Indonesian Journal of Agricultural Science 12(1), 2011: 1-8

GENESIS AND PROPERTIES OF PEAT AT TOBA HIGHLAND AREA OF NORTH SUMATRA

Bambang Hendro Prasetyo and Nata Suharta

Indonesian Center for Agricultural Land Resources Research and Development
Jalan Tentara Pelajar No. 12, Bogor 16114, Indonesia. Phone +62 251 8323012, 8327215, Fax +62 251 8311256
E-mail: bbsdlp@litbang.deptan.go.id

Submitted 5 July 2010; Accepted 11 January 2011

ABSTRACT

In Indonesia, peat soil in the highland area is only found in the plateau of Toba Highland, North Sumatra, and its morphological, physical, and chemical properties have been studied. Four profiles of peat soil were made in the field and eighteen samples were taken and analyzed in laboratory. Most of the properties of highland peat were similar with lowland peat. The differences were in their Al saturation, P retention, and andic soil properties. High Al saturation was resulted from weathering of primary minerals under the acid condition. Andic soil properties were caused by amorphous materials resulted from weathering of volcanic materials in the peat, and P retention was related with the presence of amorphous materials. Phosphate retention of the highland peat was classified high (>60%) and positively correlated with amorphous materials. The presence of amorphous materials was confirmed by ammonium oxalate extractable Al_o+½Fe_o. The presence of andic soil properties in the highland peat created problem in their classification. To provide a place for andic soil properties that influence the P retention in the highland peat soil, the soil classification of peat soil should be modified by adding andic modifier at subgroup level.

[***Keywords***: Peat, soil chemicophysical properties, highlands, Toba, North Sumatra]

INTRODUCTION

Histosols in the world covered 275 million ha. Half is found in the boreal and subartic zones of Northern Hemisphere and is particularly abundant in Central and Northern Canada, Alaska, Northern Finland, and Siberia. A third of total area is distributed in the middle latitudes and is mainly associated with mild, rainy oceanic climates, though there are also inland occurrences especially in mountaneous regions. A small proportion, close to sixth of the total area is located in the tropic, principally associated with mangrove (South Asia) and in mountaneous areas of Africa and South Africa. They can be found from sea level up to an altitude of few hundred meters. In mountaneous inland region, they appear at elevation between 1,000 and 4,000 m asl (Novoa-Munoz *et al.* 2008).

Peat was formed by the process of accumulation of relatively undecomposed organic matter under water or by conditions of continuous near saturation. The organic matter originated from plant residue and plant tissue. Generally peat was formed in the alluvial plain, especially in the basin between big rivers. Based on their site, peat soil can be differentiated as oligotrophic, mesotrophic, and eutrophic. Oligotrophic is unfertile peat that is poor of bases. Eutrophic is fertile peat which is rich in minerals and bases, while mesotrophic is peat that has properties in between oligotrophic and eutrophic.

Based on their formation and water influence, peat soil can be distinguished as topogenous peat and ombrogenous peat. The topogenous peat is the peat enriched by new materials and formed in the environment influenced by tidal water or river, while ombrogenous peat is the peat that formed in the environment influenced by rain water only.

There are 21 million ha of peat soil in Indonesia (BBSDLP 2008), distributed especially in Sumatra, Kalimantan, and Papua. In Sumatra, the peat soil is distributed mainly in Riau, South Sumatra, and Jambi, and covered about 6.59 million ha (Subagyo *et al*. 2000). The peat soil in North Sumatra is about 325,295 ha (Wahyunto *et al*. 2005), distributed in lowland (Labuhan Batu, Asahan, South Tapanuli, and Central Tapanuli Regencies), and highland (Humbang Hasundutan and Dairi Regencies).

Study of peat soil for agricultural development has been carried out in several places, and the research direction generally emphasizing in the soil classification, distribution, potential, and their constraint for agricultural purposes (Suhardjo and Widjaja-Adhi 1976; Widjaja-Adhi 1988; Widjaja-Adhi and Sudjadi, 1988; Subagyo 2002; Agus and Subiksa 2008). All of the studies were carried out in the lowland peat soil. Those researches suggested that peat soil management should pay attention on the importance of drainage to make them suitable for agriculture, decrease in thickness (sub-sidence), irreversible drying, lack of nutrients, and high content of organic acid and high cation exchange capacity (CEC) but low of bases.

Highland peat in the study area is topogenic that is enriched by volcanic materials. Even though the distribution is not as large as lowland peat, the existence of highland peat that has different properties with lowland peat becomes important. It is potentially more fertile peat. The presence of amorphous materials or andic soil properties that affect the P retention, pose a problem in Soil Taxonomy classification. Therefore, these characteristics should be included in the future approximation of Soil Taxonomy classification system. The same condition was reported by Kyoma and Mitsuchi (1985) on Histosols that was covered by volcanic ash and possesed high P retention. This study aimed to evaluate the genesis, characteristics, and classification of peat soil in the highland area.

MATERIALS AND METHODS

The study area was located in Humbang Hasundutan Regency, North Sumatra, on the hummock to hilly landforms, with elevation of 1,629-1,853 m asl. Mean annual rainfall in the study area based on 10-year observation (1998-2007) was 2,627 mm (Fig. 1). This area had a rainfall type A (Schmidt and Ferguson 1951) with no dry month and almost even distribution all year round. The highest monthly rainfall was occurred during April-May. The area had C1 class according to agroclimatic classification (Oldeman 1975), as characterized by 5 wet months (average monthly rainfall >200 mm) and no dry month (average monthly rainfall <100 mm).

Four representative highland soil profiles were used for this study, and those profiles were JH 520, SM 1091, JH 429, and KR 954 (Table 1). Those profiles were characterized by the presence of amorphous materials derived from additional volcanic material from Toba eruption and or deposited from the volcanic materials coming from the surrounding areas. Figure 2 shows the landscape profile of peat soil at Toba highland. Morphologically, those peats contained more mineral soil and the presence of mineral layer was shown by profiles JH 429 and KR 954. Eighteen soil samples were taken from each peat horizon, and brought to the laboratory for physical and chemical property analyses. Soil classification was according to Soil Taxonomy (Soil Survey Staff 2010).

To elucidate the presence of additional materials from volcanic materials and the mineral fractions in

Table 1. Location of four peat profiles in the Toba hughland, North Sumatra, measured by GPS.

Pedon	Elevation (m asl)	Coordinate
JH 520	1,629	98°33’50" East Longitude and 2°26’13" North Latitude
SM 1091	1,837	98°36’49" East Longitude and 2°30’38" North Latitude
JH 429	1,836	98°33’53" East Longitude and 2°31’07" North Latitude
KR 954	1,853	98°37’41" East Longitude and 2°29’18" North Latitude

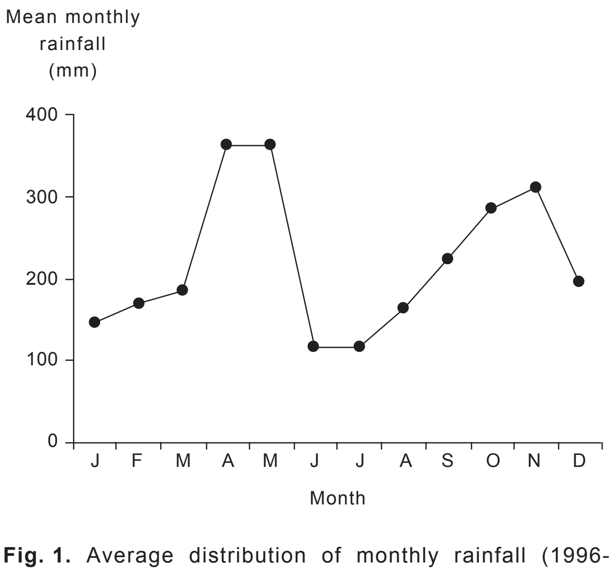

Fig. 1. Average distribution of monthly rainfall (1996-2005) in Tele station, Humbang Hasundutan Regency, North Sumatra.

Fig. 2. Landscape profile of peat soil at Toba highland, North Sumatra.

the peat soil which would influence the peat soil properties, we conducted a series of soil physical analyses. The physical analyses included sand, silt, and clay fractionation by pipette method. The chemical analyses were soil pH (H_2O) with glass electrode, organic-C (acid dichromate digestion), total N (Kjedahl digestion), P retention (Blackmore *et al*. 1981), exchangeable bases and CEC (NH_4OAc pH 7), exchangeable acidity (1N KCl), as well as an Al, Fe, and Si extracted by ammonium oxalate.

RESULTS AND DISCUSSION

Chemical Properties

All of the peat soils investigated showed very acid to acid soil reaction with pH (H_2O) ranged from 3.5 to 5.2 (Table 2). The pH has the same value with peat soil from lowland area (Agus and Subiksa 2008). These pH data indicate that there was no difference in soil reaction between highland peat and lowland peat, and confirm that peat soil is acid to very acid.

Mineral fraction of the peat was dominated by sand, followed by silt and clay. The high content of mineral fractions indicates that addition of mineral from the volcanic materials was occurred in the peat soil. There were two possibilities of the sources of additional materials. First, the additional materials were coming from volcanic materials resulted from Toba eruption carried by wind. Second, the volcanic materials were coming from the top layer of mineral soils in the upper slope areas which was eroded and deposited in the basin. The second possibility was based on the fact that the peat soil was located in the basin of the highland area surrounded by sandy soils of Andisols and Spodosols.

In general, most horizons had organic-C content of more than 18%, while the criteria for organic soil are between 12% and 18%, depending on the clay content in the peat. The peat consisted of sapric soil material, which is defined as highly decomposed organic materials with fiber content of less than one-sixth (by volume). C/N ratio was very high, and the value increased with soil depth, indicating that decomposition of organic matters in the top layer is higher than that in the subsurface. It seems that the decomposition of organic matters in the sublayer is hampered, perhaps by cold temperature and water stagnant condition.

Exchangeable bases were classified as low to very low (Table 3). The low content of exchangeable bases is typical for peat soil. In this case, the addition of volcanic materials from the surrounding areas does not affect their cations in the exchange complex. CEC ranged from 2 to 99 cmolc kg^{-1}, classified as very low to very high, but most of the layer had high to very

Table 2. Soil pH, mineral fractions (clay, silt, and sand) and organic-C of peat in Toba highland, North Sumatra.

Horizon	Depth (cm)	pH (H_2O)	Clay	Silt	Sand	Organic-C	N	C/N
			....	....	(%)	....	....	....
JH 520								
Oa1	0 - 21	3.6	11.09	17.47	71.44	21.54	0.62	35.02
Oa2	21 - 31	3.5	7.37	18.31	74.33	17.45	0.30	57.39
Oa3	31 - 51	3.7	7.88	20.98	71.14	26.92	0.37	72.96
Oa4	51 - 81	3.9	9.70	40.74	49.56	27.37	0.30	92.48
Oa5	81 - 151	4.3	33.11	66.60	0.29	38.76	0.40	96.18
SM1091								
Oa1	0 - 16	4.5	17.71	53.00	29.29	26.12	1.08	24.10
Oa2	16 - 37	4.0	15.70	57.16	27.13	17.75	0.42	42.26
Oa3	37 - 70	4.2	35.04	57.56	7.40	34.51	0.63	54.43
Oa4	70 - 140	4.3	33.97	56.47	9.55	31.01	0.65	47.56
JH 429								
Oa1	0 - 13	3.8	14.40	40.81	44.79	37.44	1.95	19.23
Oa2	13 - 26	4.1	14.82	23.95	61.22	15.21	0.57	26.64
Bms	26 - 33	4.3	12.03	14.70	63.27	7.46	0.28	27.14
Oa3	33 - 100	3.7	18.13	17.60	64.27	40.30	1.29	31.29
Oa4	100 - 140	5.2	24.00	35.71	40.29	48.00	1.29	37.30
KR 954								
Oa1	0 - 12	3.7	43.70	40.43	15.87	46.13	1.50	30.79
Bg	12 - 19	4.1	7.76	31.61	60.62	9.87	0.13	74.23
Oa2	19 - 27	4.1	4.32	3.75	91.93	26.47	0.57	46.36
Oax	27 - 51	4.4	0.12	0.48	99.40	15.88	0.24	66.43

Table 3. Exchangeable bases, cation exchange capacity, and base saturation of peat soil in Toba highland, North Sumatra.

Horizon	NH$_4$OAc 1N, pH 7 K$^+$	Na$^+$	Ca^{++}	Mg^{++}	Sum of bases	Soil CEC	Base saturation (%)
	.... cmolc kg^{-1}					....	
JH 520							
Oa1	0.22	0.08	0.20	0.18	0.68	37.34	1.83
Oa2	0.04	0.06	0.12	0.04	0.26	18.01	1.42
Oa3	0.01	0.06	0.11	0.02	0.20	55.98	0.35
Oa4	0.02	0.04	0.05	0.01	0.12	57.43	0.21
Oa5	0.02	0.06	0.10	0.02	0.20	98.99	0.20
SM1091							
Oa1	0.32	0.08	0.30	0.19	0.89	47.65	1.87
Oa2	0.18	0.06	0.45	0.14	0.83	43.39	1.91
Oa3	0.15	0.09	0.49	0.16	0.89	99.58	0.89
Oa4	0.10	0.07	0.14	0.03	0.35	86.05	0.40
JH 429							
Oa1	0.14	0.05	1.42	0.32	1.93	59.31	3.26
Oa2	0.17	0.05	0.47	0.16	0.85	31.88	2.66
Bms	0.05	0.06	0.28	0.06	0.45	37.78	1.19
Oa3	0.03	0.06	0.19	0.04	0.32	84.66	0.38
Oa4	0.03	0.05	0.15	0.03	0.25	49.17	0.51
KR 954							
Oa1	0.58	0.07	2.01	2.55	5.21	18.75	27.80
Bg	0.10	0.04	0.49	0.29	0.92	2.64	34.88
Oa2	0.24	0.04	1.31	0.59	2.18	14.85	14.66
Oax	0.07	0.05	0.08	0.03	0.23	13.27	1.73

high CEC. The very low CEC was shown by mineral layer at KR 954. The CEC was positively influenced by organic carbon (Fig. 3).

Generally, peat soils do not have Al toxicity (Agus and Subiksa 2008), but the highland peat soils investigated had exchangeable Al in the range from 0.41 to 10.7 cmolc kg^{-1}, and Al saturation from 13% to 98%, indicating the potential danger of Al toxicity. The high exchangeable Al was caused by weathering of volcanic materials in the acid condition. Suharta and Prasetyo (2009) reported that the volcanic materials in the study area consisted of quartz, volcanic glass, sanidine, biotite, oligoclase, andesine, labradorite, hornblende, augite, hypersthene, opaque, and zircon.

The value of base saturation was very low, and negatively correlated with their Al saturation with $R^2 = 0.90$. In the Soil Taxonomy (Soil Survey Staff 2010), the value of Al and Fe extractable by ammonium oxalate (Al_o+½ Fe_o) is used to indicate the presence of amorphous materials in the soil. Among the extractable ammonium oxalate ions, the Al_o content was the highest, followed by Si_o and Fe_o (Table 4). P retention ranged from low (<15%) to high (>60%) in every profile. The P retention was positively influenced by amorphous materials in the form of Al_o+½ Fe_o (Fig. 4). The positive relationships between P retention and

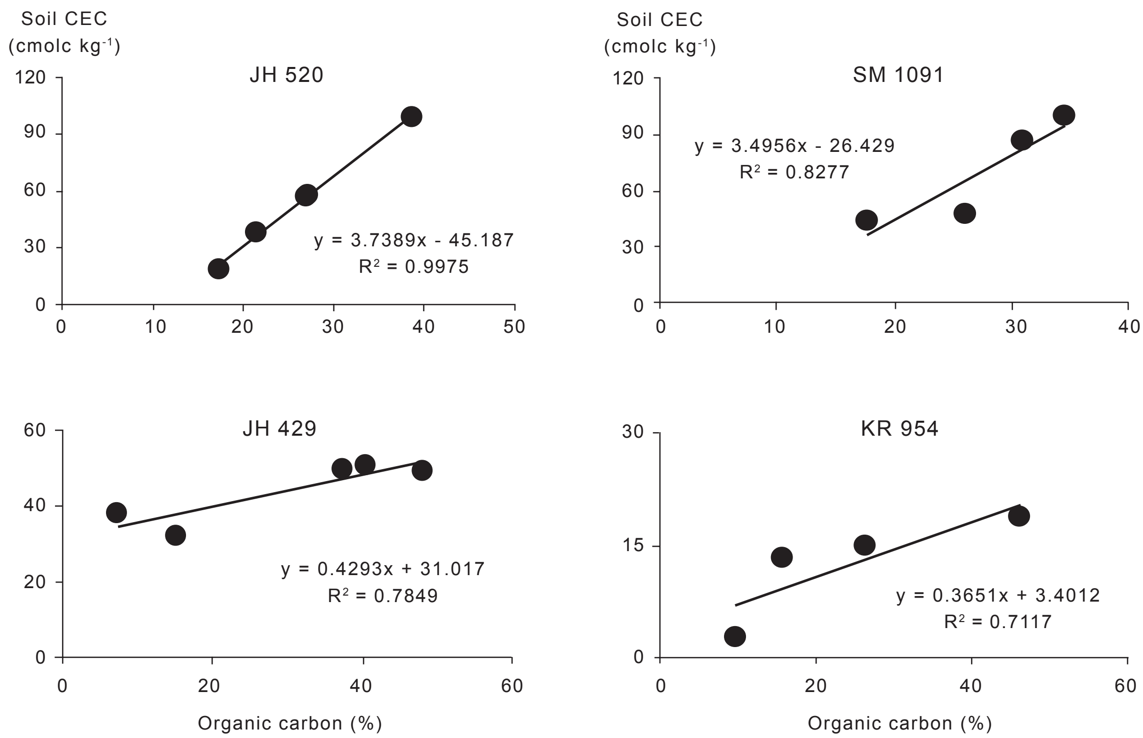

Fig. 3. Relationship between organic carbon and soil CEC of peat soil at Toba highland, North Sumatra.

Table 4. P retention and ammonium oxalate extractable Al_o, Fe_o, Si_o of peat in Toba highland, North Sumatra.

Horizon	P retention	Al_o	Fe_o	Si_o	Al_o +½ Fe_o	Al exchangeable (cmolc kg^{-1})	Al saturation (%)
	..................%				....		
JH 520							
Oa1	72.07	2.08	0.58	0.21	2.38	6.35	90
Oa2	29.87	0.59	0.03	0.01	0.61	2.86	91
Oa3	91.93	3.44	0.01	0.09	3.44	8.49	97
Oa4	96.07	4.11	0.01	0.04	4.11	5.33	97
Oa5	97.85	6.54	0.01	0.07	6.54	10.71	98
SM 1091							
Oa1	56.64	0.72	0.19	0.05	0.82	5.96	87
Oa2	55.34	0.48	0.05	0.01	0.51	5.63	87
Oa3	74.20	4.87	0.03	0.60	4.89	6.45	92
Oa4	92.75	5.70	0.01	0.84	5.71	6.60	95
JH 429							
Oa1	78.54	1.47	0.21	0.11	1.58	5.95	75
Oa2	70.95	1.18	0.06	0.02	1.21	4.91	85
Bms	79.44	3.92	0.02	1.19	3.93	3.65	89
Oa3	91.45	3.54	0.09	0.02	3.59	9.52	96
Oa4	90.81	1.17	0.05	0.01	4.21	5.72	95
KR 954							
Oa1	7.06	0.13	0.03	0.01	0.15	0.82	13
Bg	5.68	0.09	0.01	0.01	0.10	0.41	30
Oa2	51.32	1.15	0.01	0.01	1.16	2.02	48
Oax	74.55	5.37	0.01	1.22	5.38	10.00	97

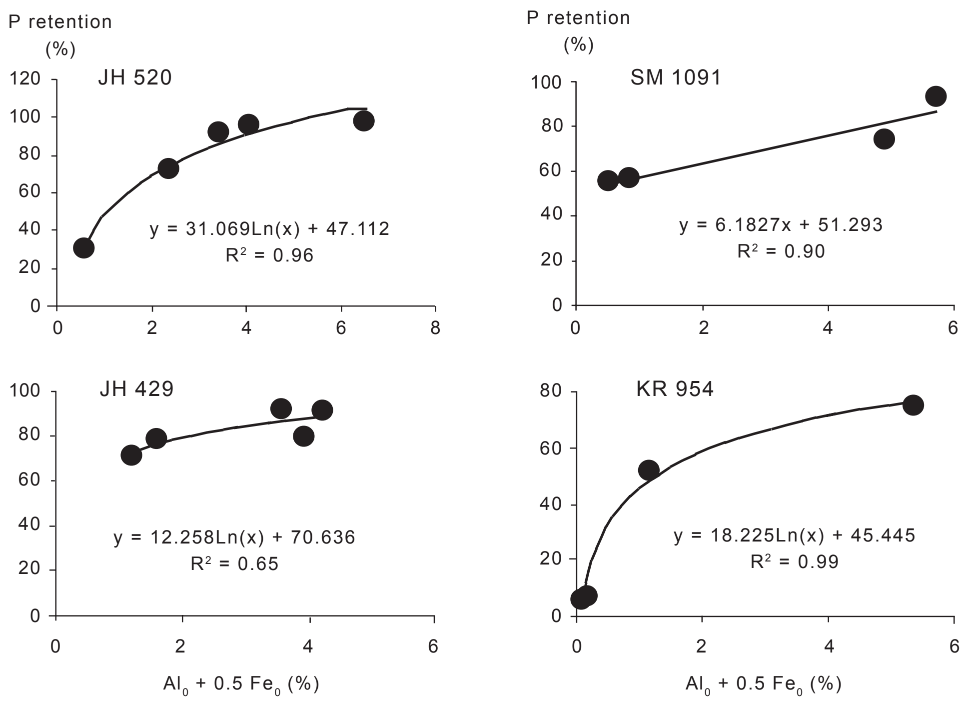

Fig. 4. Relationship between amorphous materials (Al_o+½Fe_o) and P retention of peat in Toba highland, North Sumatra.

Al_o+½Fe_o was also reported by Prasetyo and Suharta (2009) in the soil developed from pyroclastic material and Suharta and Prasetyo (2009) in the Spodosols of Toba highland.

The P retention was also influenced by Al, in the form of amorphous materials and from exchangeable complex, except in profile JH 429. The amorphous Al was more reactive than the exchangeable Al, such

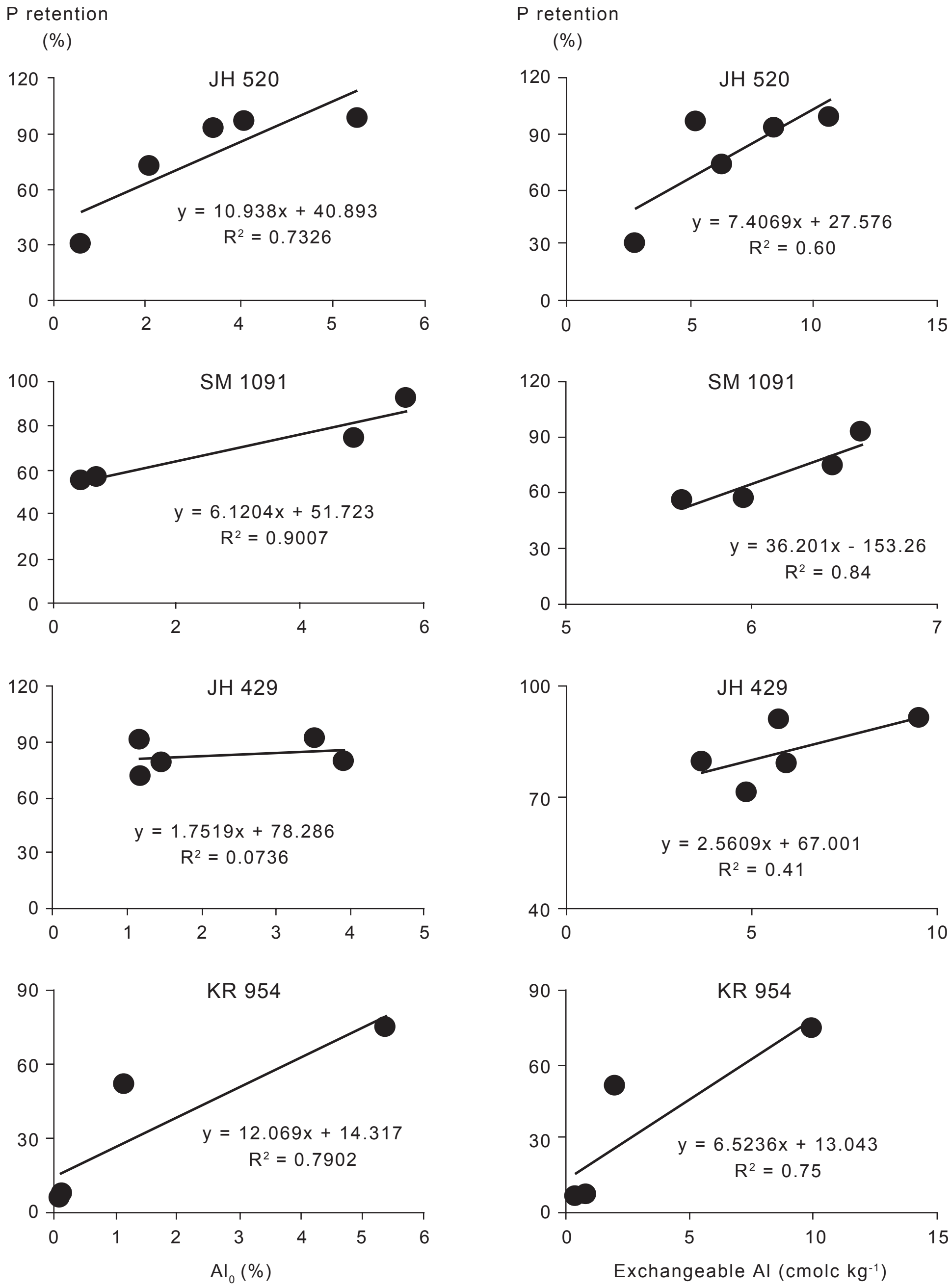

Fig. 5. Relationships between Al_o and exchangeable Al with P retention of peat in Toba highland, North Sumatra.

that the influence of Al_o on P retention was stronger than Al from the exchangeable acidity (Fig. 5).

Considering that the first (Oa1) and second (Oa2) layers of the peat soil had of Al_o+½Fe_o values that differ abruptly from sublayer (Table 4), the addition of volcanic materials apparently occurred in the top layer of the peat. The higher concentration of Al_o+½Fe_o in the sublayer than that in the top layer was caused by the fact that the base of the basin is impermeable liparite tuff which may contain more amorphous materials. The existence of amorphous materials in the peat soil and the positive relationships between P retention with Al_o+½Fe_o and exchangeable Al confirmed acceptance of the hypothesis that peat investigated is enriched by volcanic materials and the volcanic materials influence the properties of the peat.

The peat soil investigated was formed at hilly area, in the small basins that always saturated by water. The basins were filled by organic matter from natural vegetation adapted to saturated soil. In the water saturated environment, the decomposition and mineralization of organic matter are hampered and organic matter accumulated to peat soil. The peat is not only influenced by rain water, but also by the volcanic materials enriched by amorphous materials from the surrounding areas. This is the characteristic of topogenic peat soil in the highland of Toba.

The speculation that volcanic ash was added on the peat soil was proven by the high amorphous materials and high weatherable minerals (Suharta and Prasetyo 2009). The nutrient content in the peat will enhance in line with the increasing weathering stage. The addition of volcanic materials may increase the potential of the peat for agriculture. Other studies about the addition of mineral soil in the peat showed the improving growth and yield of rice (Salampak 1999; Mario 2002).

Soil Classification

Based on the morphological characteristics and laboratory data, peat soil investigated was classified following the Soil Taxonomy system (Soil Survey Staff 2010). All profiles had organic-C content of 12-18% and sapric materials, so that all profiles fulfill the peat soil criteria, but they also had Al_o+½Fe_o value of more than 1% in most layers that fulfill the criteria of the andic soil properties (Table 5).

The main requirement for soil to be classified as Histosols is that the soil does not have andic soil properties in 60% or more of the thickness between the soil surface and either a depth of 60 cm or a densic, lithic, or paralithic contact or duripan if shallower (Soil Survey Staff 2010), while one of the requirement for andic soil properties is that it does not have organic-C greater than 25%. The peat investigated has andic soil properties and the organic-C content is greater than 25%, the level that does not meet the criteria of andic soil properties even though Al_o+½Fe_o is greater than one. False information could happen if the presence of amorphous materials is not mentioned in the soil classification because of its important role in P retention. Therefore, the Soil Taxonomy system should accommodate the presence of amorphous materials in peat soil.

The JH 520 and SM 1091 profiles were classified as Typic Haplosaprists, while the JH 429 and KR 954 profiles showed a mineral soil layer of 7 cm thick, and could not be classified as Terric Haplosaprists because the thickness of inserted mineral soil was less than 30 cm, and thus should be classified as Fluvaquentic Haplosaprists (Soil Survey Staff 2010).

According to the Soil Taxonomy system (Soil Survey Staff 2010), soil with andic properties in subgroup level is soil with Al_o+½Fe_o value greater than 1% and bulk density smaller than 1 g cm^{-3}. Andic soil commonly formed during weathering of tephra or other parent materials have a significant content of volcanic glass. The andic soil properties are resulted mainly by the presence of allophane, imogollite, ferrihydrite, or of metal-humus complexes. These materials are generally called amorphous minerals and formed in moderately weathered volcanic material. Considering that the study area is located in the plateau of Toba Lake, it could be assumed that some Toba eruption materials were precipitated in the place of peat investigated. This process creates andic properties of the soils.

The problem arises in classification of these peat soils because the Histosols should not have andic properties, despite its presence in the highland areas. The same problem showed by Kyoma and Mitsuchi (1985) on the soils that has volcanic ash at the surface which is underlain by thick low moor peat

Table 5. Classification of peat soil at Toba highland, North Sumatra in family level.

Pedon	Main soil characteristics	Soil Taxonomy[1]	Proposed soil classification
JH 520	Organic-C content >17%, sapric, thickness >150 cm, Al_o+½Fe_o range from 0.61 to 6.54%	Ferrihumic, dysic, isothermic, Typic Haplosaprists	Ferrihumic, dysic, isothermic, Andic Haplosaprists
SM1091	Organic-C content >17%, sapric, thickness >150 cm, Al_o+½Fe_o range from 0.51 to 5.71%	Ferrihumic, dysic, isothermic, Typic Haplosaprists	Ferrihumic, dysic, isothermic, Andic Haplosaprists
JH 429	Organic-C content >17%, sapric, thickness 140 cm, Al_o+½Fe_o range from 1.21 to 3.59%, has mineral soil layer of 7 cm thick	Ferrihumic, dysic, isothermic, Fluvaquentic Haplosaprists	Ferrihumic, dysic, isothermic, Fluvaquandic Haplosaprists
KR 954	Organic-C content >17%, sapric, thickness 51 cm, Al_o+½Fe_o range from 0.10 to 5.38%, has mineral soil layer of 7 cm thick	Ferrihumic, dysic, isothermic, Fluvaquentic Haplosaprists	Ferrihumic, dysic, isothermic, Fluvaquandic Haplosaprists

[1]Source: Soil Survey Staff (2010)

beds that posses high P retention capacity. Considering that P retention in the andic materials affected the properties of peat soil, the classification of peat soil should be modified to include Andic instead of Typic in subgroup level. The proposed refinement of the soil classification in the studied area is listed in Table 5. This proposal is in line with Kyoma and Mitsuchi (1985) who reported that Histosols possessing high P retention should be classified in subgroup level as Andic Borohemists instead of Typic Borohemists.

CONCLUSION

In general, peat soil in the highland of Toba has the same properties with peat soil in the lowland areas, such as acid to very acid soil reaction, low exchangeable bases, high cation exchange capacity, and low base saturation. The main different properties are high exchangeable Al and Al saturation, high P retention, and high amorphous material content in the highland peat that are not found in the lowland peat. In the long run, with the weathering of volcanic materials, exchangeable cation and the nutrient content of the peat could also be affected by amorphous materials.

The presence of volcanic materials generates the presence of amorphous materials such as ammonium extractable Al_o, Fe_o, and Si_o. Based on the positive relationship between P retention and amorphous materials in the form of Al_o+½Fe_o we propose the inclution of "andic" modifier in the future approximation of Soil Taxonomy classification system.

REFERENCES

Agus, F., dan I G. Subiksa. 2008. Lahan Gambut: Potensi untuk pertanian dan aspek lingkungan. Balai Penelitian Tanah, Bogor. 36 hlm.

BBSDLP. 2008. Laporan Tahunan 2008. Konsorsium Penelitian dan Pengembangan Perubahan Iklim pada Sektor Pertanian. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian (BBSDLP), Bogor.

Blackmore, L.C., P.L. Searle, and B.K. Daly. 1981. Methods for Chemical Analysis of Soil. NZ Soil Bureau Sci. Rep. 10A. Soil Bureau, Lower Hutt, New Zealand.

Kyoma, K. and M. Mitsuchi. 1985. Wet Andisols. *In* Wetland Soils: Characterization, classification, and utilization. Proc. of workshop held on 26 March to 5 April 1984 under the joint sponsorship of the International Rice Research Institute, Soil Management Support Service Agency for International Development and United States Department of Agriculture. Bureau of Soils Philippines Ministry of Agriculture. IRRI, Los Banos, Laguna, the Philippines.

Mario, M.D. 2002. Peningkatan Produktivitas dan Stabilitas Tanah Gambut dengan Pemberian Tanah Mineral yang Diperkaya oleh Bahan Berkadar Besi Tinggi. Disertasi Program Pascasarjana, Institut Pertanian Bogor, Bogor.

Novoa-Munoz, J.C., X. Pontevedra Pombal, and A. Martinez Cortizas. 2008. Histosols. *In* W. Chesworth (Ed.). Encyclopedia of Soil Science. Springer, Dondrecht, the Netherlands.

Oldeman, L.R. 1975. An Agroclimatic Map of Java and Madura. Contr. Centr. Res. Inst. Agric. Bogor.

Prasetyo, B.H. dan N. Suharta. 2009. Karakteristik tanah-tanah bersifat andik dari bahan piroklastis masam di dataran tinggi Toba. Jurnal Tanah dan Iklim No. 29: 1-14.

Salampak. 1999. Peningkatan Produktivitas Tanah Gambut yang Disawahkan dengan Pemberian Bahan Amelioran Tanah Mineral Berkadar Besi Tinggi. Disertasi Program Pascasarjana, Institut Pertanian Bogor, Bogor.

Schmidt, F.H. and J.H.A. Ferguson. 1951. Rainfall types based on wet and dry period ratios for Indonesia, with Western New Guinee. Kementerian Perhubungan, Djawatan Meteorologi dan Geofisik. Vert. No. 42.

Soil Survey Staff. 2010. Keys to Soil Taxonomy. 11th Edition. United States Department of Agriculture, Washington, DC. 337 pp.

Subagyo, H., N. Suharta, dan A.B. Siswanto. 2000. Tanah-tanah pertanian di Indonesia. hlm. 21-65. *Dalam* A. Adimihardja (Ed.). Sumberdaya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Subagyo, H. 2002. Penyebaran dan potensi tanah gambut di Indonesia untuk pengembangan pertanian. hlm. 197-227. *Dalam* CCFPI (Climate Change, Forests and Peatlands in Indonesia). 2003. Sebaran Gambut di Indonesia. Seri Prosiding 02. Wetlands International-Indonesia Programme and Wildlife Habitat Canada, Bogor.

Suhardjo, H. and I P.G. Widjaja-Adhi. 1976. Chemical characteristics of the upper 30 cm of peat soils from Riau. Soil Res. Inst. Bull. 3: 74-92.

Suharta, N. and B.H. Prasetyo. 2009. Mineralogical and chemical characteristics of Spodosols in Toba highland, North Sumatra. Indones. J. Agric. Sci. 10(2): 54-64.

Wahyunto, S. Ritung, Suparto, dan H. Subagyo. 2005. Sebaran gambut dan kandungan karbon di Sumatera dan Kalimantan. *Dalam* Climate Change, Forest and Peatlands in Indonesia. Wetland International-Indonesia Programme and Wildlife Habitat Canada. Bogor. 254 pp.

Widjaja-Adhi, I P.G. 1988. Physical and chemical characteristics of peat soil of Indonesia. Indones. Agric. Res. Dev. J. 10(3): 59-64.

Widjaja-Adhi, I P.G. dan M. Sudjadi. 1988. Sebaran dan potensi pengembangan lahan gambut untuk pertanian di Indonesia. Kongres I Himpunan Gambut Indonesia dan Seminar Nasional Gambut I. Universitas Gadjah Mada, Yogyakarta.