clay and a general paucity of plant nutrient. In many areas, Ultisols have been successfully managed for establishment of estate crops, particularly oil palm, rubber, and pepper; however only in a few areas are they suitable for cultivation of upland food crops.

Several studies on Ultisols have been conducted, e.g., Buurman and Dai (1976) in Lampung, Suhardjo and Prasetyo (1998) in Riau, and Prasetyo and Suharta (2000) in South Kalimantan. The Lampung Ultisols were developed from acid volcanic tuff, and classified as Tropohumults and Paleudults, with extremely low nutrient status. Ultisols of Riau were

derived from sedimentary rocks, acid plutonic rocks, and acid tuffs, and classified as Kandiodults. The soils are very acid, and have low fertility status and cation exchange capacity (CEC), but high (> 65%) aluminum (Al) saturation. Similar properties are also shown by Ultisols developed from claystone and sandstone in South Kalimantan, that were classified as Hapludults and Plintudults. Soils are again acid to very acid in reaction, and exhibit low fertility status, organic content, and CEC, but high to very high Al saturation.

The present study aimed to investigate general chemical and mineralogical characteristics of Ultisols developed from claystone and sandstone in the Sasamba area, to better understand the potential of this major upland soil to support agricultural development of this area.

MATERIALS AND METHODS

Analysis data of 194 samples from 27 Ultisols pedons consisting of 14 Paleudults and 13 Hapludults, studied in the undulating to hilly relief in Sasamba area have been selected. All the 27 pedons were taken during the reconnaissance soil survey of the area carried out by the Center for Soil and Agroclimate Research (CSAR) in 1997. Soil analyses were conducted at the laboratories of the same office during 1998. The analysis data were then grouped into topsoil and subsoil samples. The upper part of soil to a depth of 50 cm was defined as the topsoil, while the lower part of soil with a depth between 50 cm and about 150 cm was grouped as the subsoil. Both topsoil and subsoil mostly consisted of two layers. Altogether there were 76 topsoil samples and 118 subsoil samples. The purpose of the grouping was to study soil properties that relate to their potential (the topsoil) and their genesis (the subsoil).

The analysis data consist of texture, organic carbon, pH (H₂O and KCl), potential phosphate (P) and potassium (K) content (by 25% HCl extraction), available P (by Bray-1 extraction), P retention method by a Blackmore *et al.* (1981), exchangeable cation and CEC (by 1 N NH₄OAc, pH 7 extraction), exchangeable Al and H (by 1 N KCl extraction), and amorphous Al and Fe (by acid ammonium oxalate extraction). The soil analyses were conducted following the standard procedure of the CSAR Soil Laboratory, most of which were described in Soil Survey Laboratory Staff (1991). Soil property values were evaluated according to criteria commonly used in CSAR (Pusat Penelitian Tanah, 1982).

Mineralogical analysis to determine clay mineral composition was carried out using X-ray diffractometer with Cu radiation. The Cu tube was operated at 40 kV and 25 mA. The clay specimens were prepared as oriented aggregate on a ceramic plate under the standard clay treatments, i.e., Mg saturation, Mg plus glycerol solvation, K saturation, and K saturation then heated to 550°C.

RESULTS AND DISCUSSION

Chemical Properties

Range, average, and standard deviation of some chemical properties of the Sasamba Ultisols, i.e., grain size distribution, pH (H₂O) and pH (KCl), delta pH, organic carbon, potential P and K, available P, and P retention are presented in Table 1. Topsoil texture ranged from loamy sand to (heavy) clay, but the average texture is clay loam with 30% clay, 39% silt, and 32% sand fraction, or the particle size class is fine loamy. The subsoil texture varies from silt loam to sandy clay or clay, but the average texture is clay, with 40% clay, 35% silt, and 23% sand fractions, or the particle size class is fine. This means that the subsoil contains a higher content of clay fraction, therefore it has finer texture than the topsoil.

From topsoil to subsoil, silt and sand fractions decrease, while the clay fraction increases. This condition indicates that physical weathering has occurred to reduce the amount and size of silt and sand fractions, and to transform them into the clay fraction. Then the illuviation process, i.e., deposition of clay removed from the upper to the lower horizon, has taken place within the soil profile that leads to formation of an argillic horizon.

In a normal sedentary soil, decreasing sand and increasing clay content in a soil horizon may indicate a predominant physical weathering, though chemical weathering may also play a role in the breakdown of particle. A negative relationship between sand and clay fractions, both in topsoil and subsoil (Fig. 2A and 2B) supports the assumption, that if the sand decreases then the clay increases. Despite breakdown from the silt fraction, increasing clay contents in certain Hapludults can be caused by addition of clay directly from the breakdown of sand (Rebertus *et al.*, 1986).

Although topsoil reaction ranges from very acid to slightly acid (H₂O-pH 3.7-6.5), and subsoil reaction varies from very acid to acid (H₂O-pH 4.2-4.7), Ultisols in general exhibit very acid reaction (H₂O-pH 4.4-4.5) in both the topsoil and the subsoil.

Table 1. Some chemical properties of the Sasamba Ultisols, East Kalimantan.

Soil properties	Topsoil			Subsoil		
	Range	Average	Standard deviation	Range	Average	Standard deviation
Sand (%)	8-79	32	19	6-58	23	13
Silt (%)	13-55	39	11	21-49	35	9
Clay (%)	8-63	30	12	17-63	40	11
H ₂ O-pH (1:2.5)	3.7-6.5	4.5	0.5	4.2-4.7	4.4	0.2
KCl-pH (1:2.5)	3.4-5.3	3.7	0.4	3.4-3.8	3.6	0.1
Delta pH	(-0.2)-(-1.4)	(-0.8)	(-0.3)	(-0.1)-(-1.3)	(-0.8)	(-0.1)
Organic-C (%)	0.28-3.14	1.24	0.74	0.13-0.69	0.34	13
Potential P (mg 100 g ⁻¹ soil)	2-19	8	4.5	2-17	5	3.8
Potential K (mg 100 g ⁻¹ soil)	3-29	14	7.4	2-16	10	4.2
Available P (ppm)	0.5-24.1	7.1	4.9	0.1-5.3	2.4	1.1
P retention (%)	13-35	23	6.7	13-46	25	10.5
Total exchangeable bases {cmol(+) kg ⁻¹ soil}	0.46-7.57	1.90	0.61	0.21-3.98	0.96	0.76
Ca {cmol (+) kg ⁻¹ soil}	0.28-1.72	0.70	0.40	0.10-0.77	0.39	0.22
Mg {cmol (+) kg ⁻¹ soil}	0.10-1.12	0.50	0.31	0.03-0.67	0.22	0.13
K {cmol (+) kg ⁻¹ soil}	0.04-0.57	0.20	0.12	0.00-0.17	0.09	0.04
Na {cmol (+) kg ⁻¹ soil}	0.00-0.16	0.05	0.04	0.01-0.09	0.04	0.03
Base saturation (%)	6-57	19	12	3-9	9	4
CEC {cmol(+) kg ⁻¹ soil}	2.8-17.0	9.3	3.4	3.2-17.9	9.6	3.6
Al {cmol (+) kg ⁻¹ soil}	0.08-11.94	4.60	2.85	2.26-15.95	7.10	3.25
H {cmol (+) kg ⁻¹ soil}	0.04-5.26	2.30	1.36	0.72-7.32	3.24	1.71
Aluminum saturation (%)	1-82	48	18	33-85	62	11

The difference between the values of KCl-pH and H₂O-pH is called delta pH (Δ pH), and is often used to indicate the net-charge characteristics of the soil. If the value of delta pH is positive, zero, or slightly negative (less than -0.5) it means that the soil is dominated by variable charge mineral (Uehara and Gillman, 1981). The point of zero charge, i.e., delta pH = 0, is reached when the positive charge is equal to the negative charge, resulting the surface charge of zero (El-Swaify and Sayegh, 1975; Kim, 1982).

Data on delta pH of the Sasamba Ultisols show that both the topsoil and the subsoil exhibit negative values, i.e., varying from -0.2 to -1.4 for topsoil and from -0.1 to -1.3 for the subsoil. The average value of delta pH of both horizons is also negative (-0.8). This means that all Ultisols of Sasamba still possess a negative net-charge characteristic, and some of the Ultisols that have delta pH of 0.5 or less are considered to have dominant variable charge mineral.

The relationship between delta pH and H₂O-pH is depicted in Fig. 2C, which shows a linear equation of y (H₂O-pH) = -0.9301x (delta pH) + 3.6484, with a correlation coefficient (r^2) of 0.87. This relation indicates that, if the value of delta pH is zero, soil pH reaches a value of 3.6, and below this pH value the soil adsorption complex is dominated by positive

charge. The value of pH to reach the point of zero charge (pzc) is low, if the clay is high in silicate minerals or the soil contains high organic matter content. The pH value to reach the pzc increases with increasing content of Fe oxide of the clay fraction (Wann and Uehara, 1978; Tessen and Jusop, 1983).

Studies reported by other researchers stated that the H₂O-pH value to reach the pzc varied among the soil groups. For example, in Andisols of Western Indonesia (Sjarif, 1990), the pzc was reached if H₂O-pH was 4.9. Below this value, the adsorption complex was dominated by positive charge. For Alfisols in the tropical Nigeria (Gallez *et al.*, 1975), the H₂O-pH value to reach the pzc was 3.3. For Oxisols in different tropical areas (van Raij and Peech, 1972), it was reported to be 4.0. In some Oxisols of Malaysia (Tessen and Jusop, 1983), the H₂O-pH value at the pzc was in the range of 4.1-5.5. In some Oxisols of West Java (Prasetyo, 1993), it was reported in the range of 4.1-4.4.

Organic carbon content of the topsoil ranges from very low to high, but its average level is low. In the subsoil, both the range and the average contents of organic carbon are very low. Thus, although the organic carbon content of the topsoil is slightly higher than that of the subsoil, the average content in the profile ranges from low to very low.

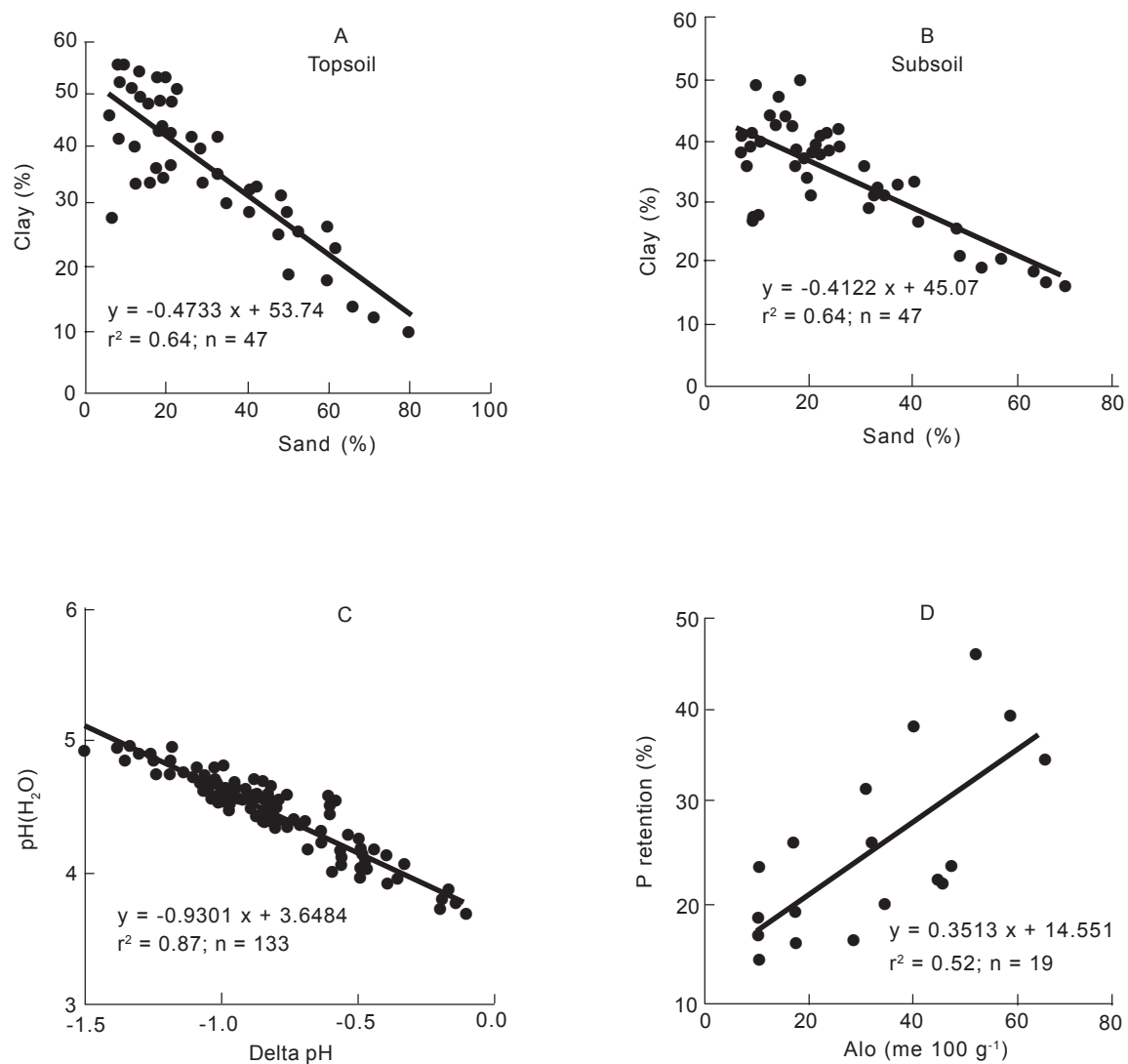


Fig. 2. Relationships between sand and clay fractions in the topsoil and subsoil (2A and 2B), between H₂O-pH and delta-pH value (2C), and between amorphous Al (Alo) and phosphate retention in the topsoil (2D) of the Sasamba Ultisols, East Kalimantan.

Observation on individual pedon shows that for every site, organic carbon content of topsoil is always higher than that of the subsoil. In most pedons, the content decreases regularly with increasing soil depth; this is an indication that most pedons were *in situ* forming soils. The low content of organic carbon in these soils, probably can be explained by the reason that most of Ultisols in Sasamba area are derived from claystone and sandstone that originally were already poor in organic carbon.

Low to very low content of organic carbon affects other important soil properties, particularly CEC. Ultisols are a member of low-activity clay (LAC) soils that have low CEC. In LAC soils, organic carbon

plays an important role, for instance by decreasing P retention.

Potential P content, expressed as mg P₂O₅ per 100 g soil (by HCl 25% extraction) in both layers ranges from very low to low, and its average is also very low. While potential K content, i.e., mg K₂O per 100 g, in topsoil varies from very low to moderate, and in subsoil ranges from very low to low. However, the average in both layers is low. The reason for low content of potential K is probably because soils have reached an advanced stage of weathering, therefore most of the K-containing minerals, such as micas and feldspars have disappeared, and only a small fraction remains as illite and vermiculite minerals in the clay

fraction (Table 2). Most K in these minerals is held in the crystal lattice, so that it is present in fixed form and is non-exchangeable nutrient.

Available P in topsoil varies from very low to moderate, in subsoil it is very low, and the average in both layers is also very low. The low content of available P may be due to two factors, firstly that the soils were inherited from parent material which was inherently poor in P-containing minerals. Secondly, in addition to the total amount of native phosphorous being low due to P fixation, the P in soils is present as insoluble iron (Fe-P) and aluminum-phosphate (Al-P) forms that render it unavailable to plants. Figure 2D seems to support this deduction. There is a tendency that amorphous aluminum (Alo), i.e., the active Al form, influence P retention. The higher the content of Alo, the higher the P retention in soil.

Data on P retention indicate that, in these Ultisols, P retention in the topsoil ranges from low to moderate, and in the subsoil from low to high. The average P retention in both layers however is moderate. The low to moderate P retention in topsoil is probably due to organic carbon content that varies from very low to high, while the mean moderate P retention in subsoil is perhaps because of the presence of the moderate amount of exchangeable Al in the subsoil.

Range, average, and standard deviation of other chemical properties of the Sasamba Ultisols, i.e., total exchangeable and individual bases (Ca, Mg, K, and

Na), base saturation and CEC of soil and of clay, exchange acidity (Al and H), and Al saturation are given in Table 1. The average content of total exchangeable bases in both topsoil and subsoil is very low, although the variation is from very low to moderate in topsoil, and very low to low in subsoil. Base saturation in both layers is also very low, though in topsoil the value is slightly higher, i.e., ranges from very low to moderate. In terms of nutrient content, the topsoil in general is slightly more "fertile" than the subsoil.

Exchangeable bases are dominated by Ca and Mg, even though the content of both bases is actually very low to low. In particular, the contents of exchangeable Ca and Na are very low in the whole layers. The contents of exchangeable Mg and K are similar; they are slightly variable in topsoil, which is very low to moderate, and the average is low. In the subsoil, they range from very low to low, but the averages are again very low.

There seems a positive relationship between exchangeable K and potential K, both in topsoil and in subsoil (Fig. 3 A and 3B). This relationship indicates that exchangeable K originates from weathering of K-bearing minerals, in this case are illite and vermiculite, which are present in the clay fraction. However since the relative amount of either illite or vermiculite in the clay fraction in most cases ranges from trace to small, especially in Paleudults (Table 2), the content of exchangeable K then is very low to low.

Table 2. Composition of clay fraction of the Sasamba Ultisols, East Kalimantan.

Soil	Profile	Depth (cm)	Position	Kaolinite	Vermiculite	Illite	Quartz
Hapludults	HP-36	0-16	Topsoil-1	++++	-	+	-
		41-70	Topsoil-2	++++	-	-	-
		110-130	Subsoil	++++	(+)	+	-
	MA-17	0-14	Topsoil-1	+++	++	+	+
		31-57	Topsoil-2	+++	+++	-	+
		114-134	Subsoil	+++	++	-	+
	HP-46	25-48	Topsoil	+++	++	(+)	++
		67-96	Subsoil	+++	++	(+)	++
	HK-80	29-50	Topsoil	+++	-	++	-
		90-140	Subsoil	+++	-	+++	-
Paleudults	HK-36	0-16	Topsoil	++++	+	(+)	-
		43-68	Subsoil-1	++++	+	-	-
		95-150	Subsoil-2	++++	+	-	-
	MA-11	0-16	Topsoil-1	++++	-	-	-
		35-61	Topsoil-2	++++	+	-	-
		141-165	Subsoil	++++	-	-	-
	MA-53	0-15	Topsoil	++++	+	-	-
		41-65	Subsoil-1	++++	+	-	-
		110-150	Subsoil-2	++++	+	-	-

Topsoil = 0-50 cm depth; subsoil = 50-150 cm depth

Relative amounts: +++++ = predominant, +++ = high, ++ = moderate, + = small, (+) = trace, - = not detected

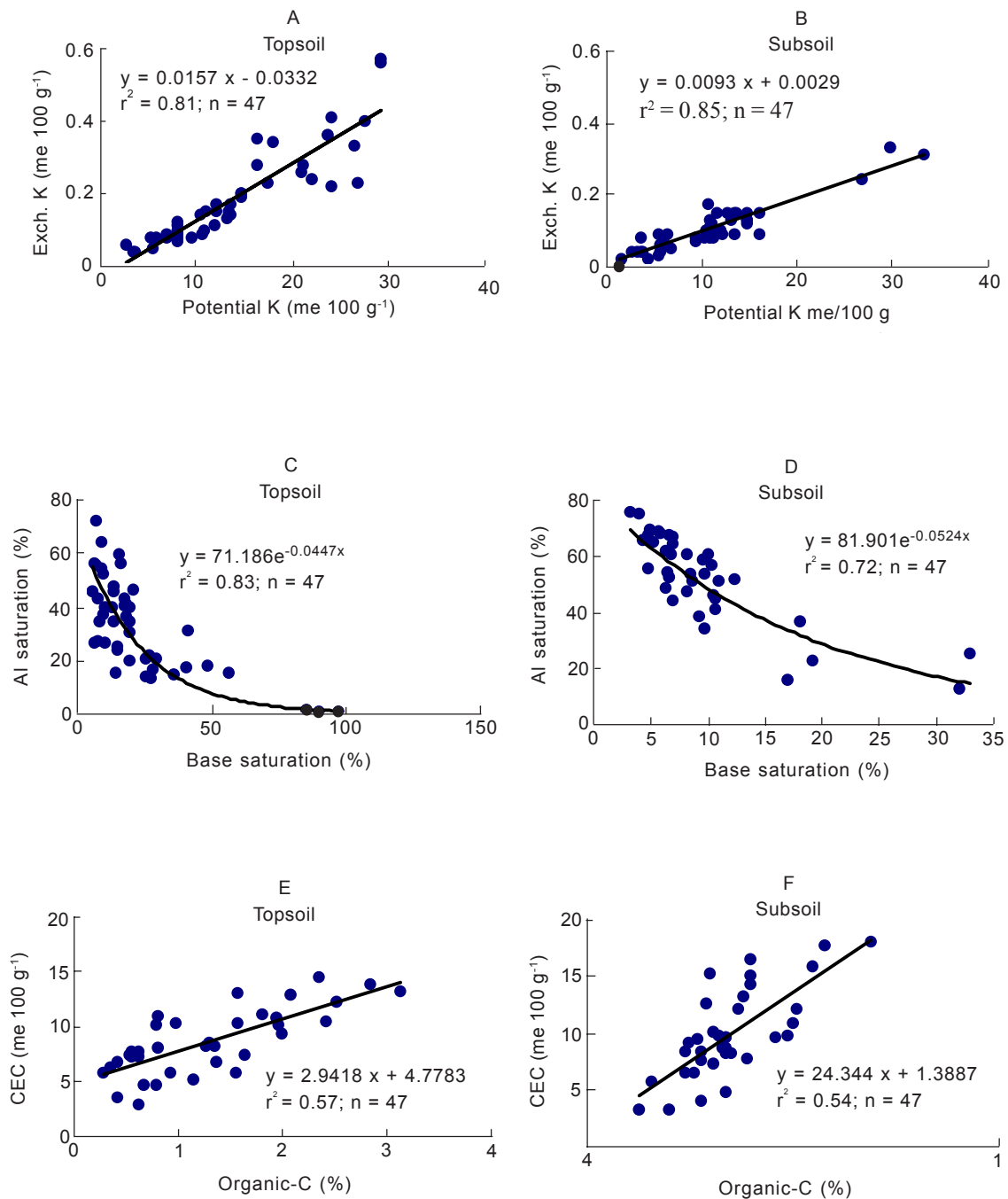


Fig. 3. Relationships between exchangeable potassium and potential potassium contents (A and B), between aluminum saturation and base saturation (C and D), and between soil CEC and organic carbon content (E and F) in the topsoil and subsoil of the Sasamba Ultisols, East Kalimantan.

As already mentioned, although base saturation in the topsoil varies from very low to moderate, the content in subsoil and the average in the whole layers are all very low. Base saturation is related with amount of exchangeable bases at the exchange complex, whilst Al saturation is also related with amount of Al cation at the same exchange complex. It

means that if base saturation is high, i.e., when a lot of exchangeable bases occupy the exchange complex, then the amount of Al cation at the same complex is less, or the Al saturation is low. On the contrary if Al saturation is high, then very little exchangeable bases are present in the exchange complex and consequently base saturation is low. It is therefore well understood

that base saturation correlates well ($r^2 = 0.72-0.83$) with Al saturation, as shown in Fig. 3C and 3D.

Cation exchange capacity of soil varies from very low to moderate in both the topsoil and subsoil, and the average value in both layers is 9.3 and 9.6 cmol(+) kg⁻¹ soil, respectively, which again is considered low. The Sasamba Ultisols therefore have low CEC and very low base saturation. It seems that the low CEC is correlated with composition of the clay mineral and low to very low organic carbon content. The clay fraction of all soils is dominated by kaolinite (Table 2 and Fig. 4) that inherently has low CEC. The CEC of pure kaolinite that was free of oxides and organic matter was reported to vary from about 2 to 12.2 cmol(+) kg⁻¹ clay (Brindley *et al.*, 1986). In Oxisols and Alfisols of West Java, the CEC of similar pure kaolinite was found to range from 1.2 to 12.5 cmol(+) kg⁻¹ clay (Prasetyo and Gilkes, 1998).

Organic matter in soils with low activity clay has an important role in increasing the CEC. Figures 3E and 3F show the positive correlation ($r^2 = 0.57$ and 0.54) between organic carbon and soil CEC, both in topsoil and subsoil. This also means that addition of organic matter would increase the CEC of soil. Positive relationships between organic carbon and CEC in some Indonesian soils have also been reported by Alkushima (1994), Prasetyo *et al.* (1996), and Suhardjo and Prasetyo (1998).

The contents of exchangeable Al and H are considered moderate to very high for all Ultisols. In the topsoil, exchangeable Al content ranges from low to very high, and the average is moderate. In the subsoil, it varies from moderate to very high, and the average is high. In terms of Al saturation, this means that the topsoil in average has moderate Al saturation, and the subsoil exhibits high Al saturation. The general rule is that if high content of exchange acidity is supported by low content of exchangeable bases, then the resulting Al saturation is high.

High Al saturation induces Al toxicity that causes real problems for crops growing in the soil. Some crops, such as soybean are very sensitive to Al toxicity. However, if the amount of exchangeable bases can be increased, Al toxicity can be alleviated. There are two options to alleviate Al toxicity, i.e., using a lot of organic matter (farm manure, green manure) or adding lime to the soil. Liming the soil with agricultural lime which adds the Ca ion, in effect increases soil pH and reduces Al activity, therefore decreases Al saturation and alleviates Al toxicity. The overall effect is to create a more favorable soil environment for crop growth.

Composition of the Clay Mineral

The results of semi-quantitative determination of the clay mineral composition of the Sasamba Ultisols are presented in Table 2. Examples of some X-ray diffractograms of the clay in both the topsoil and subsoil are illustrated in Fig. 4.

The clay fraction of the Ultisols is generally composed chiefly of kaolinite, and small amounts of illite, vermiculite, and quartz. There is no difference in the composition of clay minerals between the topsoil and subsoil. In some pedons of Hapludults, despite kaolinite being the main constituent, there are moderate to high amounts of vermiculite, and trace to moderate amounts of illite. In the more weathered Paleudults, it seems that illite has almost completely disappeared and vermiculite is left only in small amounts.

Kaolinite mineral is characterized by the peak at 7.18 Å on Mg saturated treatment. The peak does not shift on both Mg + glycerol solvated and K saturated treatments, but it disappears after for one hour heating at 550°C. The domination of kaolinite in the Sasamba Ultisols is proven and fits with the chemical soil characteristics that shows low CEC, low contents of exchangeable bases, and acid to very acid soil reaction.

Similar chemical properties and mineralogical composition were reported by Suharta and Prasetyo (1986) for West Kalimantan Ultisols, by Setyawan (1997) for South Sumatra Ultisols, and by Alkushima (2000) for Lampung Ultisols. The domination of kaolinite in the clay fraction is typical phenomena for soils in tropical areas. Isohyperthermic soil temperature regime and humid climate with distinct dry and wet seasons are the governing factors that promote the formation of kaolinite. In well drained conditions, kaolinite can be transformed directly from primary minerals such as mica, following the sequence: mica → illite → vermiculite → kaolinite (Tardy *et al.*, 1973).

Illite mineral is indicated by the peak of 10 Å in all treatments, and even after heating to 550°C the peak remains at 10 Å. Vermiculite is characterized by the peak at about 14 Å in both Mg and Mg + glycerol solvated treatments. Upon heating the K saturated treatment to 550°C for one hour, the peak collapsed to 10 Å.

Quartz is identified by two diffraction peaks at 4.26 Å and 3.34 Å. This silica mineral in the clay fraction is probably inherited from the parent material, and not formed as secondary mineral through authigenic process. According to McKeague and Cline (1963),

Fig. 4. X-ray diffractogram of clay fraction of the topsoil and subsoil of the Sasamba Ultisols, showing kaolinite (7.18 Å) Illite (10 Å), vermiculite (14 Å), and quartz (4.26 Å and 3.34 Å).

formation of secondary quartz requires that the soil must be subjected to wetting and drying cycles, and that silica dissolved on wetting is not completely removed by leaching.

Agricultural Potential

The generally deep (> 100 cm), homogenous colored, and well drained Ultisols of the Sasamba area, although acid and with low natural fertility, have some potential for agricultural development, particularly for upland food crops and perennial or estate crops. Soil management should be directed toward building up and maintaining soil fertility. This includes incorporating farm manure and/or green manure to increase soil organic matter, using agricultural lime to increase soil reaction and alleviate Al toxicity, and applying appropriate amounts of P and K fertilizers. Since soils have kaolinitic mineralogy with low CEC, split K applications for most crops should be practiced. The use of P fertilizer containing readily soluble P, such as TSP and/or SP-36, for these high P fixing capacity soils is not recommended. On the contrary, the use of slow released P phosphatic rocks, e.g., rock phosphate is much more appropriate.

Because soils have undulating to hilly topography, the slope is one of the difficult limiting factor that must be considered. To minimize erosion and soil degradation, complete soil conservation techniques should be adopted. Development of crops therefore must be adjusted to slope conditions. Upland food crops are recommended for cultivation on land with undulating topography with a slope of less than 8%. Perennial and other estate crops are suited on land with slope between 8 and 15% as the first priority, and on land with slope of 15-30% as the second priority. On land of the last priority, soil conservation techniques should be implemented. The results of soil suitability evaluation indicate that from the total Sasamba area of 319,592 ha, about 99,327 ha or 31.1% is suitable for development of upland food crops, such as maize, cassava, and groundnut, and the rest 220,265 ha or about 68.9% is suitable for the development of perennial or estate crops, such as rubber, oil palm, pepper, coffee, and cacao (Hikmatullah *et al.*, 1999).

CONCLUSION

Ultisols of Sasamba area are generally deep soils, with homogenous colored, and well drained with good internal drainage. However, the soils are very acid and have low natural fertility.

The Ultisol topsoil commonly has clay loam texture or fine loamy particle size class, while the subsoil exhibits clay texture or fine particle size class. There is a significant increase of clay fraction in the subsoil of most pedons.

Organic carbon on average is low in topsoil, and very low in subsoil. Topsoil is generally slightly more fertile than the subsoil.

Soil reaction is very acid (< 4.5) throughout the horizons. The average delta pH is negative (-0.8), which means that all the Ultisols still have negative net charge characteristics. The pzc is achieved at pH 3.6, and soil will be dominated by positive charge if soil pH is less than 3.6.

Potential and available P are very low in all horizons. Potential K is also very low in both topsoil and subsoil. P retention in topsoil ranges from low to moderate, and in subsoil varies from low to high.

Average total exchangeable bases in all horizons are very low. Base saturation in both layers is also very low, though in topsoil the values are slightly higher, i.e., very low to moderate. Although exchangeable bases are dominated by Ca and Mg, the contents of all cations (including K and Na) are very low. The low content of organic matter and domination of kaolinite cause the soils to have low CEC. In general, the topsoil has moderate Al saturation, and the subsoil exhibits high Al saturation.

The clay fraction is composed chiefly of kaolinite, and small amounts of illite, vermiculite, and quartz. In some pedons of Hapludults, despite the presence of kaolinite there are moderate to high amounts of vermiculite and trace to moderate amounts of illite. In more weathered Paleudults, illite has almost completely disappeared and vermiculite is left in small amounts.

Ultisols of Sasamba area are more potential for development of perennial or estate crops, but some are also suitable for upland food crops. The main limiting factor, besides acid reaction and low natural fertility, is the slope. Building up and maintaining soil fertility, through application of farm and green manure, liming, and appropriate amounts and kinds of P and K fertilizers are the keys of soil management to obtain sustained soil productivity.

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