Characteristics of Volcanic Ash Soils from Southern Part of Mt. Tangkuban Perahu, West Java

Karakteristik Tanah Abu Volkan dari Bagian Selatan Gunung Tangkuban Perahu, Jawa Barat

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ABSTRACT

Three soil pedons developed on young andesitic volcanic ash with high mineral deposit and high P retention, granular soil structure, high porosity, and low bulk density, were differentiated based on their morphological, physical, chemical and mineralogical characteristics. Pedons 1 and 3 are discontinue or bisequm pedons characterized by the presence of more contrast colour and new buried materials on layer 4, while pedon 2 is relatively younger than pedons 1 and 3. Mineralogical composition of pedons 1 and 3 is very different compared with pedon 2. Pedons 1 and 3 have high total porosity resulting in easy to the soil leaching. Pedon 2 with higher bulk density tends to be more compact although its soil texture is light, indicating soil character of Andisols from this young volcanic material. High P retention and low base saturation may bring about high P fertilizer need. Pedons 1 and 3 have lower feldspar content as K sources compared with pedon 2, while the content of opaque minerals is higher in pedons 1 and 3 indicating more developed pedons. The top layer of pedon 1 has lower opaque minerals but higher hornblende than pedon 3 due to different land use. The presence of alophane minerals in pedon 1 and 3 can be detected from the results of Selective Dissolution Analysis, but they do not detected on X-ray diffraction patterns. In pedon 2, however, alophane minerals show convex diffraction patterns. Based on characteristics of their soil physics, chemistry, and mineralogy, pedons 1 and 3 were classified as Thaptic Hapludands, and pedon 2 as Typic Melanudands. The increase of P availability on the three pedons can be done by P fertilization and liming to accelerate substitution of Al-P to Ca-P and increase of soil pH.

Keywords : Soil characteristics, Andesitic volcanic ash , Mt. Tangkuban Perahu, West Java.

ABSTRAK

Tiga pedon berbahan abu volkan andesit muda, dengan cadangan mineral tinggi, retensi P tinggi, struktur tanah granular, porositas tinggi, dan bobot isi rendah, dibedakan berdasarkan karakteristik morfologi, fisik, kimia dan mineraloginya. Pedon 1 dan 3 merupakan pedon yang discontinue atau bisequm yang ditandai oleh adanya warna yang lebih kontras, timbunan bahan yang lebih baru diatas lapisan 4, sementara pedon 2 relatif belum berkembang. Komposisi mineral liat pedon 1 dan 3 sangat berbeda dibandingkan dengan pedon 2. Pedon 1 dan 3 memiliki total porositas tinggi sehingga mudah tercuci. Pedon 2 memiliki bobot isi lebih berat, sehingga lebih padat meskipun teksturnya ringan, yang merupakan penciri tanah Andisols dari bahan volkan muda ini. Retensi P tinggi dan kejenuhan basa rendah menyebabkan takaran pupuk P yag diberikan harus tinggi. Pedon 1 dan 3 mempunyai kandungan feldspar sebagai sumber K lebih rendah dibandingkan pedon 2. Sedangkan kandungan mineral opak lebih tinggi pada pedon 1 dan 3 yang menunjukkan bahwa pedon tersebut lebih berkembang. Mineral opak di lapisan atas pada pedon 1 lebih rendah dari pedon 3, sebaliknya untuk hornblende, karena penggunaan lahan yang berbeda. Adanya mineral alophan pada pedon 1 dan 3 dapat dideteksi dari hasil analisis "Selective Dissolution", tetapi tidak terdeteksi pada pola difraksi X-ray. Sedangkan pada pedon 2, mineral liat alophan dicirikan oleh pola difraksi yang cembung. Berdasarkan karakteristik fisik, kimia, dan mineralogi di atas, pedon 1 dan 3 di klasifikasikan sebagai Thaptic Hapludands, dan pedon 2 sebagai Typic Melanudands. Peningkatan ketersediaan P pada ketiga pedon tersebut dapat dilakukan melalui pemupukan dan pengapuran agar terjadi substitusi Al-P menjadi Ca-P serta adanya peningkatan pH Tanah.

Kata Kunci : Karakteristik tanah, Abu volkan andesit, Gunung Tangkuban Perahu, Jawa Barat

INTRODUCTION

Volcanic ash or tephra is commonly unconsolidated, comminuted materials containing a large quantity of volcanic glass which shows the least resistance to chemical weathering (Shoji *et al.*, 1993c). The term "volcanic ash soils" is commonly used to designate soils derived from tephras or pyroclastic materials. Soils developed on volcanic ash are generally classified into Andisols, but not all volcanic soils are Andisols. It depends on the weathering and soil formation processes (Shoji *et al.*, 1993a). Andisols is a young soil characterized by high organic carbon content, low bulk density, high P retention, high CEC (Otawa, 1986), high pH NaF and high oxalate extractable Al (Al_o) and Si (Si_o) content (Balsem and Buurman, 1990). Most Andisols have excellent physical properties such as high water holding capacity, favorable tilth, and strong resistance to water erosion (Shoji *et al.*, 1993b).

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Volcanic ash soils are one of the most productive soils in the world. Their chemical and physical properties influence their productivity in various ways (Shoji *et al*., 1993b). These soils have many unique physical properties that are attributable directly to the properties of the parent material, the non-crystalline materials formed by weathering, and the soil organic matter accumulated during soil formation. These properties include difficult clay dispersion, smeariness consistency, low bulk density, and high water holding capacity (Nanzyo *et al*., 1993a).

Volcanic ash soils also display a wide range of chemical characteristics which strongly reflect the influence of parent material and degree of weathering (Nanzyo *et al*., 1993b). Of these chemical properties, soil organic matter, active Al and Fe, and variable charge are the most prominent characteristics regulating chemical reactions in volcanic ash soils. During the initial stages of soil development, volcanic ash soils are characterized by cation-rich environments and by amorphous materials with high silica to sesquioxide ratios. These young soils, even in humid environments, will supply sufficient nutrients to sustain crop production for a short time (Van Wambeke, 1992).

A distinctive feature of volcanic ash soils is the occurrence of a unique clay-size mineral assemblage dominated by non-crystalline components. Their mineralogical composition of the colloidal fraction varies widely depending on (1) chemical, mineralogical, and physical properties of the parent material, (2) post-depositional weathering environment, and (3) the stage of soil formation (Dahlgren *et al*., 1993). The formation and the transformation of clay minerals are strongly affected by accumulation of humus that forms complexes with Al and Fe. The amorphous materials of volcanic ash soils are frequently consisted of allophane and less commonly imogolite on one hand and humus complexes of Al and Fe together with opal on the other (Mizota and Van Reeuwijk, 1989).

In Indonesia, studies on volcanic ash soils are still lacking. The most recent studies were conducted by Sjarif (1990) in some locations of West Java and North Sumatra, Arifin (1994) in tea plantation of West Java, and Utami (1998) in several sites of Java Island. Although some investigations of the volcanic ash soils have been carried out in West Java, studies on the soils from southern part of Mt. Tangkuban Perahu are still limited.

The objectives of this study were to determine physical, chemical, and mineralogical properties of three representative soil pedons derived from andesitic volcanic ash in the southern part of Mt. Tangkuban Perahu, West Java, and to classify the soils according to Soil Taxonomy. Information from this study can be used to support the soil management.

MATERIALS AND METHODS

Description of the study area

The study area was located in the southwest slope of Mt. Tangkuban Perahu (2,076 m asl). It is situated in the intensively cultivated vegetable growing areas and secondary forest areas of Lembang, about 10 km to the north of Bandung, West Java, Indonesia. Geographically, the area lies between 107º35′ to 107º40′ E and 6º45′ to 6º 50′ S.

Three representative pedons were selected for this study (Table 1). Pedon 1 is located in Sukajaya (Cisarua Sub-District), pedon 2 in Karyawangi (Cisarua Sub-District) and pedon 3 in Genteng (Lembang Sub-District). These pedons are located on the nearly flat to sloping topography (slope ranging from 2 to 10 percent) and elevation of 1,200 to 1,500 meters above sea level (asl). The parent materials of all pedons are andesitic volcanic ash that originated from Mt. Tangkuban Perahu eruption during the early Quaternary activity (Holocene to Late Pleistocene) (Dam *et al*., 1993). The main landforms in this area are volcanic plain and lower 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	Sukajaya 6°48′03.23″ S 107°35′47.95″ E	Vegetable garden	1,305	10
2	Karyawangi 6°48′30.65″ S 107°34′39.08″ E	Vegetable garden	1,246	2
3	Genteng 6°47′17.74″ S 107°37′16.18″ E	Secondary forest	1,500	9

asl = above sea level

The mean annual rainfall and mean annual air temperature of the study area is 2,401 mm and 20°C, respectively (stasiun Margahayu, Lembang). Based on the data, the study area can be classified as A climatic type (according to Schmidt and Ferguson, 1951) and B2 agroclimatic zone (Oldeman, 1975). The study area has an udic soil moisture regime and an isothermic soil temperature regime. The study area was mainly cultivated with vegetables such as cauliflower (*Brassica oleracea botrytis*), carrot (*Daucus carota*), string bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), and cabbage (*Brassica oleracea capitata*). The secondary forest areas around the Mt. Tangkuban Perahu are planted with pine trees (*Pinus merkusii*).

Methods

All laboratory determinations, except for bulk density and water retention, were made on air-dried materials passing a 2-mm sieve. Particle-size distribution was determined by a pipette method after dispersion. Bulk density was measured on undisturbed soil samples. Soil water content at -33 kPa and -1,500 kPa was determined by using pressure membrane method.

Soil pH was measured potentiometrically in water (1:2.5) and in 1 M NaF (1:50), respectively. 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 determined by atomic absorption spectrometry (AAS). Exchangeable Al was extracted with 1 M KCl. 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. Iron, Al, and Si were extracted by ammonium oxalate (Fe_o, Al_o, Si_o); Fe and Al were also extracted by sodium pyrophosphate (Fe_p, Al_p). Iron, Al and Si in the extract were determined by AAS. The allophone content was estimated from selective dissolution extracts using the formula of Parfitt and Wilson (1985).

The mineralogy of total fine sand fractions (50 – 500 μm) was identified on a glass slide using a petrographic microscope and 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 and collected by sedimentation in water. The mineralogy of clay fraction was determined using a Philips PW 3050/60 X-ray diffractor X'Pert PRO equipped with Ni filtered CuKα radiation generated at 40 kV and 30 mA. The samples were scanned from 3° to 40°2θ, at a scan speed of 1°2θ min^{-1}.

RESULTS AND DISCUSSION

Morphological characteristics

All pedons are very deep (> 150 cm) due to the intermittent deposition of volcanic ash (Shoji *et al*., 1985). Pedons 1 and 3 have a buried organic-rich horizon (i.e. horizon 2Ab) and are characterized by very darker colour compared with upper and lower horizons. Formation of this horizon is considered as a result of repetitively thin ash fall and continuous development or rejuvenation of soil (Saigusa *et al*., 1978; Shoji *et al*., 1987). As consequences, they have variable fertility, different degree of weathering and mineral deposits. Pedon 2, however, has no buried horizons and is characterized by an A/Bw horizon sequence.

The surface horizons of all pedons are typically very friable to friable, reflecting development of very porous aggregates of granular structure (Shoji *et al*., 1993). In contrast, the subsurface horizons generally are very friable to firm. The soils are generally non-sticky to slightly sticky and non-plastic in the surface horizons, and tend to be more sticky and plastic in the subsurface horizons. Most horizons of the pedons exhibit varying degrees of smeariness. The smeariness reflects the presence of volcanic amorphous materials, mainly allophane, in the clay fraction (Ping *et al*., 1988). Consequently these soils are easy to tillage and provide good drainage that is needed for optimum growth of upland crops.

The boundaries between A and lower horizons are generally clear and smooth to wavy, while the boundaries within the subsurface horizons are generally gradual to clear and smooth. The boundaries between the 2Ab and the lower horizons of the soils are generally abrupt to clear and wavy, reflecting the intermittent nature of the volcanic ash falls. The stratification of intermittent ash fall is further supported by the multisequum pedons. These features are common in soils developed from volcanic ash (Ping *et al*., 1988).

Physical properties

The soils is generally dominated by silt fraction, followed by clay and sand fractions (Table 3). In general, the buried horizons of pedons 1 and 3 have lower sand content (13 to 28%) than the upper horizons (25 to 36%). This indicates that the buried horizons have higher degree of weathering than the upper horizons. According to USDA, the

Table 2. Major morphological properties of the soils studied

Horizon	Depth	Colour (moist)	Texture	Structure	Consistence	Horizon boundary
	cm					
Pedon 1, Sukajaya-Cisarua						
Ap	0-13/18	10YR 3/2	L	1, f, gr	vfr, so, po	c, w
AB	13/18-30/35	7.5YR 3/4	SiL	1, m, gr	fr, ss, po	a, w
2Ab	30/35-55	10YR 2/1	SiL	1, f, gr	fr, ss, po	c, sm
2Bwb1	55-90	10YR 4/6	SiL	1, f, gr + sb	fr, ss, sp	g, sm
2Bwb2	90-150	10YR 3/6	C	2, f, sb	fm, s, sp	c, sm
2Bwb3	150-160	7.5YR 4/6	SiCL	2, m, sb	fm, s, sp	-
Pedon 2, Karyawangi-Cisarua						
Ap1	0-15	10YR 2/1	CL	1, f, gr	vfr, ss, po	g, sm
Ap2	15-35	10YR 2/1	CL	1, f + m, gr	vfr, ss, po	g, sm
AB	35-65	10YR 2/1	SiL	1, m, gr	vfr, ss, po	g, sm
Bw1	65-100	10YR 2/2	SiL	1, m + f, gr + sb	vfr, ss, po	g, sm
Bw2	100-170	10YR 2/2	CL	1, m + f, gr + sb	fr, ss, po	c, sm
Bw3	170-190	7.5YR 3/4	CL	1, m + f, gr + sb	fr, ss, po	-
Pedon 3, Genteng-Lembang						
A	0-10	10YR 3/3	CL	1, f, gr	fr, ss, po	c, sm
Bw	10-50/60	10YR 3/4	CL	1, f, gr	vfr, ss, po	a, w
2Ab	50/60-75	10YR 2/1	C	1, f, sb	fr, ss, po	g, w
2ABb	75-110	10YR 2/2	CL	1, m, sb	fr, ss, po	c, sm
2Bwb1	110-120/125	10YR 3/2	SiL	2, m, sb	fm, ss, po	c, w
2Bwb2	120/125-145	10YR 3/6	SiL	2, f-co, sb	fm, ss, sp	c, sm
2Bwb3	145-170	7.5YR 4/6	C	1, co, sb	fm, ss, sp	-

Remarks : L = loam, CL = clay loam, SiL = silty 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, sm = smooth, w = wavy

Table 3. Physical properties of the soils studied

Horizon	Particle-size distribution			Textural class USDA	Density		Total porosity	Moisture content		Available water
	Sand 0.05-2 mm	Silt 2-50 μm	Clay < 2 μm		Bulk	Particle		-33 kPa	-1,500 kPa	
	.... %				.... mg m^{-3}		%	.... % v		
Pedon 1, Sukajaya-Cisarua										
Ap	36	37	27	L	0.66	2.09	68	32.1	16.9	15.2
AB	25	55	20	SiL	0.50	1.71	71	46.5	17.5	29.0
2Ab	19	54	27	SiL	0.49	1.95	75	51.7	20.0	31.7
2Bwb1	17	71	12	SiL	0.51	1.79	72	49.2	18.2	31.0
2Bwb2	13	32	55	C	0.52	1.88	72	54.1	19.5	34.6
2Bwb3	17	46	37	SiCL	0.59	2.08	72	55.8	23.3	32.5
Pedon 2, Karyawangi-Cisarua										
Ap1	25	39	36	CL	0.73	2.16	66	50.4	21.7	28.7
Ap2	29	41	30	CL	0.71	1.64	57	38.4	18.4	20.0
AB	34	58	8	SiL	0.79	1.74	55	40.4	20.7	19.7
Bw1	24	62	14	SiL	0.76	2.26	66	41.8	22.1	19.7
Bw2	27	36	37	CL	0.69	1.98	65	33.4	19.5	13.9
Bw3	24	44	32	CL	-	-	-	-	-	-
Pedon 3, Genteng-Lembang										
A	33	35	32	CL	0.55	1.61	66	34.0	21.0	13.0
Bw	36	36	28	CL	0.78	2.16	64	56.0	29.9	26.1
2Ab	17	38	45	C	0.40	2.05	80	60.3	35.8	24.5
2ABb	28	36	36	CL	0.38	2.30	84	58.8	36.5	22.3
2Bwb1	17	64	19	SiL	0.40	1.99	80	58.8	36.7	22.1
2Bwb2	23	57	20	SiL	0.48	2.26	79	60.7	39.1	21.6
2Bwb3	17	21	62	C	-	-	-	-	-	-

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

soil textures are generally classified as silt loam to clay loam. All pedons show textural stratifications. This might have resulted from repeated falls of volcanic ash (Shoji and Ono, 1978).

Bulk density of the soils is generally low, ranging from 0.38 to 0.79 Mg/m^3 (Table 3). This is because the soils have high total porosity (55 to 84%). The high pore spaces are related to the presence of large amounts of organic matter (Table 4) and allophane content (Table 5). Organic matter and allophane contribute to soil aggregation (Sanchez, 1976) and they are therefore responsible for the development of porous structure (Nanzyo *et al*., 1993a). In these aggregated soils, pores exist both between and within the granules (Brady and Weil, 2000). This condition assures high total pore space and low bulk density. These contribute to the more favourable soil tilth leading to easy tillage and root development.

The buried horizons of soil under forest (pedon 3) tend to have lower bulk density than those of cultivated soils (pedons 1 and 2) because of higher aggregation and less compaction. Large amounts of plant roots in the soil under forest play an important role in the formation of soil aggregate. This causes decrease in bulk densities (Brady and Weil, 2000).

The soil moisture content at -33 kPa and -1,500 kPa ranges from 32.1 to 60.7% and from 16.9 to 39.1%, respectively (Table 3). In general, the soil under forest (pedon 3) tends to have higher moisture content at -33 kPa and -1,500 kPa than those of cultivated soils (pedons 1 and 2). The soil under forest has higher organic matter content, which can increase the water-holding capacity of the soil.

Available water is generally defined as moisture content difference between -33 kPa (or field capacity) and -1,500 kPa (or permanent wilting point) (Nanzyo *et al.*, 1993a). Available water content of the soils ranges from 13.0 to 34.6% (Table 3). The surface horizons of pedon 1 and 3 contain lower values of available water than the subsurface horizons due to higher sand content. Greater contents of sand, the amount of available water tends to be smaller (Brady and Weil, 2000).

Chemical properties

According to Soil Survey Manual, the soil reactions are classified as extremely to moderately acidic and vary with depth (Soil Survey Division Staff, 1993). Horizons in pedon 2 show lower pH H_2O values than those in pedon 1 and 3 due to high exchangeable aluminum content. The exchangeable aluminum contributes to soil acidity through provision of Al^{3+} ions to the soil solution that are then hydrolyzed to produce H^+ ions (Brady and Weil, 2000). Aluminum saturations in pedon 2 are quite high which may cause aluminum toxicity and affect negatively to plant growth (Sanchez, 1976).

The pH NaF is used as a simple and convenient index to identify andic materials (Fieldes and Perrot, 1966 as cited by NSSC, 1995). The results show that all the soils have high pH NaF indicating that the soils contain high amounts of amorphous clay minerals. The high level of pH NaF value also indicates the presence of active hydroxy-Al and/or Fe components (Shoji and Ono, 1978; Mizota and Wada, 1980).

All the soil pedons contain high organic carbon. The 2Ab horizons of pedons 1 and 3 contain higher amount of organic carbon than the other horizons. This indicates that the soil horizons have been buried. The high organic C may contribute to low bulk density, notable friability, weak stickiness, formation of soil aggregates. It also greatly influences productivity of the soils through its role in supplying nutrient elements, retaining available water for plants, and development of a

Table 4. Chemical properties of the soils studied

Horizon	pH		Organic C	Exchangeable bases				CEC	Aluminum		BS	P retention
	H_2O	NaF		Ca	Mg	Na	K		Exchange	Saturation		
			%	.... $cmol_c\ kg^{-1}$						.... %		
Pedon 1, Sukajaya-Cisarua												
Ap	4.71	10.11	4.27	2.70	0.17	0.03	0.51	36.43	0.37	9.78	9.33	92.9
AB	4.29	10.47	3.06	4.38	0.40	0.01	0.64	29.19	3.47	39.04	18.59	97.6
2Ab	5.18	10.65	4.80	6.57	0.93	0.19	0.62	35.96	0.17	2.06	23.08	98.0
2Bwb1	5.88	10.26	2.03	4.76	0.79	0.37	0.19	21.46	0.03	0.56	28.47	96.9
2Bwb2	5.21	10.54	1.59	3.44	0.68	0.22	0.22	25.64	0.06	1.27	17.75	99.1
2Bwb3	4.59	9.47	1.44	2.96	0.23	0.13	1.06	11.66	0.55	11.10	37.61	93.0
Pedon 2, Karyawangi-Cisarua												
Ap1	4.18	9.96	6.43	1.00	0.05	0.05	0.17	45.91	3.25	72.07	2.75	88.6
Ap2	3.52	10.00	5.61	0.45	0.03	0.03	0.14	41.79	2.62	80.01	1.57	88.5
AB	3.90	10.33	4.61	0.37	0.04	0.02	0.14	34.55	5.24	90.05	1.68	94.7
Bw1	3.99	10.47	5.66	0.77	0.02	0.04	0.23	38.21	4.87	82.09	2.78	95.3
Bw2	4.16	10.52	5.18	1.09	0.03	0.06	0.40	36.16	5.07	76.28	4.36	95.9
Bw3	4.54	9.96	3.29	3.99	0.32	0.08	1.39	31.00	2.86	33.12	18.63	93.9
Pedon 3, Genteng-Lembang												
A	4.80	10.65	6.77	2.78	0.11	0.07	0.21	25.91	1.04	24.61	12.25	92.9
Bw	4.61	11.05	5.46	0.23	0.04	0.02	0.10	26.43	0.57	59.03	1.49	98.9
2Ab	4.74	11.06	10.18	0.51	0.19	0.25	0.23	29.11	1.10	48.25	4.05	98.8
2ABb	4.96	11.02	6.91	0.51	0.13	0.10	0.08	31.09	0.09	9.89	2.62	99.2
2Bwb1	4.78	11.03	4.57	0.04	0.02	0.04	0.06	35.06	0.10	37.78	0.47	99.5
2Bwb2	4.60	10.84	2.97	0.06	0.02	0.05	0.05	26.94	0.09	32.57	0.65	99.4
2Bwb3	4.63	10.80	1.84	0.52	0.27	0.03	0.03	31.81	0.09	9.69	2.66	99.4

CEC = cation exchange capacity, BS = base saturation favourable rooting environment (Nanzyo *et al.*, 1993b).

Exchangeable bases (Ca, Mg, K, and Na) of the soils studied are variable. Pedon 1 shows higher exchangeable bases than pedons 2 and 3. In pedon 1, Ca contents are greater than those in pedons 2 and 3. Other cations, such as Mg, Na, and K are relatively low in all the soil horizons. In productive agricultural soils, the exchangeable bases are usually dominated by Ca^{2+} followed Mg^{2+}, K^{+}, and Na^{+} (Bohn *et al.*, 1979 as cited by NSSC, 1995). The high Ca content in pedon 1 may be as a result of intensive liming activities. In comparison with pedon 2, the high content of Ca in pedon 1 may also indicate that pedon 1 has less degree of soil nutrient leaching. This is because pedon 2 is located in flat area that are generally used for more intensive cultivation.

All the soils show a wide variation in base saturation, CEC values, and P retention. Pedon 1 shows higher base saturation than pedons 2 and 3. The base saturation values of pedon 1 range from 9.33 to 37.61%, while pedons 2 and 3 have generally the values of less than 5%. The high base saturation values correspond with the amounts of basic cations.

Pedon 2 shows higher CEC values than pedons 1 and 3. The high CEC values may relate to the accumulation of organic matter and the presence of allophane minerals. Those values reflect that the soils have high capacity to adsorb and exchange cations.

Phosphate retention is one of the important soil properties to differentiate Andisols from other soil orders. A phosphate retention value of more than 85% is one of the criteria for andic soil properties. The laboratory data show that phosphate retention values of the soil pedons are greater than 85%. The high P retention may relate positively to the presence of amorphous materials such as allophane. Bezama and Aomine (1977) reported that high P retention in soils might be due to the presence of allophanic materials derived from the volcanic ashes. The P retention value of volcanic ash soils decreased with the crystallization of the amorphous inorganic materials. Although exchangeable Al values in pedons 1 and 3 are low, they still have high P retention. This indicates that the high exchangeable Al in volcanic ash soils is not always followed by high P retention. In the ash soils, the high P retention is strongly influenced by the presence high amount of the acid oxalate extractable Al (Table 5). As presented in Figure 1, P retention values are positively correlated with Al content extracted by acid oxalate.

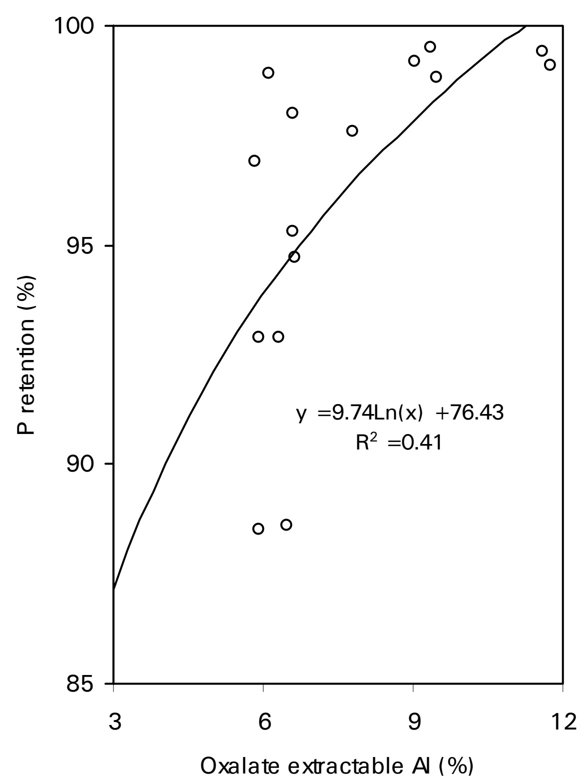


Figure 1. Relationship between P retention and oxalate extractable Al

Selective dissolution analysis

Table 5 presents laboratory data on selective dissolution of the soils studied. The pyrophosphate extraction has been used to indicate the amount of

Table 5. Selective dissolution data of the soils studied

Horizon	Pyrophosphate		Acid oxalate				Allophane
	Al_p	Fe_p	Al_o	Fe_o	Si_o	$Al_o + 1/2\ Fe_o$	
	....	....	....	%	....	....	....
Pedon 1, Sukajaya-Cisarua							
Ap	0.83	0.37	6.33	2.44	2.83	7.55	22
AB	0.69	0.32	7.79	2.95	3.16	9.27	27
2Ab	0.37	0.36	6.59	3.35	2.92	8.27	24
2Bwb1	0.50	0.28	5.83	3.36	4.95	7.51	28
2Bwb2	0.57	0.24	11.76	3.99	3.17	13.76	67
2Bwb3	1.81	1.09	3.20	3.16	2.52	4.78	12
Pedon 2, Karyawangi-Cisarua							
Ap1	1.31	0.75	6.48	2.61	2.37	7.79	20
Ap2	1.28	0.79	5.90	2.32	1.13	7.06	64
AB	1.12	0.73	6.63	2.13	2.40	7.69	21
Bw1	1.03	0.61	6.58	2.01	2.75	7.59	22
Bw2	0.84	0.54	3.65	1.76	2.37	4.53	14
Bw3	0.95	0.51	2.61	1.94	3.53	3.58	17
Pedon 3, Genteng-Lembang							
A	1.08	1.11	5.96	2.79	1.85	7.36	20
Bw	1.06	1.10	6.13	3.51	1.99	7.89	20
2Ab	1.20	2.51	9.49	4.75	2.77	11.87	37
2ABb	0.70	0.32	9.04	2.13	4.59	10.11	33
2Bwb1	0.57	0.25	9.34	2.36	3.95	10.52	34
2Bwb2	0.53	0.22	11.62	3.46	4.21	13.35	44
2Bwb3	0.89	0.21	3.40	2.20	4.16	4.50	21

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) values in the upper horizons of the soils are generally higher than the lower horizons. This condition may be related to organic matter content, where pedon 2 contains higher values of Al_p than pedons 1 and 3 due to higher organic matter content. The high values of pyrophosphate extractable Fe and Al indicate the high proportion of organically bound Fe and Al (Chartres and Van Reuler, 1985).

The oxalate extraction dissolves "active Al" (Al_o) and Fe components that are present in non-crystalline materials (NSSC, 1995). All the soils have high oxalate extractable Al (Al_o), Fe (Fe_o) and Si (Si_o) (Table 5). The Al_o values are significantly higher than the Si_o values. This probably arises from the dissolution of allophane (Parfitt and Childs, 1988). The high Al_o and Fe_o contents may contribute to the high P retention (Parfitt, 1989). The Al_o + ½ Fe_o values which are high (greater than 2%) indicate that all pedons meet one of the requirements for andic soil properties. High values of oxalate extractable Si in the soils inform the presence of non-crystalline materials such as allophane. Allophane content is calculated using the formula proposed by Parfitt and Wilson (1985). Allophane is present in large amounts.

Mineralogical properties

Mineralogy of sand fractions

The data on mineral composition of sand fraction detected using line counting method are presented in Table 6. The results show that sand fractions of the soils are relatively dominated by hornblende, ranging from 20 to 50%. Microscopic investigation shows that the sizes of mineral grains in the soils are large and are still relatively fresh. This investigation indicates that the soils are either young or rejuvenated (Utami, 1998). The low amount of hornblende is only observed in the bottom of pedon 1 and in the A horizon of pedon 3, indicating that both horizons are at an advanced stage of weathering. This is also supported by the presence of large amount of opaque minerals (48 to 67%) in the horizons.

In general, the amount of opaque minerals is relatively low to moderate. This means that the soils have low degree of weathering. The moderate amount of opaque minerals can be found in the lower parts of pedons 1 and 3. The high amount of opaque minerals tends to follow the decrease in feldspar. Pedon 2 shows higher amount of feldspar but lower opaque minerals than pedons 1 and 3. This indicates that pedon 2 is relatively younger than the other pedons. Weathering of feldspar in pedon 2 results in K as soil nutrients. In pedon 3 covered with pinus, the A horizon of the pedon has high opaque minerals but low hornblende. This is because pinus may emit humic acid that will release Ca and Mg elements from ferromagnesian minerals (such as hornblende, augite, and hypersthene) and increase the opaque mineral content. The high amount of opaque minerals may reduce soil resistance to wind erosion.

Other sand minerals investigated by using optical microscope are quartz, rock fragments, volcanic glasses, augite, and hypersthene. Quartz is generally found in trace amount, while rock fragments, augite, hypersthene, and volcanic glasses are only observed in low amount (less than 15%) in most of horizons. The low amount of quartz indicates low stage of the soil weathering. The presence of large amount of feldspar and ferromagnesian minerals (hornblende, hypersthene, and augite) of the andesitic to basaltic origin in sand fraction, however, must be of great value. These

Table 6. Microscopic data of the sand fractions of the soils studied

Horizon	Total sand fraction								
	Op	Qz	Wm	Rf	Vg	Fd	Hb	Au	Hp
	.... %								
Pedon 1, Sukajaya-Cisarua									
Ap	12	tr	6	5	1	24	38	7	7
AB	14	1	2	6	4	22	43	4	4
2Ab	25	tr	4	1	3	7	51	2	7
2Bwb1	29	-	7	5	8	5	38	2	5
2Bwb2	29	tr	5	8	6	1	31	4	13
2Bwb3	48	3	12	4	13	2	14	tr	3
Pedon 2, Karyawangi-Cisarua									
Ap1	8	1	4	9	3	29	31	8	7
Ap2	19	tr	4	7	3	20	28	10	9
AB	20	1	3	3	1	14	38	7	13
Bw1	12	tr	2	4	2	34	27	9	10
Bw2	3	1	3	9	3	42	18	15	6
Bw3	11	1	5	5	7	34	25	7	5
Pedon 3, Genteng-Lembang									
A	67	2	3	3	5	1	9	3	7
Bw	13	tr	4	14	14	17	20	9	10
2Ab	22	tr	6	2	5	10	47	5	5
2ABb	8	1	4	6	11	11	23	22	14
2Bwb1	23	tr	6	2	5	8	40	7	9
2Bwb2	24	tr	10	2	10	20	18	5	11
2Bwb3	39	tr	2	tr	2	2	42	4	9

Remarks : Op = opaque, Qz = quartz, Wm = weathered minerals, Rf = rocks fragment, Vg = volcanic glass, Fd = feldspar, Hb = hornblende, Au = augite, Hp = hypersthene; tr = trace (< 1%)

minerals are easy to weather and can supply many chemical elements in the soils.

Mineralogy of clay fractions

X-ray diffractograms of the clay fraction after oxalate treatment of the volcanic ash soils are given in Figure 2, while the relative abundance of the minerals is shown in Table 7. The results show that metahalloysite (0.744 nm) is only observed in small amount in some horizons of pedons 1 and 3. The formation of halloysite is favoured in environments where silica is supplied abundantly by percolating water (Wada, 1980). Moderate amount of gibbsite (0.485 nm) is found in the Bw horizon of pedon 3, indicating a high level of leaching. The formation of gibbsite may be as a result of desilication of amorphous materials in which the drainage condition is good (Wada, 1989). As reflected in X-ray diffractograms of pedon 1, layer 2Bwb2 contains metahalloysite and gibbsite. It is indicated that the layer is more developed than upper layers. Differences in pattern of XRD difractogram of pedon 1 and 3 indicate that the pedons are discontinue, while pedon 2 show similar XRD patterns in all the layers indicating homogenous degree of weathering and soil materials. In this study, the presence of allophane can not be detected by XRD analysis but only by selective dissolution analysis (Table 5), because it is amorphous to XRD analysis. This means that it exhibits a featureless XRD pattern (Tan, 1994).

Cristobalite (0.404 to 0.411 nm) is observed in minor amount in pedon 1 but it is more dominant in pedons 2 and 3. Looking at the XRD pattern, cristobalite tends increase towards the soil surface. This indicates that the cristobalite is inherited from rejuvenation processes of volcanic ash. Cristobalite can be considered as a primary volcanic mineral of the parent rock and is not formed during soil forming processes (Hardjosoesatro, 1956). Quartz (0.335 nm) and magnetite (0.254 nm) minerals are generally present in trace to minor amount. From agricultural point of view, the presence of both minerals in the volcanic ash soils is not so important for plants (Hardjosoesastro, 1956), and they are very resistant to weathering process.

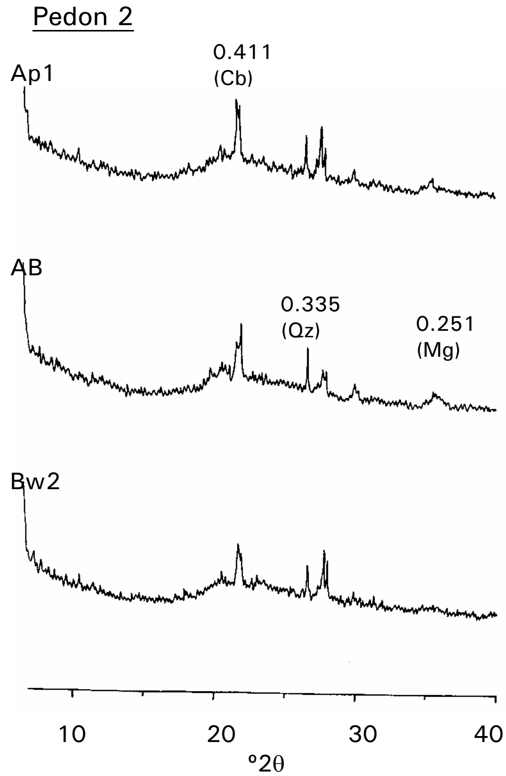
Soil classification

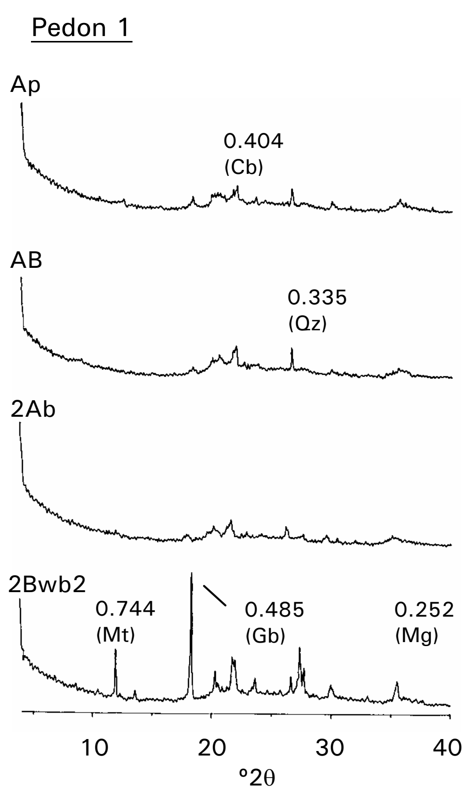
Classification of the soils studied is presented in Table 8. At order level, all the soils are classified as Andisols because they are strongly characterized by andic soil properties. These properties are indicated by high amount of oxalate extractable Al and Fe, low bulk density, and high P retention. At family level, pedons 1 (covered with vegetable garden) and 3 (secondary forest) are the same in soil classification name. They are classified as fine-loamy, amorphic, isothermic, Thaptic Hapludands. This fact indicates that land use does not affect the soil classification at family level. The different classification of both pedons may be in the soil series. At family level, pedon 2 is classified as fine loamy, amorphic, isothermic, Typic Melanudands. The main different of the soil classification between pedons 1 and 3 to pedon 2 is in Subgroup level. Pedon 1 and 3 are classified as Thaptic Halpudands due to the presence of buried horizon as a result of repetition of thin ash fall (rejuvenation processes). In contrast, pedon 2 is classified as Typic Melanudands due to the presence of melanic epipedon. The dark color (moist Munsell value and chroma of 2 or less) of the epipedon is attributable to organic matter with a predominance of A-type humic acid which shows the highest degree of humification.

Table 7. Relative abundance of minerals in the clay fractions of the soils studied as identified by XRD

Horizon	Mt	Gb	Cb	Qz	Mg
Pedon 1, Sukajaya-Cisarua					
Ap	(-)	(-)	+	(-)	(-)
AB		(-)	+	+	(-)
2Ab	(-)	(-)	+	(-)	(-)
2Bwb2	+	+ +	+	+	+
Pedon 2, Karyawangi-Cisarua					
Ap1		(-)	+ +	+	(-)
AB			+ +	+	+
Bw2			+ +	+	(-)
Pedon 3, Genteng-Lembang					
Ah	(-)	(-)	+ +	+	
Bw	+	(-)	+ + +	+ +	(-)
2Ab			+ + +	(-)	(-)
2ABb			+ +	(-)	(-)
2Bwb2			+	(-)	

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





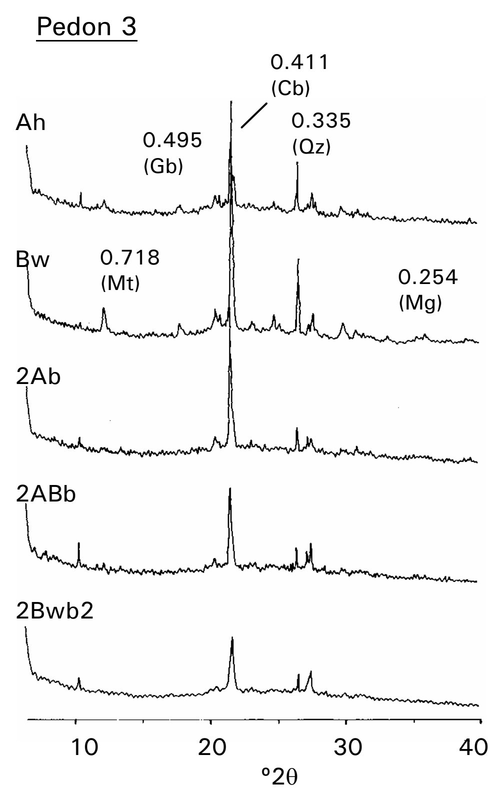


Figure 2. X-ray diffractograms of the clay fractions of Pedons 1, 2, and 3 after oxalate treatment

Cb : Cristobalite, Gb : Gibbsite, Mg : Magnetite, Mt : Metahalloysite, Qz : Quartz, Mt : Metahalloysite, Td : Tridymite, Qz : Quartz

Table 8. The soil classification according to Soil Taxonomy (Soil Survey Staff, 2003)

Pedon	Epipedon	Subhorizon	Subgroup	Soil family
1	Umbric	Cambic	Thaptic Hapludands	Fine-loamy, Amorphic, Isothermic, Thaptic Hapludands
2	Melanic	Cambic	Typic Melanudands	Fine-loamy, Amorphic, Isothermic, Typic Melanudands
3	Umbric	Cambic	Thaptic Hapludands	Fine-loamy, Amorphic, Isothermic, Thaptic Hapludands

CONCLUSIONS

1. All the pedons are classified as Andisols because they show strong andic soil properties as reflected by high amount of oxalate extractable Al and ½ Fe, low bulk density, and high phosphate retention. The presence of significant amounts of allophane minerals contributes to the andic soil properties. Allophane produces high active Al (Al_o) that will retain soil phosphate to cause its un-availability in soil solution.
2. Uncultivated soil (pedon 3) has lower bulk density, higher total porosity and larger amount of cristobalite minerals than the cultivated soils (pedon 1 and 2).
3. Considering the soils phisical, chemical, and mineralogical properties, the soils are highly potential to support agricultural production, particularly horticultural crops. However, high soil acidity and phosphate retention are the most limiting factors for plant growth. Liming and phosphorus fertilizer applications are recommended to improve the soil productivity.

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