Mineralogical, Physical, and Chemical Properties of Soils from Andesitic Volcanic Tuff of Mt. Burangrang, West Java

Sifat Mineralogi, Fisika, dan Kimia Tanah Terbentuk dari Tuf Volkan Andesit di Sekitar Gunung Burangrang, Jawa Barat

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ABSTRACT

Information of soils on andesitic volcanic tuff in Indonesia is still limited. Three soil pedons, formed in andesitic volcanic tuff situated in the intensively cultivated vegetable growing areas and secondary forest areas around the Mt. Burangrang, were studied to understand the physical, chemical and mineralogical properties of these soils. All pedons are located in the middle slope with elevation of about 1000 m above sea level (asl). Bulk and undisturbed soil samples of each horizon were analyzed in the laboratory. The results indicated that all the pedons have very deep solum (> 150 cm), granular to subangular blocky structures and friable to very friable consistences. Mineralogy of the clay fraction of pedons 2 and 3 is dominated by metahalloysite, whereas large amounts of gibbsite are only present in pedon 1. Mineralogical composition of the sand fraction is predominantly composed of opaque minerals, while weatherable minerals such as hornblende, augite, hypersthene and plagioclase (andesine and labradorite) are present in various amounts. Soil bulk density values are generally less than 0.9 mg m^{-3}. Soil reaction is acid to extremely acid, whereas soil pH NaF is of less than 9.4. Aluminum saturation is high in pedon 3 and upper horizons of pedon 1. Organic carbon contents are generally medium in the surface horizons and decrease with depth. Exchangeable bases are dominated by Ca and Mg in medium to very low amounts, cation exchange capacity is medium to high, and base saturation varies ranging from very low to medium. All the pedons studied do not meet the requirements of andic soil properties (P retention of less than 85%), and are classified as Andic Dystrudepts. The low bulk density may contribute to the more favourable soil tilth leading to easy tillage and root development. However, high soil acidity in most soils studied is a limiting factor for plant growth.

Key Words : Soil properties, Andesitic volcanic tuff, West Java, Mt. Burangrang

ABSTRAK

Informasi tanah-tanah yang terbentuk dari tuf volkan andesit di Indonesia masih terbatas. Tiga pedon tanah yang terbentuk dari tuf volkan andesit di daerah kebun sayuran dan hutan sekunder di sekitar Gunung Burangrang telah diteliti untuk memahami sifat-sifat fisika, kimia dan mineralogi tanah tersebut. Semua pedon terletak pada lereng tengah dengan ketinggian sekitar 1000 m di atas permukaan laut. Contoh tanah terganggu dan utuh dari setiap horison di analisis di laboratorium. Hasil penelitian menunjukkan bahwa semua pedon memiliki solum yang sangat dalam (> 150 cm), struktur granuler hingga gumpal bersudut, dan konsistensi gembur sampai sangat gembur. Mineralogi fraksi liat didominasi oleh mineral metahaloisit (pedon 2 dan 3), sedangkan gibsit hanya terdapat pada pedon 1. Susunan mineral fraksi pasir didominasi oleh mineral opak, sedangkan mineral-mineral mudah lapuk seperti hornblende, augit, hiperstin dan plagioklas (andesin dan labradorit) ditemukan dalam jumlah yang bervariasi. Bobot isi tanah umumnya kurang dari 0,9 mg m^{-3}. Reaksi tanah masam sampai sangat masam, sedangkan pH NaF kurang dari 9,4. Kejenuhan Al sangat tinggi pada pedon 3 dan lapisan atas pedon 1. Kandungan karbon organik umumnya sedang pada lapisan atas dan jumlahnya menurun menurut kedalaman. Basa-basa dapat dipertukarkan di dominasi oleh Ca dan Mg dalam jumlah sedang sampai sangat rendah, kapasitas tukar kation sedang sampai tinggi, dan kejenuhan basa bervariasi dari sangat rendah sampai sedang. Semua pedon yang diteliti tidak memenuhi persyaratan sifat-sifat tanah andik (retensi P kurang dari 85%) dan diklasifikasikan sebagai *Andic Dystrudepts.* Bobot isi tanah yang rendah berpengaruh baik terhadap pengolahan tanah ataupun perkembangan perakaran. Akan tetapi, kemasaman tanah yang tinggi pada beberapa tanah yang diteliti dapat menjadi faktor pembatas bagi pertumbuhan tanaman.

Kata Kunci : Sifat-sifat tanah, Tuf andesit volkan, Jawa Barat, Gunung Burangrang

INTRODUCTION

Soils derived from volcanic materials arround the mountain are very important in Indonesia because they have high potential for agricultural production. Many agricultural crops such as vegetables, flowers, and tea are cultivated on these soils. For improving productivity, sustainable utilization and conservation of the soils, understanding of the nature and properties of these soils is necessary.

In Indonesia, these soils are distributed from Sumatra in the west, over Java and to the Lesser Sunda Islands (Bali, Lombok, Sumbawa, Flores) in the east (Tan, 1965). These soils cover about 124 million hectares or 0.84% of the world's land

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ISSN 1410 – 7244

surface (Leamy, 1984). Soils developed from volcanic materials are generally classified as Andisols but not all volcanic soils are Andisols. It depends on the weathering and soil formation processes (Shoji *et al*., 1993a). The type of volcanic materials, age of parent materials and elevation may influence soil formation and finally soil characteristics.

The properties of soils formed from volcanic materials have been widely studied in many countries (Mizota and van Reeuwijk, 1989; Shoji *et al*., 1993; Vacca *et al*., 2003). In Indonesia, soils developed in different type and age of volcanic materials have been investigated by Mohr *et al*. (1972), Subardja and Buurman (1980), Subagjo and Buurman (1980), Goenadi and Tan (1989). The most recent study was carried out by Fauzi (2002). He reported that soils developed on old volcanic tuff in Banten at altitude of < 500 m generally have high clay content, high bulk density (> 0.9 mg m^{-3}) and low available water. These soils also showed low pH, low organic matter, low exchangeable bases and variable CEC. The sand fraction mineral of the soils was dominated by opaque, whereas their clay fractions were composed of kaolinite, except for pedon at high elevation, which was dominated by halloysite.

Studies on soils formed from younger volcanic tuff at higher elevation around the Mt. Burangrang in West Java are still needed to get better understanding of the soil properties. In addition, information of these soil properties can be used to support the soil management. The objective of this study was to investigate the physical, chemical, and mineralogical properties and classification of three pedons developed from andesitic volcanic tuff in the Burangrang mountain area.

MATERIALS AND METHODS

Materials

The study area is located in the southwest slope of Mt. Burangrang (2054 m asl), Bandung Regency, West Java Province. It is situated in the intensively cultivated vegetable and secondary forest areas. Geographically, the area lies between 107º 30′ - 107º 35′ E and 6º 45′ - 6º 50′ S.

Three representative soil pedons were selected for this study (Table 1). Pedon 1 is located in Gandasoli (Cisarua District), pedon 2 in Bojongloa (Cisarua District) and pedon 3 in Pasirmanggu (Cikalong Wetan District). These pedons are located in the middle slope with topography of sloping to steep (slope ranging from 12 to 30 percent). The elevation of the pedons is about 1000 meters asl. All the soils are derived from andesitic volcanic tuff materials that are from the currently non-active Mt. Burangrang eruption with volcanisms in the Upper Pliocene (Dam *et al*., 1993). The main landform in this area is middle volcanic ridges (Pusat Penelitian Tanah dan Agroklimat, 1993).

Table 1. Locations, land uses, elevations, and slopes for all pedons studied

Pedon	Location	Land use	Elevation	Slope
			m asl	%
1	Gandasoli 6º47′40.32″ S 107º31′04.89″ E	vegetable garden	1052	12
2	Bojongloa 6º47′35.48″ S 107º30′22.63″ E	vegetable garden	1037	30
3	Pasirmanggu 6º45′24.19″ S 107º30′16.18″ E	secondary forest	1035	14

asl = above sea level

This area has a mean annual rainfall of 1,920 mm and mean annual air temperature of 21.5ºC. Based on the climatic data, the study area can be classified into B climate type (Schmidt and Ferguson, 1951) and B2 agroclimatic zone (Oldeman, 1975). The area also has a udic soil moisture regime and isohyperthermic soil temperature regime. The study area is mainly cultivated with vegetables such as string bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), tomato (*Lycopersicon esculentum*), cabbage (*Brassica oleracea capitata*), and chili (*Capsium* sp.). The forest or secondary forest areas around the Mt. Burangrang are mainly planted with pine trees (*Pinus merkusii*).

Soil sample collection

The morphological characteristics of the pedons were described following the Soil Survey Manual (Soil Survey Division Staff, 1993). Bulk soil samples were collected from each genetic horizon for chemical and mineralogical analysis. Undisturbed samples were also collected with cylindrical metal sampler for physical analysis (bulk density and water retention).

Laboratory analysis

Bulk samples were air-dried and crushed to pass a 2-mm sieve. Particle-size distribution was determined by a pipette method. Bulk density and water content at 33 kPa and 1500 kPa were determined according to Soil Survey Laboratory Staff (1992).

Soil pH was measured with a glass electrode in soil/solution suspensions of 1 : 2.5 H_2O, and 1 : 50 1 M NaF. Organic carbon was determined according to the method of Walkley and Black. Exchangeable bases were extracted with 1 M NH_4OAc at pH 7.0 and the solutions were determined by an atomic absorption spectrometry (AAS). Exchangeable Al was extracted with 1 M KCl. Available P was extracted with Bray-1 reagent. Phosphate retention was determined by the method of Blakemore *et al*. (1981). The cation exchange capacity (CEC) was determined by saturation with the 1 M NH_4OAc at pH 7.0. $NH4^+$ content was determined from the leachate of K_2SO_4 by Auto Analyzer (Soil Survey Laboratory Staff, 1992). Iron (Fe), Al, and Si were extracted by ammonium oxalate (Fe_o, Al_o, Si_o). Iron and aluminum were also extracted by sodium pyrophosphate (Fe_p, Al_p). Iron, Al and Si in the extractant were determined by AAS. The allophane content was estimated from selective dissolution extracts using the formula of Parfitt and Wilson (1985).

Mineralogical composition of the total fine sand fraction (50 – 500 μm) was identified on a glass slide using a petrographic microscope. The minerals were then counted according to the line method.

The clay fraction (< 2 μm) was separated from the soils (< 2 mm) of selected horizons of the three pedons after dispersion in water with 15 ml of 30% H_2O_2, and collected by sedimentation in water. The untreated clay suspensions were placed on a glass slide and let until dry. The mineralogy of clay fraction was determined using a Philips PW 3050/60 X-ray diffractor X'Pert PRO equipped with Ni filtered CuK_α radiation generated at 40 kV and 30 mA. The samples were scanned from 3º to 40º 2θ, at a scan speed of 1º 2θ min^{-1}. Relative abundance of minerals was estimated by measuring the peak heights for the respective mineral species. Intercalation with formamide (CH_3NO) was also used to distinguish halloysite (d ~ 7 Å) from kaolinite (Churchman *et al*., 1984). Formamide expands halloysite in a few minutes to d ~ 10 Å, but takes 4 hours or more to expand kaolinite (Van Ranst, 1995).

To support the XRD results, a differential thermal analysis (DTA) was done to determine the clay minerals. The sample was heated by Perkin Elmer Thermal Analyzer from 50ºC to 1000ºC at a controlled rate of 10ºC min^{-1}. The identification of the soil minerals was based on the endothermic and exothermic peaks.

Scanning electron microscopy (SEM) observations of the small soil aggregates were also performed. The samples were mounted on aluminum stubs, coated with gold and examined under a microscope.

RESULTS AND DISCUSSION

Morphological properties

Major morphological properties of the soils studied are shown in Table 2. All the pedons are very deep (> 150 cm) and are characterized by a horizon sequence A/Bw. The soil colour of the

Table 2. Major morphological properties for all pedons studied

Horizon	Depth	Colour (moist)	Texture	Structure	Consistence	Horizon boundary
	cm					
Pedon 1						
Ap	0-20	10YR 3/3	C	1, m, gr	vfr, so, sp	c, sm
AB	20-36	10YR 3/3	C	1, m, gr	vfr, ss, sp	c, sm
Bw1	36-60/70	10YR 3/4	C	1, m, sb	fr, ss, sp	c, w
Bw2	60/70-90	10YR 3/2	CL	1, m, sb	fr, ss, sp	g, sm
Bw3	90-140	10YR 3/2	SiCL	1, f-co, sb	fr, ss, sp	g, sm
Bw4	140-160	10YR 2/2	C	1, m, sb	fr, ss, sp	-
Pedon 2						
Ap	0-15/22	10YR 3/2	C	1, m, gr	vfr, ss, sp	c, w
AB	15/22-44	10YR 3/3	C	1, f-m, gr+sb	vfr, s, sp	c, sm
Bw1	44-70	10YR 3/4	C	1, f-m, sb	fr, s, sp	g, sm
Bw2	70-96	10YR 3/4	C	1, f-m, ab-sb	fr, s, sp	g, sm
Bw3	96-140	10YR 3/4	C	1, m, ab	fr, s, sp	g, sm
Bw4	140-160	10YR 3/6	C	1-2, m, ab	fm, s, sp	-
Pedon 3						
A	0-12	10YR 3/3	C	1, f, gr	fr, ss, sp	c, sm
Bw1	12-40	7.5YR 4/4	C	1, m, gr	fr, s, sp	d, sm
Bw2	40-65	7.5YR 4/4	C	1, m, sb	fr, s, sp	d, sm
Bw3	65-115	7.5YR 4/4	C	1, f-m, sb	fr, s, sp	d, sm
Bw4	115-170	7.5YR 4/6	C	1, f-co, sb	fm, s, p	-

Remarks : L=loam, CL=clay loam, SiCL=silty clay loam, C=clay, 1=weak, 2=moderate, f=fine, m=medium, co=coarse, gr=granular, sb=subangular blocky, ab=angular blocky, fr=friable, vfr=very friable, fm=firm, so=non sticky, po=non plastic, ss= slightly sticky, sp=slightly plastic, s=sticky, p=plastic; a=abrupt, c=clear, g=gradual, d=diffuse, w=wavy, sm=smooth

surface horizons is generally dark brown (10 YR 3/3) to very dark grayish brown (10YR 3/2) whereas the subsurface horizons are generally dark yellowish brown (10 YR 3/4) to brown (7.5 YR 4/4). Except for pedon 1, the chroma intensity tends to increase with depth. This indicates that the presence of organic matter content decreases with depth.

The surface horizons of the soils generally have weak, fine to medium, granular soil structures. Most of the Bw horizons have weak, medium, subangular blocky structures. The size of the soil structures tends to increase with depth. The angular blocky structures are observed in the lower layers of pedon 2.

Under moist condition, soil consistencies of the surface horizons are generally very friable in pedons 1 and 2, and friable in pedon 3. Most of the subsurface horizons have friable consistency. A firm consistency is only observed in the lowest horizons of pedons 2 and 3. Under wet condition, the soil consistencies are generally slightly sticky to slightly plastic in the surface horizons and sticky to plastic in the subsurface horizons.

Mineralogical properties

Mineralogy of sand fraction

Sand fraction of the soils is dominated by opaque minerals, ranging from 30 to 80% (Table 3). Pedon 1 shows lower amount of opaque minerals compared to pedons 2 and 3. This indicates that pedon 1 has lower degree of weathering than the other pedons. Hornblende is observed in large amounts (17 to 42%) in pedon 1 and small amounts

Table 3. Microscopic data of the sand fractions for all pedons

Horizon	Depth	Total sand fraction										
		Op	Qz	Wm	Rf	Vg	An	Ld	Bw	Hb	Au	Hp
	cm	....					%					....
Pedon 1												
Ap	0-20	37	-	5	6	1	2	10	tr	30	2	7
AB	20-36	38	1	4	7	1	2	8	tr	27	5	7
Bw1	36-60/70	58	tr	3	4	1	1	6	tr	17	3	7
Bw2	60/70-90	49	1	2	3	1	2	6	tr	26	4	6
Bw3	90-140	32	tr	4	3	1	1	8	tr	42	3	6
Bw4	140-160	31	1	4	4	1	3	10	1	32	7	6
Pedon 2												
Ap	0-19	78	1	2	2	1	1	3	-	6	3	3
AB	19-44	64	tr	2	2	1	tr	4	tr	17	4	6
Bw1	44-70	73	1	6	3	5	1	4	-	7	tr	tr
Bw2	70-96	62	1	6	5	2	1	8	-	14	tr	1
Bw3	96-140	76	tr	7	1	1	1	6	-	9	-	tr
Bw4	140-160	82	tr	2	tr	tr	1	3	-	12	-	tr
Pedon 3												
A	0-12	29	1	2	tr	1	-	1	tr	58	3	5
Bw1	12-40	59	tr	6	1	7	tr	1	-	13	6	7
Bw2	40-65	65	2	17	2	5	tr	2	-	6	tr	1
Bw3	65-115	78	2	10	3	3	tr	1	-	3	tr	tr
Bw4	115-170	73	2	21	tr	1	-	2	-	1	-	tr

Remarks : Op = opaque, Qz = quartz, Wm = weathered minerals, Rf = rocks fragment, Vg = volcanic glass, An = andesine, Ld = labradorite, Bw = bitownite, Hb = hornblende, Au = augite, Hp = hypersthene, tr = trace ($< 1\%$)

in most horizons of pedons 2 and 3. Plagioclase (andesine and labradorite), quartz, rock fragments, volcanic glass, augite, and hypersthene are only observed in small amounts in all soils indicating intense weathering during soil formation. Although the soils tend to have large amounts of opaque minerals, the presence of total amounts of weatherable minerals is still dominant. The presence of small amounts of quartz and large amounts of hornblende minerals indicates that the soils are developed from andesitic parent materials. Similar results have been reported by Subagjo *et al*. (1997) and Sukarman *et al*. (1999) who investigated soils formed from andesitic volcanic materials of Mt. Manglayang, Bandung and Mt. Kimangbuleng, Flores, respectively.

Mineralogy of clay fraction

X-ray diffractograms of the clay fractions are presented in Figure 1, while the relative abundance of the minerals is given in Table 4. The result shows that pedons 2 and 3 have a dominance of 1 : 1 layer silicate (metahalloysite), as indicated by the prominent basal reflections, 001 (0.73 – 0.74 nm) and 002 (0.357 – 0.359 nm) with a hkl reflection at 0.445 nm. The reflection at 0.445 nm is caused by clays, probably disordered halloysite (Silber *et al*., 1994). The 0.7 nm peak expands to 1.0 nm peak after 30 minutes of formamide intercalation.

It means that the 0.7 nm peaks observed in the soils were identified as metahalloysite or (dehydrated) halloysite. The peaks of this mineral disappear after heating at 550°C due to dehydroxylation. The halloysite, present in these pedons, shows a basal spacing over a broad range. It is due to a partial and irregular distribution of water molecules between the layers. The presence of H_2O causes a complete irregularity in the stacking of the layers, resulting in diffuse and broad reflections (Van Ranst, 1995). SEM analysis of the

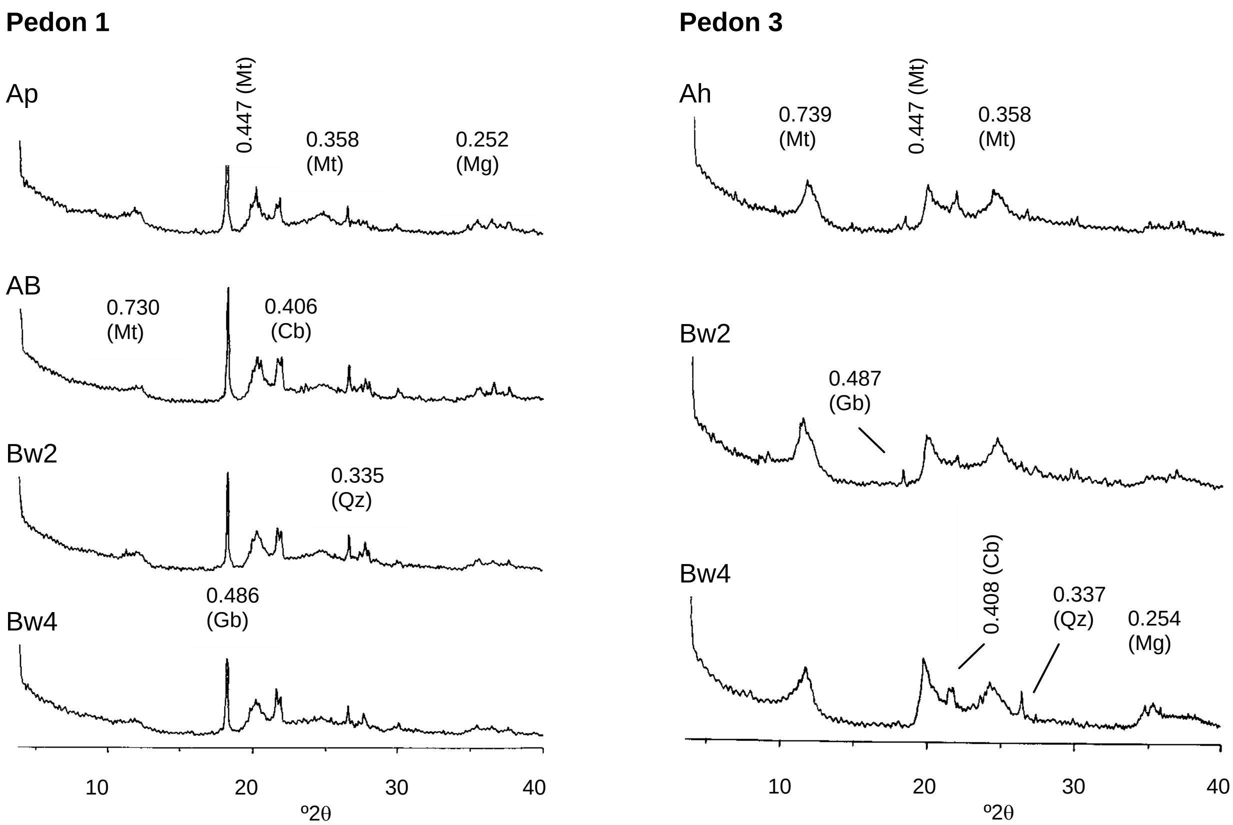

Figure 1. X-ray diffractograms of the clay fractions of pedons 1 and 3

(Cb : Cristobalite, Gb : Gibbsite, Mg : Magnetite, Mt : Metahalloysite, Qz : Quartz)

Table 4. Relative abundance of clay minerals in the fractions of the soils as identified by XRD

Horizon	Depth	Mt	Gb	Cb	Qz	Mg
	cm					
Pedon 1						
Ap	0-20	+	+ + +	+	(-)	(-)
AB	20-36	(-)	+ + +	+	(-)	(-)
Bw2	60/70-90	(-)	+ + +	+	(-)	(-)
Bw4	140-160	(-)	+ + +	+	(-)	(-)
Pedon 2						
Ap	0-15/22	+ + +		(-)		
AB	15/22-44	+ + +	(-)	+	(-)	(-)
Bw1	44-70	+ +	(-)	(-)		(-)
Bw3	96-140	+ + +	(-)	(-)	(-)	(-)
Pedon 3						
Ah	0-12	+ + +	(-)	+	(-)	(-)
Bw2	40-65	+ + +	(-)	(-)		(-)
Bw4	115-170	+ + +		+	+	+

Remarks : Mt = metahalloysite, Gb = gibbsite, Cb = cristobalite, Qz = quartz, Mg = magnetite;
+ + + : major, + + : moderate, + : minor, (-) : trace

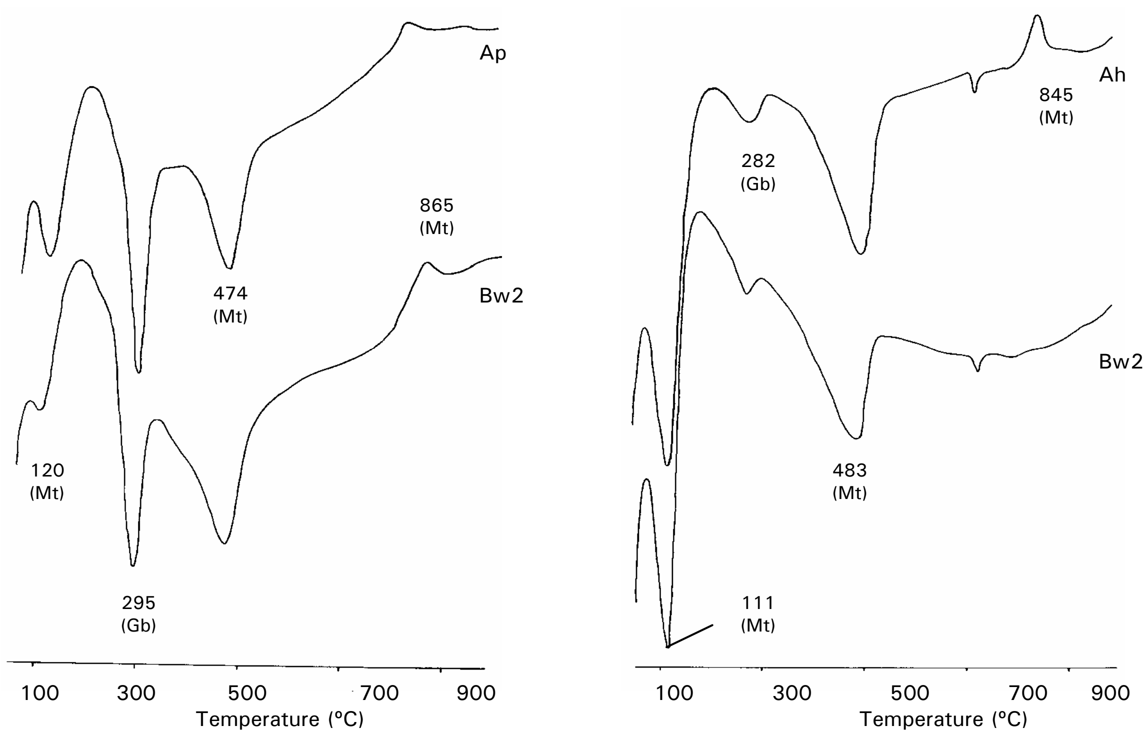

Figure 2. DTA curves of the clay fractions of Pedons 1 and 3
Cb : Cristobalite, Gb : Gibbsite, Mg : Magnetite, Mt : Metahalloysite, Qz : Quartz

Bw1 horizon of pedon 2 shows the presence of spheroidal halloysite (Figure 3). A similar finding has been reported by Arifin (1994) who investigated Andisols developed on andesitic and basaltic volcanic ash at tea plantation, West Java and Adamo *et al*. (2001) who studied halloysite in pyroclastic deposits from the Roccamonfina volcano, Southern Italy.

The presence of halloysite in the soils is also indicated by DTA (Figure 2). The halloysite displays a medium to strong intensity of endothermic peak at 100 to 200°C and a strong asymetrical endothermic peak at 450 to 500°C. The low endothermic peak at 100 to 200°C is due to loss of adsorbed water. Halloysite is also displayed by a small exothermic peak above 800°C. According to Tan *et al*. (1986) the DTA curve of halloysite is similar to that of kaolinite. However, it has in addition a low temperature (100-200°C) endothermic peak of medium to strong intensity. A similar result was reported by Parfitt *et al*. (1988).

Gibbsite (0.485 nm) is the major mineral in the pedon 1 (Figure 1). In the other soil pedons, gibbsite is only observed in trace amounts. Gibbsite is characterized by DTA curves with a strong endothermic peak at 270 to 300°C (Figure 2). The formation of gibbsite is related to the rainfall, desilication, intense leaching together with good drainage (Parfitt *et al*., 1988). The results of the sand fraction analysis showed that pedon 1 was younger than other pedons as indicated by the presence of large amounts of weatherable minerals. However, the clay fractions of this pedon indicate a domination of gibbsite that is often associated with soils in the advanced stages of weathering. In this pedon, the formation of gibbsite may be as a result of desilication of amorphous materials.

The other minerals that are present in the clay fraction are cristobalite, quartz, and magnetite. Cristobalite (0.405 to 0.410 nm) is present in trace to minor amounts, while quartz (0.335 nm) and magnetite (0.254 nm) are only observed in trace amount in most of the soil horizons. The presence of cristobalite mineral may indicate that the pedons studied are developed on volcanic materials.

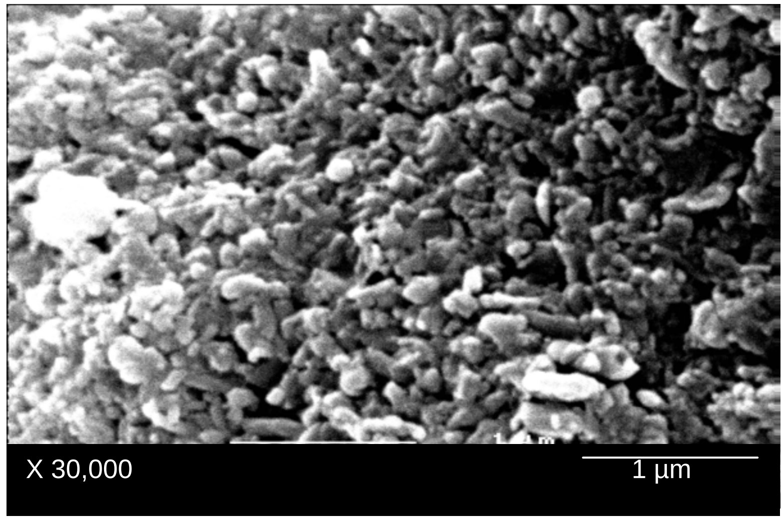

Figure 3. Scanning electron micrograph showing spheroidal halloysite in the Bw1 horizon of pedon 2

Physical properties

Particle-size distribution of the soils is dominated by clay fraction, ranging from 28 to 56% in pedon 1 and 61 to 79% in pedons 2 and 3 (Table 5). Although the soils have high clay content, they do not meet the argillic requirements due to no evidence of clay illuviation (no clay films). Moreover, the subsurface horizons of all the pedons do not contain at least 8% (absolute) more clay than the eluvial horizon so that they do not have argillic horizons. The high clay content in the pedons studied may be due to in situ weathering processes of the parent materials.

Bulk density of the soils ranges from 0.66 to 1.01 mg m^{-3} (Table 5). The bulk density tends to increase with depth in pedons 2 and 3 and varies in

Table 5. Physical properties for all pedons

Horizon	Depth	Particle-size distribution			Textural class USDA	Density		Total porosity	Moisture content		Available water
		Sand	Silt	Clay		Bulk	Particle		33 kPa	1500 kPa	
		0.05-2 mm	2-50 μm	< 2 μm							
	cm	.... %				...... mg m^{-3}....		%	.... %vol		
Pedon 1											
Ap	0-20	21	30	49	C	0.81	2.12	62	30.0	20.8	9.2
AB	20-36	24	26	50	C	0.89	2.02	56	32.1	23.7	8.4
Bw1	36-60/70	22	22	56	C	0.92	2.01	54	33.3	24.3	9.0
Bw2	60/70-90	23	40	37	CL	0.82	2.12	61	31.2	21.4	9.8
Bw3	90-140	13	59	28	SiCL	0.83	2.25	63	30.7	21.7	9.0
Bw4	140-160	15	39	46	C	0.86	2.53	66	32.9	23.3	9.6
Pedon 2											
Ap	0-15/22	6	20	74	C	0.89	1.98	55	31.0	23.7	7.3
AB	15/22-44	7	32	61	C	0.86	2.15	60	42.4	28.4	14.0
Bw1	44-70	5	22	73	C	0.87	2.16	60	44.0	31.9	12.1
Bw2	70-96	5	22	73	C	0.96	2.39	60	50.6	37.0	13.6
Bw3	96-140	5	23	72	C	1.01	2.07	51	54.4	39.9	14.5
Bw4	140-160	5	23	72	C	-	-	-	-	-	-
Pedon 3											
A	0-12	10	18	72	C	0.67	1.99	66	35.8	23.7	12.1
Bw1	12-40	9	19	72	C	0.66	2.30	71	36.6	25.9	10.7
Bw2	40-65	6	18	76	C	0.70	2.35	70	40.2	27.0	13.2
Bw3	65-115	6	15	79	C	0.76	2.06	63	47.7	30.1	17.6
Bw4	115-170	14	23	63	C	0.88	2.06	57	52.6	36.6	16.0

Remarks : CL = clay loam, SiCL = silty clay loam, C = clay

Table 6. Chemical properties for all pedons

Horizon	Depth	pH H_2O	Exch. Al	Al sat.	pH NaF	Organic C	Exchangeable bases				CEC	Base Sat.	Available P	P Retention
							Ca	Mg	Na	K				
	cm		cmol$_c$ kg^{-1}	%		%	.... cmol$_c$ kg^{-1}					%	mg kg^{-1}	%
Pedon 1														
Ap	0-20	3.93	5.19	64.75	9.29	2.41	1.37	0.12	0.09	1.25	31.02	9.10	67.2	85.2
AB	20-36	4.40	2.90	57.14	9.43	2.26	1.94	0.07	0.01	0.15	26.38	8.25	46.9	86.0
Bw1	36-60/70	4.45	3.23	46.72	9.21	2.43	2.86	0.27	0.05	0.50	29.51	12.47	34.7	83.6
Bw2	60/70-90	5.26	0.14	1.22	9.45	1.95	9.63	1.60	0.11	0.19	24.35	47.38	11.6	83.4
Bw3	90-140	5.47	0.05	0.40	9.52	1.56	10.31	2.08	0.14	0.53	30.06	43.41	9.2	84.5
Bw4	140-160	5.65	0.03	0.17	9.47	2.28	12.23	3.02	0.21	0.82	31.09	52.36	8.8	88.0
Pedon 2														
Ap	0-15/22	4.67	1.24	14.88	8.36	1.52	4.91	1.96	0.03	0.19	18.65	38.04	12.5	58.8
AB	15/22-44	5.07	0.08	0.86	8.59	1.35	6.60	2.73	0.09	0.15	23.83	40.17	5.4	61.7
Bw1	44-70	5.28	0.06	0.71	8.87	0.60	6.09	2.73	0.14	0.07	22.80	39.61	3.8	65.3
Bw2	70-96	5.17	0.14	1.62	8.91	0.63	5.55	2.46	0.11	0.07	18.13	45.16	3.3	70.0
Bw3	96-140	5.00	0.14	1.76	9.06	0.57	5.16	2.37	0.12	0.07	22.28	34.61	3.5	73.0
Bw4	140-160	5.16	0.05	0.70	9.20	0.53	6.13	1.26	0.14	0.08	17.61	43.23	3.2	69.9
Pedon 3														
A	0-12	4.77	2.21	39.40	9.03	3.94	2.36	0.77	0.10	0.18	23.70	14.36	7.5	78.4
Bw1	12-40	4.57	5.15	84.16	9.22	1.60	0.60	0.09	0.21	0.06	22.62	4.29	1.1	86.5
Bw2	40-65	4.58	5.55	82.73	9.15	1.21	0.63	0.30	0.18	0.05	19.37	5.98	1.2	83.1
Bw3	65-115	4.63	5.81	88.54	9.24	1.00	0.46	0.06	0.19	0.04	23.16	3.25	1.2	82.2
Bw4	115-170	4.57	5.89	91.51	9.18	0.95	0.33	0.03	0.16	0.03	24.24	2.25	1.2	79.5

pedon 1. The bulk density of the soils tends to decrease with increasing organic matter content. This is because soils with a high organic matter content tend to be better aggregated and consequently have a greater pore volume. In general, soil under forest (pedon 3) tends to have lower bulk density and higher pore spaces than cultivated soils (pedons 1 and 2). Decomposition of the plant residues of the forest may produce humus that contributes to the improvement of the soil structure. The humus may retain the soil particles to form larger soil aggregates leading to the formation of higher pore spaces.

Moisture content held at 33 kPa and 1500 kPa and available water content of the soils ranges from 30.0 to 54.4%, 16.9 to 39.1% and 7.3 to 17.6%, respectively (Table 5). The values of moisture content held at 33 kPa, 1500 kPa and available water content are generally higher in pedons 2 and 3 than in pedon 1. This may be related to the clay contents. Pedons 2 and 3 show higher amount of clay contents (72%) compared to the pedon 1 (44%). The higher the contents of clay in the soil, the amount of water tends to be greater (Brady and Weil, 2000).

Chemical properties

The soil pH H_2O ranges from 3.93 to 5.65 (Table 6) and can be classified as extremely acid to acid according to Soil Survey Manual (Soil Survey Division Staff, 1993). In general, pedon 3 and the upper parts of pedon 1 have lower pH H_2O (3.93 to 4.77) compared to pedon 2 (4.67 to 5.28). The low values of pH H_2O in pedon 3 and the upper parts of pedon 1 are related to the presence of high amounts of exchangeable aluminum (2.21 to 5.89 cmol$_c$ kg^{-1}). The increasing values of exchangeable aluminum are generally followed by an increasing Al saturation (Table 6). The Al saturation values range from 46.72 to 64.75% in the upper parts of pedon 1, from 39.40 to 91.51% in pedon 3 and are generally less than 2% in pedon 2.

Most of the soil horizons have pH NaF of less than 9.4 after 2 minutes stirring (Table 6). This indicates that the soils are dominated by crystalline

Table 7. Selective dissolution data of the pedons

Horizon	Depth	Pyrophosphate		Acid oxalate				Allophane[1]
		Al_p	Fe_p	Al_o	Fe_o	Si_o	$Al_o + 1/2Fe_o$	
	cm	....	....	....	%	....	....	....
Pedon 1								
Ap	0-20	1.12	0.63	2.27	1.71	2.27	3.13	11
AB	20-36	1.34	0.66	1.94	2.81	1.16	3.35	6
Bw1	36-60/70	0.97	0.62	1.77	1.64	1.30	2.59	6
Bw2	60/70-90	0.68	0.38	2.04	1.98	0.98	3.03	6
Bw3	90-140	0.88	0.40	1.78	2.19	1.03	2.88	5
Bw4	140-160	0.44	0.54	1.20	1.59	1.07	2.00	5
Pedon 2								
Ap	0-15/22	0.15	0.39	0.58	1.15	0.31	1.16	2
AB	15/22-44	0.07	0.26	0.70	1.65	0.42	1.53	3
Bw1	44-70	0.02	0.18	0.52	1.45	0.70	1.25	4
Bw2	70-96	0.01	0.16	0.62	1.39	0.25	1.32	2
Bw3	96-140	0.08	0.16	0.51	1.22	0.25	1.12	2
Bw4	140-160	0.21	0.14	1.19	1.66	0.43	2.02	4
Pedon 3								
A	0-12	1.05	1.66	1.18	1.36	0.31	1.86	1
Bw1	12-40	1.35	1.75	0.88	1.39	0.30	1.58	1
Bw2	40-65	1.73	1.50	0.75	1.69	0.26	1.60	1
Bw3	65-115	0.87	1.44	0.70	1.93	0.33	1.67	1
Bw4	115-170	0.43	0.81	0.72	1.55	0.45	1.50	2

[1] Parfitt and Wilson (1985)

clay minerals. Mizota *et al*. (1982), Alvarado and Buol (1982) suggested the lower limit of pH NaF to estimate soils rich in allophane is 9.7 and 10.7, respectively. The higher pH NaF indicates the increase of allophane content. Pedon 1 has higher pH NaF (close to 9.4) than pedons 2 and 3 (8.36 to 9.24). This is related to the contents of active Al and Fe. The pH NaF values tend to increase with increasing Al and Fe extracted by ammonium oxalate (Table 7).

The organic carbon content of the pedons ranged from 0.53 to 3.94% (Table 6). In general, the surface horizons tend to have higher organic carbon content than the subsurface horizons. The surface horizons generally have larger plant residues than the subsurface horizons.

The soils also show a wide variation in the exchangeable base values (Ca, Mg, K, and Na). Pedon 2 shows medium Ca and Mg contents, ranging from 4.91 to 6.60 $cmol_c\ kg^{-1}$ and 1.26 to 2.73 $cmol_c\ kg^{-1}$, respectively. In this pedon, the contents of these cations are relatively stable with depth. In pedon 3, however, the contents of exchangeable bases tend to decrease with depth. The A horizon of this pedon shows higher contents of exchangeable bases compared to the lower ones. This is because the A horizon has higher amounts of hornblende as a result of addition of new materials (Table 3). The exchangeable bases tend to increase with depth in pedon 1. The upper horizons of this pedon have very low to low Ca and Mg contents, ranging from 1.37 to 2.86 $cmol_c\ kg^{-1}$ and 0.07 to 0.27 $cmol_c\ kg^{-1}$, respectively. In contrast, its lower horizons have medium to high exchangeable Ca and Mg, ranging from 9.63 to 12.23 $cmol_c\ kg^{-1}$ and 1.6 to 3.02 $cmol_c\ kg^{-1}$, respectively. The base saturation of this pedon also show similar trend. The base saturation values are very low (9.1 to 12.47%) in the upper horizons and medium in the lower ones (43.41 to 52.36%). The low levels of exchangeable bases and base saturation in the upper horizons of pedon 1 reflect the strong leaching soil condition.

Cation exchange capacity (CEC) of the soils ranges from 17.61 to 31.09 $cmol_c\ kg^{-1}$ (Table 6). Pedon 1 generally has higher CEC than pedons 2 and 3. The presence of large amount of organic matter in pedon 1 might have contributed to the high CEC.

The surface horizons of the soils have higher available phosphorus than the subsurface horizons probably due to P from organic matter. The available phosphorus values of the A horizons of pedon 1, 2 and 3 are 67.2, 12.5, and 7.5 mg kg^{-1}, respectively.

Most horizons of all the pedons have phosphate retention of less than 85% (Table 6). This means that the soils do not meet the requirements of andic soil properties. This is also related to the presence of large amounts of halloysite and gibbsite minerals in the pedons studied. Phosphate retention values of soils developed on volcanic materials decreases with the crystallization of the amorphous materials (Bezama and Aomine, 1977). Furthermore, Shoji *et al*. (1990) reported that weathering of tephra and active transformation of non-crystalline materials to halloysite mineral resulted in the alteration of andic soil properties.

Selective dissolution analysis

The pyrophosphate extraction has been used to indicate the amounts of Fe and Al associated with organic matter (Childs *et al*., 1983; Parfitt and Childs, 1988). The amount of pyrophosphate extractable Fe (Fe_p) and Al (Al_p) of the soils ranges from 0.01 to 1.73% and 0.14 to 1.75%, respectively (Table 7). In comparison to the other soil pedons, the Fe_p and Al_p values of pedon 2 are lower (0.14 to 0.39% and 0.01 to 0.21%). Low Fe_p and Al_p indicate lower organic complexes of aluminum and iron (McKeague and Schuppli, 1982). This also indicates that pyrophosphate extractable Fe and Al species associated with humus in this soil were not present in large amounts (Parfitt and Childs, 1988).

The oxalate extraction dissolves selectively "active Al", Si, and Fe components that are present in non-crystalline materials (NSSC, 1995). All the soils have low values of oxalate extractable Al (Al_o), Fe (Fe_o) and Si (Si_o), ranging from 0.51 to 2.27%, 1.22 to 2.81% and 0.25 to 2.27%, respectively (Table 7). The values of Al_o plus ½ Fe_o range from 2 to 3.35% in pedon 1 and less than 2% in the others. This means that pedon 1 meets one of the requirements for andic properties. However, most pedons generally show low amounts of oxalate extractable Al, Fe and Si. This indicates that the presence of amorphous materials such as allophane is not significant. Allophane is present only in the range of 1 to 11%. The low amount of allophane in the soils may indicate that soil already developed to Inceptisols. The allophane probably has weathered to halloysite or gibbsite minerals. This allophane content also not detected by both XRD and DTA instruments.

Classification of the soils

Classification of soils according to Soil Taxonomy of the soils studied is presented in Table 8. Based on the morphological and chemical properties, all the soils have an umbric epipedon. This is because the surface horizons of the pedons have value and chroma (moist) of 3 or less and base saturation of less than 50%. All the soils do not have subsurface horizons which show andic soil properties in 60% or more of the thickness between the soil surface, do not have spodic and oxic properties, and do not have properties of an argillic, kandic or nitric horizon. The subsurface horizons, however, meet the criteria for a cambic horizon. Thus, all the soils can be classified as Inceptisols. Based on the rainfall data, the soils have an udic moisture regime so that they are classified as Udepts at the Suborder level.

Table 8. Soil classification according to Soil Taxonomy (Soil Survey Staff, 1999) for all the soils studied

Pedon	Orders	Great Groups	Subgroups	Soil Families
1	Inceptisols	Dystrudepts	Andic Dystrudepts	fine, gibbsitic, Isohyperthermic, Andic Dystrudepts
2	Inceptisols	Dystrudepts	Andic Dystrudepts	very-fine, halloysitic, Isohyperthermic, Andic Dystrudepts
3	Inceptisols	Dystrudepts	Andic Dystrudepts	very-fine, halloysitic, Isohyperthermic, Andic Dystrudepts

At the Great Group level, all the soils are classified as Dystrudepts because they have a base saturation of less than 60% (by NH_4OAc) in all the subhorizons between depths of 25 and 75 cm below the soil surface. At Subgroup level, they can be classified as Andic Dystrudepts. This is because the soils have both a bulk density of less than 1.0 mg m^{-3} and Al plus ½ Fe percentages (by ammonium oxalate) totaling more than 1.0% in fine-earth fraction of one or more horizons with a total thickness of 18 cm or more within 75 cm of the mineral soil surface. To meet the requirements of andic soil properties, a soil must have Al plus ½ Fe percentages (by ammonium oxalate) totaling 2.0% or more, bulk density of 0.9 mg m^{-3} or less and phosphate retention of 85% or more within 60 cm of the mineral soil surface.

At the family level, for the particle size class, pedon 1 is classified as fine because the pedon has less than 60% clay (by weighted average) in the fine earth fraction. On the other hand, pedons 2 and 3 are classified as very-fine because they have 60% or more clay. For mineralogy class, pedon 1 is classified as gibbsitic because the soil is dominated by gibbsite in the clay fraction, whereas pedons 2 and 3 are classified as halloysitic because they are dominated by halloysite in the clay fraction. All the pedons are classified as isohyperthermic temperature regime because they have a mean annual soil temperature of 22°C or higher.

CONCLUSIONS

Soils developed on andesitic volcanic tuff in the Burangrang mountain area have high potential capacity for agricultural production because they have very deep solum, friable consistencies, low bulk density, medium to high cation exchange capacity and moderate amounts of weatherable minerals. However, high soil acidity in most soils studied as indicated by low soil pH, high Al saturation, is limiting factors for plant growth and development. To solve this problem, liming application may be recommended.

Exchangeable bases and base saturation varied between pedons. Soil drainage condition and the presence of weatherable minerals may influence the content of exchangeable bases and the level of base saturation.

In general, the mineralogy of sand fraction of all the pedons are dominated by opaque minerals. Pedons 2 and 3 tend to have higher opaque minerals than pedon 1, indicating pedon 1 less weathered than the other pedons.

All the pedons do not meet the requirements for andic soil properties and are classified as Andic Dystrudepts. This is highly related to the presence of large amounts of crystalline clay minerals such as metahalloysite and gibbsite. Allophane is not present in significant amounts as indicated by pH NaF of less than 9.4, phosphate retention of less than 85% and low amounts of oxalate extractable Al, Fe, and Si.

ACKNOWLEDGEMENTS

We would like to thank the Participatory Development of Agricultural Technology Project (PAATP) of the Agency for Agricultural Research and Development (AARD), Government of Indonesia for funding the study. We also thank Mr. Bambang Kaslan, Center for Soil and Agroclimate Research and Development, Bogor for his technical assistance in soil sampling and pedon description.

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