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PROPERTIES AND MANAGEMENT IMPLICATIONS OF SOILS FORMED FROM VOLCANIC MATERIALS IN LEMBANG AREA, WEST JAVA

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ABSTRACT

Soils formed from volcanic materials have a high potential for agricultural development, especially for horticultural crops, tea, and pine trees. Data on the characteristics of these soils are important for the management planning. Six representative soil profiles developed on andesitic volcanic ash and tuff in Lembang area, West Java were studied to determine the soil physical, chemical, and mineralogical properties, to study the relationship between the soil properties, and to classify the soils according to the Soil Taxonomy. The results indicated that all the soils had very deep (>150 cm) solum. In general, the volcanic ash soils were darker colored, more granular, more friable, less sticky and less plastic than the volcanic tuff soils. Physically, the ash soils had lower bulk density (0.44-0.73 mg m^{-3}) and higher available water content (13-33%) than the tuff soils. Bulk density decreased with increasing allophane. Chemically, the ash soils had higher pH_{NaF} (mostly > 10), higher organic carbon (4.3-6.8% in upper horizons), higher CEC (20-44 $cmol_c$ kg^{-1}), and higher P retention (> 85%) than the tuff soils. P retention logarithmically increased with increasing oxalate extractable Al and allophane. The sand fractions of the ash soils were dominated by hornblende, while the tuff soils were predominantly composed of opaque minerals. In the clay fractions, the ash soils were dominated by allophane, whereas the tuff soils showed high contents of gibbsite and metahalloysite. Soils developed on volcanic ash were classified as Thaptic Hapludands and Typic Melanudands, while soils formed from volcanic tuff were classified as Andic Dystrudepts. The low bulk density and friable consistency of the soils contributed to favorable soil tilth. However, high P retention and Al saturation in most soils are limiting factors for plant growth. Application of P fertilizers and liming coupled with efficient placement can be recommended to enhance P availability and reduce Al toxicity. Organic matter can be used to reduce Al toxicity. Soil conservation needs to be considered, especially in the steep slope areas.

[***Keywords***: Volcanic soils, soil parent materials, soil chemico-physical properties, soil morphological features, soil classification, West Java]

INTRODUCTION

The Indonesian archipelago is predominantly mountainous with some 400 volcanoes, 129 of which are active. Twenty-one of these volcanoes are located in West Java (Van Bemmelen 1970). The activity of these volcanoes may produce various volcanoclastic materials such as ash, tuff, pumice, cinders, lahars, and other volcanic ejecta.

The beneficial effects of volcanic eruption are often more subtle, occurring on a geologic time-scale rather than during the lifetime of an individual. The development and rejuvenation of soils provide an environment favorable for organisms, including human beings. The periodic additions of volcanic ash renew the long-term fertility status by providing a source of nutrients from the rapid weathering of ash (Shoji *et al*. 1993a).

Soils formed from volcanic materials have many distinctive properties that are rarely found in soils derived from other parent materials (Wada 1986). These soils have high potentials for agricultural production. However, some of them produce well below their potential capacity due to lack of understanding of the nature and properties and proper management of these soils.

Soils developed on volcanic materials are generally classified as Andisols, but not all volcanic soils are Andisols, depending on the weathering and soil formation processes (Shoji *et al*. 1993a). Andisols have been 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), and the presence of large amount of short-range-order minerals such as allophane (Mizota and Van Reeuwijk 1989). In Indonesia, Andisols cover about 5.39 million ha or 2.9% of the Indonesia's total land area and 0.50 million ha of the soils are distributed in West Java (Subagyo *et al*. 2000). In Lembang and the surrounding areas, West Java, they were classified as Thaptic Hapludands and Typic Melanudands covering about 1919 ha, while Andic Dystrudepts cover about 2743 ha (Pusat Penelitian Tanah dan Agroklimat 1993).

Lembang is one of the most intensively cultivated areas for horticultural crops, tea and, pine trees in

West Java. Agricultural practices carried out here were based on medium input farming with little attention of land conservation aspects and soil conditions. Based on geologic information and field observation, soils in this area were developed on different volcanic materials (ash and tuff) and ages. The distinctions of the parent materials may result in different characteristics of the soils. As a consequence, the productivity of the soils may also be different. Data on the soil properties in Lembang area, however, are still lacking. Thus, it is important to study these soils to provide more accurate information of their behavior and performance to support their management.

The objectives of this study were to (1) determine the physical, chemical, and mineralogical properties of soils developed on two types of volcanic materials (ash and tuff) from Lembang area, West Java, (2) study the relationship between the soil properties, and (3) classify the soils according to Soil Taxonomy (Soil Survey Staff 2006).

MATERIALS AND METHODS

Description of the Study Area

The study area is located in the southwest slope of Mt. Tangkuban Perahu (2076 m asl) and Mt. Burangrang (2054 m asl). It is situated in the intensively cultivated vegetable growing areas and uncultivated or secondary forest areas of Lembang, about 10 km north of Bandung, West Java. Geographically, the area lies between 107º30’-107º40’ east longitude and 6º45’-6º50’ south latitude. Administratively, the study area belongs to the Districts of Lembang, Cisarua, and Cikalong Wetan, Bandung Regency, West Java. Locations of soil profile description are presented in Figure 1.

The soil profiles are located in the nearly flat to hilly topography with slopes ranging from 2 to 30%. The elevation of the profiles is between 1000 and 1500 m asl. There were six soil profiles selected for this study, i.e., VA-1, VA-2, VA-3, VT-1, VT-2, and VT-3. The location of each profile was selected mainly based on the distinctive types and age of volcanic parent materials, slope, and land use. Major physical environment of the studied soils is shown in Table 1.

Parent materials of profiles VA-1, VA-2 and VA-3 are andesitic volcanic ash that was originated from Mt. Tangkuban Perahu eruption during the early Quaternary activity (Holocene to Late Pleistocene). Volcanic ash is an unconsolidated pyroclastic deposit composed mainly of small particles with diameter between 1/16 to 2 mm. The other soil profiles (VT-1, VT-2 and VT-3), however, are derived from andesitic volcanic

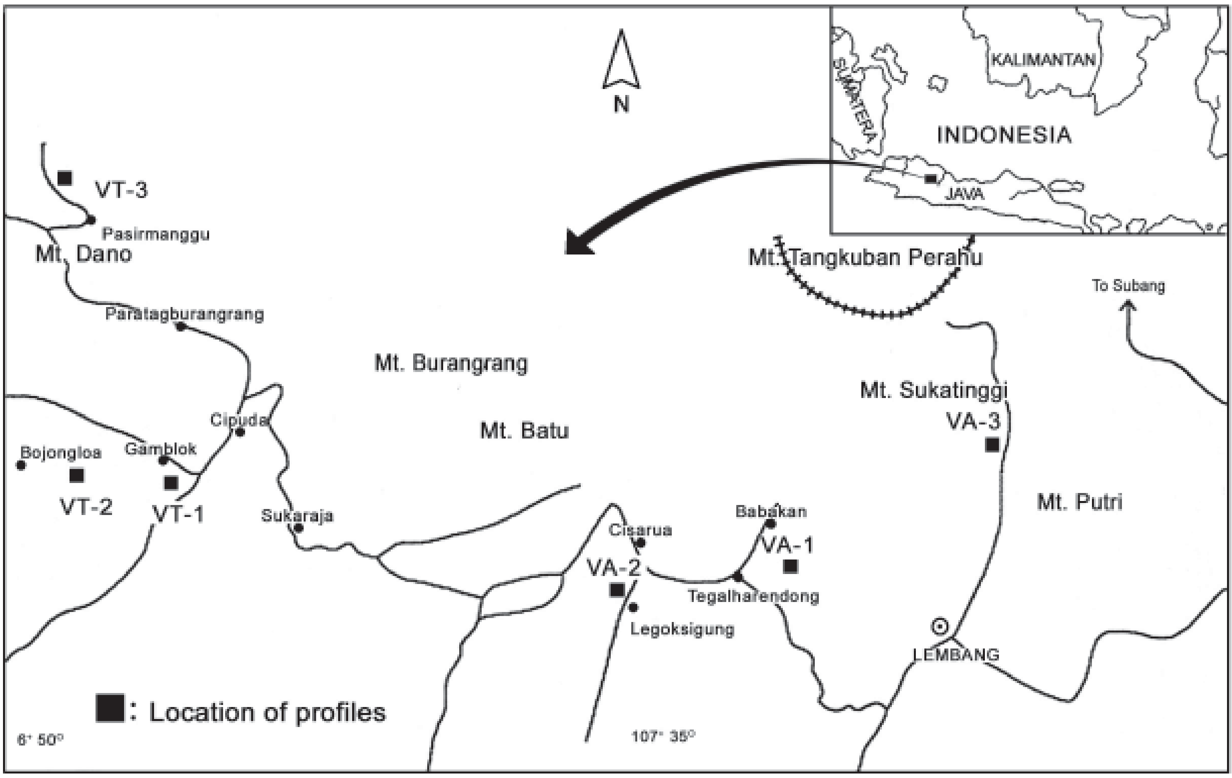

Fig. 1. Location and sites of the studied soil profiles, Lembang area, West Java.

Table 1. Major physical environment of the volcanic ash soils and volcanic tuff soils in Lembang area, West Java.

Profile code	Land use	Parent material	Age[1]	Elevation (m asl)	Slope (%)
VA-1	Vegetable garden	Andesitic ash	Late Pleistocene	1305	10
VA-2	Vegetable garden	Andesitic ash	Late Pleistocene	1247	2
VA-3	Secondary forest	Andesitic ash	Late Pleistocene	1500	9
VT-1	Vegetable garden	Andesitic tuff	Upper Pliocene	1052	12
VT-2	Vegetable garden	Andesitic tuff	Upper Pliocene	1037	30
VT-3	Secondary forest	Andesitic tuff	Upper Pliocene	1035	14

[1]Dam *et al.* (1993)

tuff materials originated from the currently non-active Mt. Burangrang eruption with volcanisms in the Upper Pliocene. Volcanic tuff is a consolidated rock.

The areas have a mean annual rainfall of 2401 mm and classified as A rainfall type (Schmidt and Ferguson 1951) meaning that they do not have any dry month, or B2 agroclimatic zone (Oldeman 1975) with 7 wet months (> 200 mm) and 2 dry months (< 100 mm). The wet period starts from October to May, with the wettest month reaching 307 mm of rainfall. It has an udic soil moisture regime. The mean annual air temperature is 20ºC. Some profiles located at 1000 m asl or less have an isohyperthermic soil temperature regime, while others located above 1200 m asl are isothermic. Most of the areas are cultivated with cauliflower, carrot, string bean, potato, tomato, and chile, while the forest areas are planted with pine trees.

Methods

The soil samples were collected from pedons developed on andesitic volcanic ash and tuff. 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 property analysis (bulk density and water retention).

Particle-size distribution was determined by a pipette method. Bulk density and water content at 33 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 determined by 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), and the CEC was by saturation with 1 M NH_4OAc at pH 7.0. NH_4^+ content was determined from the leachate of K_2SO_4 by Auto Analyzer (Soil Survey Laboratory Staff 1992). Iron, Al, and Si were extracted by ammonium oxalate (Fe_o, Al_o, Si_o) and 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 fractions (50-500 µm) was identified on a glass slide using a petrographic microscope. The minerals were then counted according to the line method. 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/minute.

RESULTS AND DISCUSSION

Morphological Properties

All of the soils developed from andesitic volcanic ash and tuff materials had very deep solum (> 150 cm). Profiles VA-1 and VA-3 had a buried horizon (2Ab) due to repeated thin ashfall deposition or rejuvenation processes. The horizon sequences of the soils were characterized by A (umbric epipedon)/Bw/Ab/Bwb (cambic) horizons. Profile VA-2, however, showed thick ashfall deposition, indicated by black or darker soil color (10YR 2/1 to 10YR 2/2) in almost all the soil horizons. The horizon sequences of the soil were characterized by A (melanic epipedon)/Bw (cambic) horizons.

The thick ash deposition in the profile VA-2 was related to the nearly flat topography. The presence of the buried thin ash layers and the thick ash deposition in the volcanic ash soils was originated from the eruption of Mt. Tangkuban Perahu. In contrast, the volcanic tuff soils exhibited no buried horizon because the materials are influenced by the currently non-active Mt. Burangrang eruption. The soils were characterized by A (umbric)/Bw (cambic) horizon sequences.

The surface horizons of all the profiles generally had weak, fine to medium, granular structures, while the subsurface horizons were weak to moderate, fine to coarse, subangular blocky structures. The presence of organic matter may be responsible for the formation of granular structures. Moist consistencies of the surface horizons of all the profiles were friable to very friable, while the subsurface horizons generally showed variable consistencies ranging from friable to firm. Wet consistencies of the volcanic ash soils were generally non-sticky to slightly sticky and non-plastic and tend to be more sticky and plastic in the volcanic tuff soils, depending on the clay content.

The volcanic ash soils showed abrupt to smooth and clear to wavy horizon boundaries, reflecting very young soil development or rejuvenation processes. In the volcanic tuff soils, however, the boundaries were generally clear and smooth in the upper horizons and gradual to diffuse and smooth in the lower horizons, indicating a relatively older soil formation.

Physical Properties

General physical properties of the studied soils are shown in Table 2. Profiles developed on volcanic ash were generally dominated by silt (35-40% in the A horizons and 47-61% in the B horizons), followed by clay and sand, while profiles formed from volcanic tuff are high in clay content (42-74%). The soil texture is related to the nature of the volcanic materials and the time of its eruption (Inoue and Yoshida 1981).

The bulk density values of the volcanic ash soils were lower (0.44-0.73 mg m^{-3}) than those of the volcanic tuff soils (0.67-0.95 mg m^{-3}). The high amount of organic matter and the presence of allophane minerals in the volcanic ash soils may contribute to the low bulk density. As shown in Figure 2A and 2B, the bulk density of the studied soils decreased with increasing organic carbon ($R^2 = 0.31$, $p < 0.01$) and allophane ($R^2 = 0.64$, $p < 0.01$), respectively. Soils with high organic matter tend to have better aggregates and porous structures (Brady and Weil 2000). The development of porous soil structure is the primary factor responsible for the low bulk density (Nanzyo *et al*. 1993a). Allophane is one of the most important non-crystalline materials contributing to the low bulk density of Andisols through the development of porous soil structure (Nanzyo *et al*. 1993a).

Table 2. Physical properties of the volcanic ash soils and volcanic tuff soils in Lembang area, West Java.

Horison	Texture (%)			Class[1]	Bulk density (mg m^{-3})	Total porosity (%)	Water content (%v)		Available water content (%v)
	Sand	Silt	Clay				33 kPa	1500 kPa	
Volcanic ash soils									
Profile VA-1									
Ap	36	37	27	L	0.66	68	32	17	15
2Bwb	16	50	35	SiCL	0.54	72	53	20	33
Profile VA-2									
Ap	27	40	33	CL	0.72	62	44	20	24
Bw	25	47	28	CL	0.73	66	38	21	17
Profile VA-3									
A	33	35	32	CL	0.55	66	34	21	13
2Bwb	20	61	20	SiL	0.44	80	60	38	22
Volcanic tuff soils									
Profile VT-1									
Ap	21	30	49	C	0.81	62	30	21	9
Bw	18	40	42	C	0.86	61	32	23	9
Profile VT-2									
Ap	6	20	74	C	0.89	55	31	24	7
Bw	5	22	73	C	0.95	57	50	36	13
Profile VT-3									
A	10	18	72	C	0.67	66	36	24	12
Bw	9	19	73	C	0.75	65	44	30	14

[1]L = loam, SiCL = silty clay loam, CL = clay loam, SiL = silt loam.

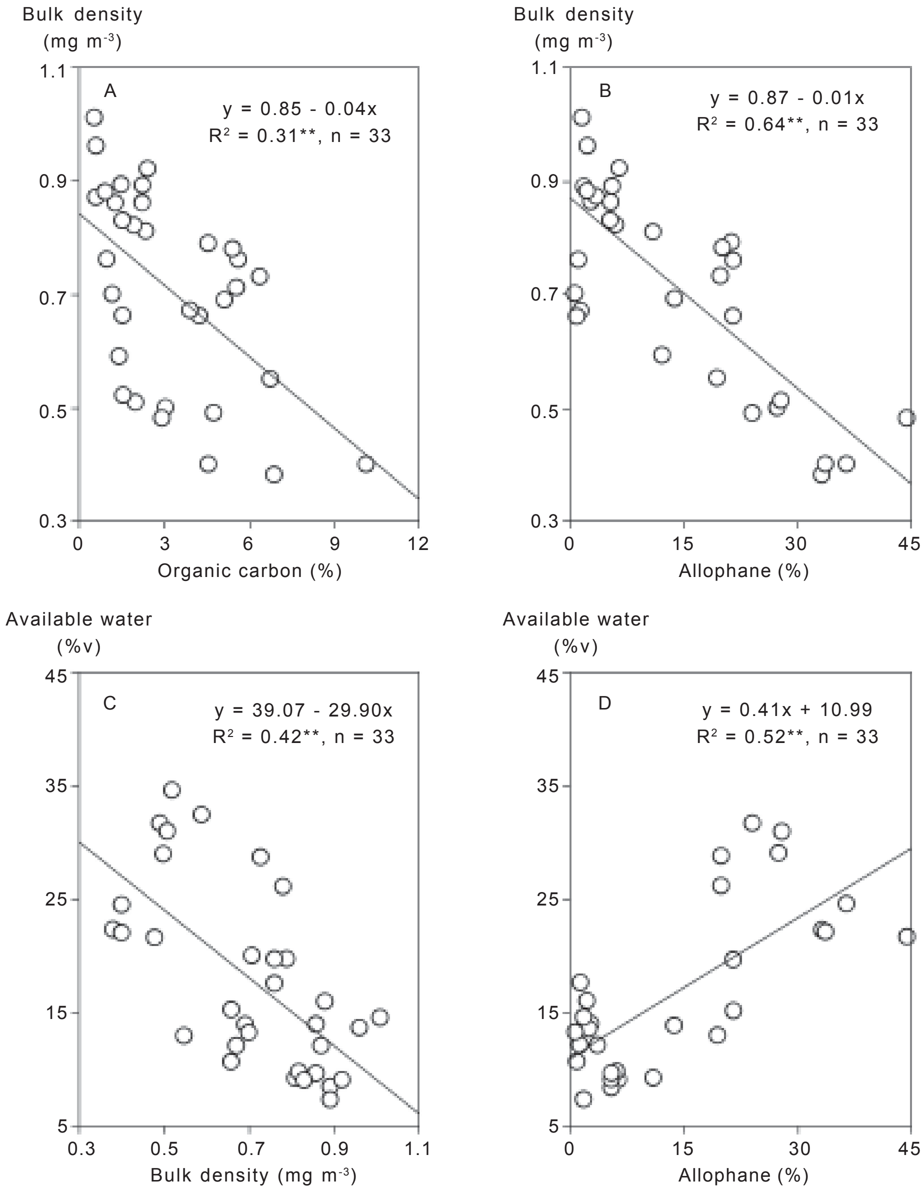

Fig. 2. Relationship between bulk density and organic carbon (A), bulk density and allophane (B), available water and bulk density (C), and available water and allophane (D) of soils formed from volcanic materials in Lembang, West Java.

The available water percentages were higher in the volcanic ash soils (13-33%) compared to the volcanic tuff soils (7-14%). The high available water in the ash soils is related to large amounts of organic matter and allophane. Available water content increased with decreasing bulk density ($R^2 = 0.42$, $p < 0.01$) (Fig. 2C) and increased with increasing allophane content ($R^2 = 0.52$, $p < 0.01$) (Fig. 2D). The high available water in volcanic ash soils is primarily due to their large volume of mesopores and micropores (Nanzyo *et al*. 1993a). These pores are produced within the stable soil aggregates. Formation of these aggregates is greatly enhanced by allophane and soil organic matter. Organic matter has a direct effect on available water through its hydrophilic characteristics and indirect effects on structure (Shoji and Ono 1978).

The uncultivated (secondary forest) soils as represented by profiles VA-3 and VT-3 tend to have lower bulk density and higher total porosity values than cultivated soils (Table 2). This is because they have a larger and higher amount of roots and organic matter than the cultivated soils. The presence of roots and organic matter play an important role on soil aggregation. Other physical properties of cultivated and uncultivated soils are similar.

Chemical Properties and Selective Dissolution Analysis

General chemical properties of the studied soils are presented in Table 3. Except profile VA-2, most of the volcanic ash soils showed acid soil reaction (pH_{H2O} 4.7 to 5.2). The pH_{H2O} of the volcanic tuff soils ranged from 3.9 to 4.8 (very acid to acid) in the surface horizons and from 4.6 to 5.2 (acid) in the subsurface horizons. Profile VA-2 and A horizon of profile VT-1 had higher soil acidity than the other soil profiles. This is because they have a high amount of exchangeable Al. The extractable Al can enter the soil solution and it reacts with water to form hydroxy Al compounds and free hydrogen ions that can make the soil acidic (Sopher and Baird 1982).

Profiles developed on volcanic ash had higher values of pH_{NaF} than those derived from volcanic tuff. pH_{NaF} values range from 9 to 11 in the ash soils and 8 to 9 in the tuff soils. High pH_{NaF} values in the volcanic ash soils indicated the presence of active hydroxy-Al and/or Fe (Shoji and Ono 1978; Mizota and Wada 1980; Shoji *et al*. 1985). High pH_{NaF} values also associated with the presence of allophane. As shown in Figure 3A, pH_{NaF} increases with increasing allophane content ($R^2 = 0.80$, $p < 0.01$).

The volcanic ash soils tend to have high organic N and C, however N application among the local farmers is usually high for vegetable crops. The N fertilizer used for the crops generally ranges from 62 to 101 kg ha^{-1} (Shoji *et al*. 1993b). The volcanic ash soils had higher organic carbon content (4.3-6.8% in A horizon and 1.7-4.7% in B horizons) than the volcanic tuff soils (1.5-3.9% in A horizon and 0.6-2.1% in B horizons). The volcanic ash soils also showed higher C/N ratios (9-14) than the volcanic tuff soils (6-12), suggesting a lower organic matter decomposition level of the volcanic ash soils (National Soil Survey Center 1995).

All the studied soils had a wide variation in base saturation. High levels of base saturation were found in profile VT-2 and subsurface horizons of profiles VA-1 and VT-1, with mean of about 38-41%, 28% and 39%, respectively. The other soil profiles (VA-2, VA-3 and VT-3) showed low base saturation levels, with mean of less than 14%. The high base saturation values correspond with the amounts of basic cations, especially Ca content. Base saturation is also related to soil acidity. Figure 3B shows the relationship between base saturation and pH_{H2O}. Base saturation values increased with increasing pH_{H2O} ($R^2 = 0.46$, $p < 0.01$).

All of the soils showed a wide variation of CEC values, ranged from 20-44 $cmol_c\,kg^{-1}$ in the volcanic ash soils to 19-31 $cmol_c\,kg^{-1}$ in the volcanic tuff soils. In general, however, the volcanic ash soils seemed to have higher CEC than the volcanic tuff soils. High CEC values may be related to the soil texture, clay mineralogical composition, and accumulation of organic matter (Shoji *et al*. 1982). The CEC (pH 7) values of the studied soils increased with increasing organic carbon content ($R^2 = 0.39$, $p < 0.01$) (Fig. 3C) and allophane content ($R^2 = 0.23$, $p < 0.01$) (Fig. 3D). Humus, as well as non-crystalline clay materials contributed substantially to the total CEC of the soils (Utami 1998). Nanzyo *et al*. (1993b) mentioned that the main components contributing to the variable charge in Andisols are allophanic clays and humus. These soil colloids have negative charge sites originating from SiO^- of allophane clays and $–COO^-$ of humus. Humification produces an organic colloid of high specific surface and high CEC. Organic matter can make a substantial contribution to the CEC of the whole soil, and hence to the retention of exchangeable cations, especially in soils with low clay content (White 1987).

All horizons of the profiles developed on volcanic ash had phosphate retention values ranging from 89 to 99%. The values were higher compared to the soils derived from volcanic tuff (59-85%). The high P retention values of the volcanic ash soils may be related to the contents of active Al (Al_o) and allophane. As shown in Figure 3E and 3F, retention logarithmically increased with increasing Al_o ($R^2 = 0.74$) and allophane content ($R^2 = 0.60$), respectively. The active Al in allophane, and Al-humus complexes is highly reactive with anion such as phosphate. The capacity of soil material to retain large amounts of phosphate is also due to the very high specific surface of the amorphous minerals (Van Wambeke 1992).

Mineralogical Properties

The sand fractions of the volcanic ash soils were dominated by hornblende, ranging from 20 to 50%. The volcanic tuff soils, however, were predominantly composed of opaque minerals or iron oxides, ranging from 30 to 80%. Feldspar was present in minor to moderate amount in the volcanic ash soils, while only traces in the volcanic tuff soils. Quartz, cristobalite, and tridymite were generally found in trace to minor amount in both parent materials. Rock fragments, augite, hypersthene, and volcanic glass were only observed in low amount (less than 15%) in most

Table 3. Chemical properties of the volcanic ash soils and volcanic tuff soils in Lembang area, West Java.

Horizon	pH H_2O	Exch. Al ($cmol_c$ kg^{-1})	Al sat. (%)	pH NaF	Organic C (%)	Organic N (%)	C/N	Exchangeable bases Ca	Mg	Na	K	Sum BC	CEC	BS (%)	Available P (mg kg^{-1})	P retention (%)	Acid oxalate Al_o	Fe_o	Si_o	Allophane (%)
								.... $cmol_c$ kg^{-1}	....			...$cmol_c$ kg^{-1}...					.... %	....		
Volcanic ash soils																				
Profile VA-1																				
Ap	4.7	0.37	10	10	4.3	0.5	9	2.70	0.17	0.03	0.51	3.40	36	9	40	93	6.3	2.4	2.8	22
2Bwb	5.2	0.21	4	10	1.7	0.2	11	3.72	0.57	0.24	0.49	5.02	20	28	5	96	6.9	3.5	3.5	36
Profile VA-2																				
Ap	3.9	2.94	76	10	6.0	0.6	10	0.73	0.04	0.04	0.16	0.96	44	2	303	89	6.2	2.5	1.8	42
Bw	4.2	4.27	64	10	4.7	0.5	9	1.95	0.12	0.06	0.67	2.80	35	9	10	95	4.3	1.9	2.9	18
Profile VA-3																				
A	4.8	1.04	25	11	6.8	0.7	9	2.78	0.11	0.07	0.21	3.17	26	12	23	93	6.0	2.8	1.9	20
2Bwb	4.7	0.09	27	11	3.1	0.2	14	0.21	0.10	0.04	0.05	0.39	31	1	1	99	8.1	2.7	4.1	33
Volcanic tuff soils																				
Profile VT-1																				
Ap	3.9	5.19	65	9	2.4	0.3	8	1.37	0.12	0.09	1.25	2.82	31	9	67	85	2.3	1.7	2.3	11
Bw	5.2	0.86	12	9	2.1	0.3	7	8.76	1.74	0.13	0.51	11.14	29	39	16	85	1.7	1.9	1.1	6
Profile VT-2																				
Ap	4.7	1.24	15	8	1.5	0.2	7	4.91	1.96	0.03	0.19	7.09	19	38	13	59	0.6	1.2	0.3	2
Bw	5.2	0.10	1	9	0.6	0.1	6	5.73	2.21	0.13	0.07	8.14	20	41	3	70	0.7	1.4	0.4	3
Profile VT-3																				
A	4.8	2.21	39	9	3.9	0.5	9	2.36	0.77	0.10	0.18	3.40	24	14	8	78	1.2	1.4	0.3	1
Bw	4.6	5.60	87	9	1.2	0.1	12	0.51	0.12	0.19	0.05	0.86	22	4	1	83	0.8	1.6	0.3	1

BC = basic cations, CEC = cation exchange capacity, BS = base saturation.

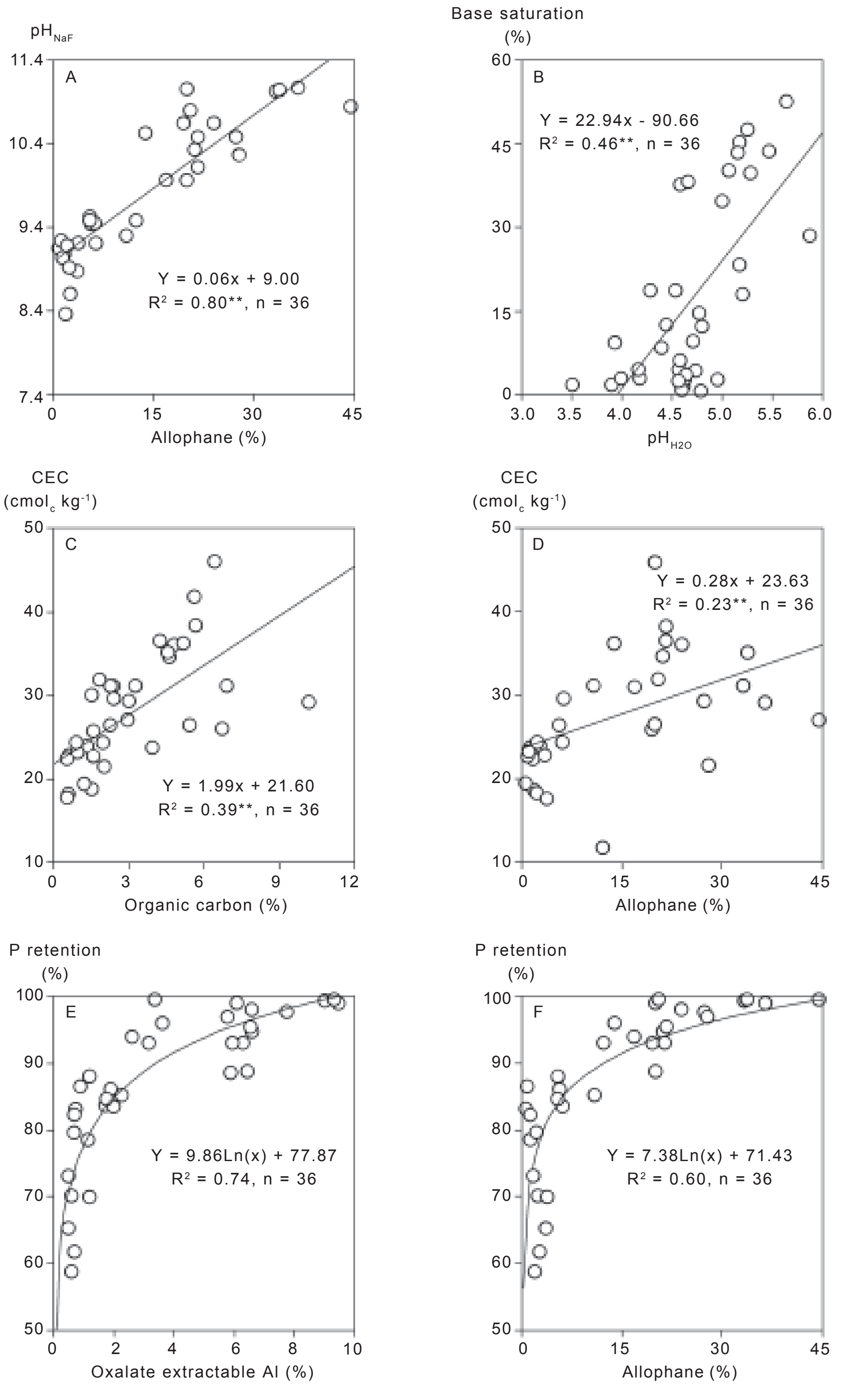

Fig. 3. Relationship between pH_{NaF} and allophane (A), base saturation and pH_{H2O} (B), CEC and organic carbon (C), CEC and allophane (D), P retention and oxalate extractable Al (E), and P retention and allophane (F) of soils formed from volcanic materials in Lembang, West Java.

horizons of the volcanic ash soils. Lesser amount was observed in the volcanic tuff soils.

In the clay fractions, the volcanic ash soils were dominated by allophane, ranging from 20 to 40%, while the volcanic tuff soils were predominantly composed of metahalloysite and gibbsite. Cristobalite (0.404-0.410 nm) was present in varying amount in the volcanic ash soils and trace to minor amount in the volcanic tuff soils. Quartz (0.335 nm) and magnetite (0.254 nm) were only observed in trace amount in both parent materials. This means that all the studied soils are still young or have low stages of weathering. However, the presence of halloysite and gibbsite in the tuff soils indicates that those soils are older than the ash soils.

Soil Classification

Classification of the studied soils according to Soil Taxonomy (Soil Survey Staff 2006) is given in Table 4. In general, the volcanic ash soils were classified as Andisols because they have strong andic soil properties (bulk density < 0.9 mg m^{-3}, Al_o+1/2 Fe_o > 2%, and P retention > 85%) within 60 cm of the mineral soil surface, while the volcanic tuff soils were classified as Inceptisols because of the presence of a cambic horizon and weak andic soil properties.

At family level, soils on volcanic ash were classified as fine-loamy, amorphic, isothermic, Thaptic Hapludands and Typic Melanudands due to the presence of a buried organic-rich horizon and thick organic-rich horizons (melanic epipedon), respectively, low clay content, high amounts of allophane, and low soil temperature or located at high elevation. Soils derived from volcanic tuff, however, were classified as fine to very fine, halloysitic to gibbsitic, isohyperthermic, Andic Dystrudepts due to low base saturation, weak andic properties, high clay content, high amounts of halloysite and gibbsite minerals, and moderate soil temperature or located at medium elevation.

Table 4. Soil classification at family level of the volcanic ash soils and volcanic tuff soils in Lembang area, West Java.

Profil code	Soil classification
Volcanic ash soils	
VA-1	Fine-loamy, amorphic, isothermic, Thaptic Hapludands
VA-2	Fine-loamy, amorphic, isothermic, Typic Melanudands
VA-3	Fine-loamy, amorphic, isothermic, Thaptic Hapludands
Volcanic tuff soils	
VT-1	Fine, gibbsitic, isohyperthermic, Andic Dystrudepts
VT-2	Very-fine, halloysitic, isohyperthermic, Andic Dystrudepts
VT-3	Very-fine, halloysitic, isohyperthermic, Andic Dystrudepts

Soil Management Implication

The presence of large amount of organic matter and allophane in the volcanic ash soils is responsible in formation of large pore space in the soils because soils with high organic matter content tend to be well aggregated and consequently have better porosity. These properties provide a condusive soil environment for deeper rooting activity and therefore supply more nutrients and water for vigorous plant growth (Shoji *et al*. 1993b). In addition, low bulk density and friable consistency contribute to more favorable soil tilth leading to easy tillage, seedling emergence, and root development. Aggregates of the volcanic ash soils are highly stable, being cemented by noncrystalline materials and soil organic matter. Stable aggregate and high porosity of soils could minimize water erosion. These properties significantly contribute to maintaining the high productivity of the volcanic ash soils.

Soil acidity problems are associated with pH level of < 5.5 and the high concentration of exchangeable Al in the soils. Percent Al saturation is also a useful measurement of soil acidity (Sanchez 1976). Profiles VA-2, VT-1, and VT-3 had the highest values of exchangeable Al (up to 5 $cmol_c$ kg^{-1}) and Al saturation (> 70%) among the soil profile studied. This was observed in the soil horizons, which had a pH_{H2O} value of < 5.0. This is because exchangeable Al is precipitated at pH of about 5.5-6.0 (Sanchez 1976). Thus, little or no exchangeable Al is found at higher soil pH values. Al toxicity may cause soil infertility in profiles VA-2, VT-1, and VT-3. Al toxicity can be corrected by liming to pH > 5.5 to precipitate the exchangeable Al as aluminum hydroxide (Sanchez 1976). Alternatively, organic matter addition can reduce Al toxicity by binding the Al ions in organic matter complexes (Brady and Weil 2000).

Phosphorus is commonly the growth-limiting nutrient element in the volcanic material-derived soils in a natural ecosystem because its supply is strongly adsorbed by allophane and hydrated iron and Al oxides (amorphous colloids) making it sparingly available for plant uptake (Parfitt 1989; Shoji *et al*. 1993b). In this study, although the surface horizons of cultivated soils had a high phosphate retention, the available P of the horizons was relatively high.

The high values of available P in the surface horizons may be due to the residue of applied fertilizers as indicated by relatively low available P in the surface horizons of soils under forest compared to the cultivated soils. It means that naturally, the element supply is low. To enhance P fertility, heavy application of P fertilizers coupled with efficient placement (band or hill application) is recommended.

CONCLUSION

Soils developed on volcanic ash in the Lembang area had low stickiness and bulk density, high pore spaces, available water, pH_{NaF}, organic carbon, CEC, P retention, and highly friable consistency. The soils were dominated by hornblende and allophane minerals, and classified as Thaptic Hapludands and Typic Melanudands.

Compared with the volcanic ash soils, all soils derived from volcanic tuff showed different physical-chemical, and mineralogical properties. They were composed of opaque minerals or iron oxides, gibbsite and metahalloysite, and classified as Andic Dystrudepts.

The presence of allophane or amorphic minerals in the soils developed on volcanic materials had influenced soil bulk density values, available water contents, pH_{NaF}, CEC, and P retention. The lower bulk density and more friable consistency of the volcanic ash soils than those of the volcanic tuff soils suggest that the volcanic ash soils have a more favorable soil tilth. However, high P retention of all the soils and high Al saturation of profiles VA-2, VT-1, and VT-3 are limiting factors for plant growth. Thus, liming and or organic matter application for the profiles VA-2, VT-1 and VT-3, and band or hill P fertilizer application for both ash and tuff soils are recommended.

REFERENCES

Balsem, T. and P. Buurman. 1990. Chemical and Physical Analyses Required for Soil Classification. Technical Report No. 11. Version 2. LREP Project, Center for Soil and Agroclimate Research, Bogor.

Blakemore, L.C., P.L. Searle, and B.K. Daly. 1981. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau. Scientific Report 80. Lower Hutt, New Zealand. 103 pp.

Brady, N.C. and R.R. Weil. 2000. Elements of Nature and Properties of Soils. Prentice-Hall, Inc., New Jersey. 559 pp.

Inoue, K. and N. Yoshida. 1981. Physical, chemical, and clay mineralogical properties of the A1 and buried A horizons of Ando soils from the Upper Kitakami River Basin, Japan. Soil Sci. Plant Nutr. 27: 523-534.

Mizota, C. and K. Wada. 1980. Implications of clay mineralogy to the weathering and chemistry of Ap horizons of Ando soils in Japan. Geoderma 23: 257-268.

Mizota, C. and L.P. van Reeuwijk. 1989. Clay mineralogy and chemistry of soils formed in volcanic material in diverse climatic regions. Soil Monograph 2. ISRIC, Wageningen, Netherlands.

Nanzyo, M., S. Shoji, and R. Dahlgren. 1993a. Physical characteristics of volcanic ash soils. p. 189-207. *In* S. Shoji, M. Nanzyo, and R. Dahlgren (Eds.). Volcanic Ash Soil – genesis, properties, and utilization. Developments in Soil Science 21, Elsevier, Amsterdam.

Nanzyo, M., R. Dahlgren, and S. Shoji. 1993b. Chemical characteristics of volcanic ash soils. p. 145-187. *In* S. Shoji, M. Nanzyo, and R. Dahlgren (Eds.). Volcanic Ash Soil – genesis, properties, and utilization. Developments in Soil Science 21, Elsevier, Amsterdam.

National Soil Survey Center. 1995. Soil Survey Laboratory Information Manual. Soil Survey Investigations Report No. 45 version 1. Soil Survey Laboratory, USDA, Lincoln, Nebraska.

Oldeman, L.R. 1975. An Agroclimatic Map of Java. Central Research Institute of Agriculture, Bogor.

Otawa, M. 1986. Morphology and classification. p. 3-20. *In* K. Wada (Ed.). Ando Soils in Japan. Kyushu University Press, Japan.

Parfitt, R.L. and A.D. Wilson. 1985. Estimation of allophane and halloysite in three sequences of volcanic soils in New Zealand. p. 1-8. *In* E.F. Caldas and D.H. Yaalon (Eds.). Volcanic Soils: Weathering and landscape relationships of soils on tephra and basalt. Catena Supplement 7, Catena Verlag.

Parfitt, R.L. 1989. Phosphate reactions with natural allophane, ferrihydrite and goethite. J. Soil Sci. 40: 349-369.

Pusat Penelitian Tanah dan Agroklimat. 1993. Penelitian Optimalisasi Penggunaan Lahan di Daerah Aliran Sungai (DAS) Citarum Hulu, Bandung-Jawa Barat. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, Inc., New York.

Schmidt, F.H. and J.H.A. Ferguson. 1951. Rainfall Types Based on Wet and Dry Period Ratios for Indonesia with Western New Guinea. Jawatan Meteorologi dan Geofisika, Jakarta.

Shoji, S. and T. Ono. 1978. Physical and chemical properties and clay mineralogy of Andosols from Kitakami, Japan. Soil Sci. 126: 297-312.

Shoji, S., Y. Fujiwara, I. Yamada, and M. Saigusa. 1982. Chemistry and clay mineralogy of Ando soils, Brown Forest soils, and Podzole soils formed from recent Towada ashes, Northeastern, Japan. Soil Sci. 133: 69-86.

Shoji, S., T. Ito, M. Saigusa, and I. Yamada. 1985. Properties of nonallophanic Andosols from Japan. Soil Sci. 140: 264-277.

Shoji, S., R. Dahlgren, and M. Nanzyo. 1993a. Terminology, concepts and geographic distribution of volcanic ash soils. p. 1-5. *In* S. Shoji, M. Nanzyo, and R. Dahlgren (Eds.). Volcanic Ash Soil – genesis, properties, and utilization. Developments in Soil Science 21, Elsevier, Amsterdam.

Shoji, S., M. Nanzyo, and R. Dahlgren. 1993b. Productivity and utilization of volcanic ash soils. p. 209-251. *In* S. Shoji, M. Nanzyo, and R. Dahlgren (Eds.). Volcanic Ash Soil – genesis, properties, and utilization. Developments in Soil Science 21, Elsevier, Amsterdam.

Soil Survey Laboratory Staff. 1992. Soil Survey Laboratory Methods Manual. Soil Survey Investigation Report No. 42, version 2.0. USDA, Washington D.C.

Soil Survey Division Staff. 1993. Soil Survey Manual. USDA Handbook No.18. USDA, Washington DC.

Soil Survey Staff. 2006. Keys to Soil Taxonomy. 10th edition. USDA-NSSC, Washington DC.

Sopher, C.D. and J.V. Baird. 1982. Soils and Soil Management. 2nd edition. Reston Publishing Company, Inc. Virginia. 312 pp.

Subagyo, H., N. Suharta, dan A.B. Siswanto. 2000. Tanah-Tanah Pertanian di Indonesia. hlm. 21-65. *Dalam* A. Adimihardja, L.I. Amien, F. Agus, dan D. Djaenuddin (Ed.). Sumber Daya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Utami, S.R. 1998. Properties and Rational Management Aspects of Volcanic Ash Soils from Java, Indonesia. Ph.D Thesis. Department of Geology and Soil Sciences, University of Gent, Belgium. 388 pp.

Van Bemmelen, R.W. 1970. The Geology of Indonesia. Vol. IA. 2nd ed. The Hague, The Netherlands.

Van Wambeke, A. 1992. Soils of the Tropics: Properties and appraisal. McGraw-Hill Inc., New York. 343 pp.

Wada, K. 1986. Ando Soils in Japan. Kyushu University Press, Japan.

White, R.E. 1987. Introduction to the Principles and Practice of Soil Science. 2nd ed. Blackwell Scientific Publications, Osney Mead, Oxford. 244 pp.