

Research Article

Soil mineralogy and chemical properties as a basis for establishing nutrient management strategies in volcanic soils of Mount Ceremai, West Java

Sukarman*, Padana Aperta Barus, Rachmat Abdul Gani

Indonesian Center for Agricultural Land Resources Research and Development of the Ministry of Agriculture,
Jl. Tentara Pelajar No. 12, Kampus Penelitian Pertanian, Cimanggu Bogor, 16114, Indonesia

*corresponding author: sukarmandr@yahoo.co.id

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Abstract: Soil mineralogy and its effect on chemical properties of volcanic soils located in Mount Ceremai has not been studied thoroughly. The objective of the study was to assess soil mineralogy and chemical properties of volcanic soils derived from different types and ages as an integrated strategic consideration to establish nutrient management. Field research and laboratory analysis were carried out on four soil profiles derived from different parent materials, namely young lava (KM-01), young pyroclastic fall (KM-02), old lava (KM-03), and old pyroclastic fall (KM-04). Results showed that KM-04 soil had limited nutrient reserved mineral (NRM), while KM-01, KM-02, and, unexpectedly, KM-03 soil still contained high NRM. There were no apatite and K-bearing mineral found in all soils, so regular P and K fertilization were recommended. Clay composition in the surface layer of KM-01 soil was dominated by amorphous minerals, while other soils contained amorphous mineral, gibbsite, and halloysite. Although all soils contained NRM such as labradorite, augite, and hypersthene, all soils had low exchangeable cations. P retention is a serious problem for all soils, especially KM-03 which has the highest amount of allophane. Therefore, nutrient management should be focused on accelerating NRM weathering, increasing soil CEC, and improving P fertilization efficiency.

Keywords: *Ceremai mountain, nutrient management, soil mineralogy, volcanic soils*

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Introduction

The Province of West Java is an area that mostly occupied by volcanoes, including Mount Ceremai. This mountain is a stratovolcano, which has an altitude of 3,078 meters above sea level, and the highest mountain in West Java Province. Administratively, this mountain is included in the area of Majalengka Regency and Kuningan Regency. Astronomically, this mountain peak is located at 106° 59' East Longitude and 6° 47' South Latitude. According to Sukarman et al. (2017a), the land around Ciremai Mountain is a potential area for the development of food crops and horticultural crops. Volcanic soils in Indonesia have been widely discussed (Wibisono et al., 2015; Suryani et

al., 2015; Yatno et al., 2016; Anda et al., 2016; Purwanto et al., 2016; Suratman et al., 2018; Nurcholis et al., 2019). Even so, there is no comprehensive information on morphology, mineralogy, and fertility status of volcanic soil from Mount Ceremai.

Volcanic eruptions released volcanic material in the form of lava (effusive eruption) and pyroclastic deposit (explosive eruption). In the initial stages, the relatively new material formed a soil called Regosol. In the next stage, in wet and cold climates, Regosol developed further into Andisols with unique and distinctive properties that were not owned by other types of soil: pH-dependent clay, high P retention, low bulk density,

and high water retention. In lower regions, volcanic material developed into Inceptisols (Dahlgren et al., 2004; McDaniel et al., 2012). Geological mapping conducted by Situmorang et al. (1995) showed that Ceremai Mountain had experienced at least four periods of activity, namely: 1). Gunung Putri Eruption 2). Mount Gegerhalang Eruption 3). Mount Ceremai Eruption 4). Crevice eruptions. The eruption products of Mount Ceremai can be grouped into 1) old lava, 2) old pyroclastic deposits, 3) young lava, 4) young pyroclastic deposits.

From a mineralogy perspective, the parent material which contains a variety of primary minerals with large amounts of potential nutrients will produce fertile soil. The composition of primary minerals plays a key role in releasing nutrients in the soil, while secondary minerals (clay) determine the ability of the soil to retain various cations and anions released from weathering primary minerals. According to Sukarman et al. (2020), minerals in the soil can be divided into primary minerals or mineral sand and silt, as well as secondary minerals or clay minerals. The existence of a type of mineral in the soil can be used as a clue to the status of the natural fertility of the soil.

This study aimed to discuss soil mineralogy of volcanic soil derived from different type and age and its effect on nutrient availability for crops. The results of this study are expected to provide an integrated strategic consideration to establish nutrient management in supporting the development of agricultural commodities in this location.

Materials and Methods

The study was carried out in Kuningan Regency, West Java Province, Indonesia. Four soil profiles representing each type/age of volcanic material have been examined in the field and sampled for analysis in the laboratory (Table 1). Each profile represented four different geologic formations (Djuri, 1995). The procedure for soil description follows the guidelines of Sukarman et al. (2017b). This approach was designed to assess soil mineralogy and fertility status from different type/age of volcanic material. KM-01 was derived from young basaltic andesite lava, while KM-02 was derived from breccia, lahar mixed with young basaltic andesite lava. The location of the two young volcanic soils is on the northeast slope of Mount Ceremai. KM-03 was derived from old andesite lava. KM-04 was derived from breccia and lahar mixed with old andesitic lava. The old volcanic soils are located on the southeast slope of Mount Ceremai. Climate information was obtained from the climate observation station of Mount Ceremai National Park. Annual rainfall ranges within 2,500-4,500 mm/year with the lowest intensity is 13.6 mm/day and the highest is 34.8 mm/day. Air temperature ranges from 18 - 22°C. Based on rainfall data, air temperature, and latitude - longitude position, which are processed by the Newhall Simulation Model (Van Wambeke et al., 1986), the study area is included in udic soil moisture regime and isohyperthermic soil temperature regime. Soil morphology was described and soil classification was determined according to Keys to Soil Taxonomy (Soil Survey Staff, 2014).

Tabel 1. General information on the study area.

Soil Profile	Parent material	Soil Classification	Landuse	Elevation (m. asl.)	Slope (%)	Geographical Position	
						East Longitude	South Latitude
KM-01	Young Lava	Typic Udivitrands	Upland farming	757	10	108° 27' 24.1"	06° 52' 08.5"
KM-02	Young Pyroclastic Deposits	Typic Udivitrands	Upland farming	664	35	108° 27' 47.7"	06° 52' 25.0"
KM-03	Old Lava	Typic Hapludands	Upland farming	1094	45	108° 26' 03.4"	06° 57' 04.4"
KM-04	Old Pyroclastic Deposits	Andic Dystrudepts	Upland farming	880	45	108° 27' 01.3"	06° 56' 59.5"

The mineralogical composition of coarse fractions (ϕ 0.05 - 2 mm) was measured for all soil samples, while mineralogical analysis of fine fractions (ϕ < 0.002 mm) was determined only for A horizon of each pedon. The composition of coarse fractions was determined by the line counting method using a polarizing microscope (Buurman, 1990). Primary

minerals were divided into four groups, namely total volcanic glass (TVG), nutrient reserve minerals (NRM), resistant minerals (RM), and weathered fractions (WF). Fine mineral fraction analysis was determined qualitatively using an X-ray diffractometer (XRD). The image of clay minerals was examined using the Scanning

Electron Microscope (SEM), EVO MA10 (Carl Zeiss Microscopy Ltd., Cambridge, England). The selective dissolution analysis method was used to describe Al/Fe-active quantitatively on the soil. All soil samples used were < 0.5 mm in size. Sodium pyrophosphate 0.1 M solution (soil ratio: 1:100 solution) was used to dissolve Al/Fe-humus in the soil. Ammonium oxalate 0.2 M pH 3 solution (soil ratio: 1:50 solution) was used to dissolve Al, Fe, and Si compounds derived from non-crystalline minerals such as allophane, imogolite, and ferrihydrite. The content of pyrophosphate extract (Al_p and Fe_p) and oxalate extract (Al_o , Fe_o , and Si_o) were then measured using Atomic Absorption Spectroscopy (AAS). The Al/Si ratio of allophane was calculated using:

$$(1) Al/Si = Al_o - Al_p/Si_o$$

The percentage of allophane in the soil was calculated using:

$$(2) \% \text{ allophane} = 100/Si_a \times Si_o$$

The value of Si_a in equation (2) was obtained from:

$$(3) Y = -5.1X + 23.4,$$

where Y is Si_a and X is the Al/Si ratio. The percentage of ferrihydrite was calculated using:

$$(4) \% \text{ ferrihydrite} = \% Fe_o \times 1.7$$

Determination of soil texture was done using the pipette method and bulk density (BD) was determined using the ring sample. Soil reaction (pH) was measured in H_2O , KCl solutions (ratio 1:2.5), and NaF solution (ratio 1:50). Soil organic content (SOC) was determined using the Walkley and Black method. The Kjeldahl method was used to determine total nitrogen. Total P_2O_5 and K_2O content of the soil were analyzed using 25% HCl extract. The exchangeable cations (Ca, Mg, K and Na) and the cation exchange capacity (CEC) of the soil were determined by saturation of a 1 M NH_4OAc solution of pH 7.0. Phosphate retention was measured by the Blakemore method. All soil chemical analysis methods were guided by the Technical Guidelines for Soil, Water, and Fertilizer Analysis (Eviati and Sulaeman, 2012).

Results and Discussion

Morphological properties

The morphological description of volcanic soil is presented in Table 2. A significant difference in soil texture occurred between young volcanic soils (KM-01 and KM-02) and old volcanic soils (KM-03 and KM-04). The contrasting soil texture indicates the difference in the rate and duration of soil weathering. The sand fraction predominated in

young volcanic soils, ranged within 64 - 78%, and the clay fraction varied within 10 - 32%. Young volcanic soils had sandy loam to sandy clay loam textures, suggesting a low rate of weathering. In contrast, old volcanic soils had well developed cambic horizons (Bw) with higher silt and clay content, ranging within 29 - 42% and 29 - 49% respectively. The amount of clay fraction increased with depth, both in young and old volcanic soils.

KM-01 soil and KM-04 soil revealed the existence of lithological discontinuity, as shown by contrasting texture classes at a depth of 41 cm (KM-01) and a depth of 95 cm (KM-04). Soil texture changed from sandy loam to sandy clay loam in KM-01 soil. Meanwhile, KM-04 soil had clay loam at Bw3 horizon and changed abruptly to clay at the lower horizon. The presence of lithological discontinuity is associated with different periodic eruptions. All profiles had a smeary nature on all soil horizons except the sub-surface horizon of KM-04 soil. Smeary is a characteristic that appears in soils containing non-crystalline minerals such as allophane, ferrihydrite, and imogolite (Sukarman and Dariah, 2014).

Young volcanic soils dominantly exhibited *hue* values of 10 YR, while the old volcanic soils were dominated by 7.5 YR. Furthermore, the chroma values in young volcanic soils were lower (1 - 3) compared to old volcanic soils (2 - 6). The difference in *hue* value pointed out that old volcanic soils is redder than younger volcanic soils. This feature arises because old volcanic soils have experienced weathering over a longer period.

Bulk density (BD) in volcanic soils of Mount Ceremai ranged within 0.89 - 1.28 g/cm^3 for young volcanic soils and 0.89 - 0.95 g/cm^3 for old volcanic soils. According to Dahlgren et al. (2004), the low BD is typical for volcanic soils at the weathering stage where a porous soil structure has developed, which is strongly influenced by non-crystalline minerals and high organic matter content. The reason for the high BD value in young volcanic soils is due to the low quantity of clay fraction containing non-crystalline minerals. Yatno et al. (2016) reported sandy loam volcanic soils in North Sulawesi also had high BD values ranging within 0.89 - 1.19 g/cm^3 . Although BD values were relatively high, the volcanic soils of Mount Ceremai were suitable for plant root development. Field observations showed root activity at deep soil depths.

Mineral composition in sand fraction

The composition of mineral sand fraction (ϕ 0.05 - 2 mm) from four volcanic soils are presented in Table 3. Nutrient Reserve Minerals (NRM) consisted of olivine, pyroxene group (augite and

hypersthene), amphibole group (hornblende), and plagioclase group (labradorite and bytownite). Resistance Minerals (RM) consisted of opaque, turbid quartz, and clear quartz, while Weathered Fractions (WF) were weathered minerals and iron concretions. Apatite and K-bearing minerals were not found in all volcanic soils. KM-01 soil and KM-02 soil were dominated by NRM, ranging from 50 - 61% and 68 - 71%, respectively. The order of magnitude of NRM in both profiles was augite>labradorite> hypersthene. Olivine was also

present in minor proportions. The significant differences between KM-01 and KM-02 soils were the percentage of TVG (34 - 44% vs 11 - 14%) and percentage of RM (2 - 7% vs 13 - 16%). The high percentage of sand fractions containing NRM in large proportion proves the low weathering rate in young volcanic soils. KM-02 soil is more weathered than KM-01, which indicates a higher percentage of WF. Overall, KM-01 and KM-02 soils have a rich potential source of nutrients, especially Ca, Mg, and Fe.

Table 2. The soil morphological properties of Mount Ceremai.

Horizon	Depth (cm)	Soil Texture (%)			Texture	Colour	Bulk Density (g/cm ³)	Smeary
		Sand	Silt	Clay				
KM-01 derived from young lava, 757 m asl, was classified as Typic Udivitrands								
Ap	0-19	78	8	14	SL	10 YR 3/1	0.89	++
Bw1	19-41	81	2	17	SL	10 YR 4/3	1.07	++
2Bw2	41-69	66	2	32	SCL	10 YR 3/1	-	++
2BC	69-187	72	3	25	SCL	10 YR 3/3	-	++
KM-02 derived from young pyroclastic fall, 664 m asl, was classified as Typic Udivitrands								
Ap	0-24	75	15	10	SL	10 YR 3/1	1.15	++
Bw1	24-57	67	16	17	SL	10 YR 4/3	1.28	++
Bw2	57-91	68	18	14	SL	10 YR 3/1	-	++
Bw3	91-110	64	17	19	SL	10 YR 3/3	-	++
KM-03 derived from old lava, 1094 m asl, was classified as Typic Hapludands								
Ap	0-25	31	32	32	CL	7,5 YR 3/3	0.89	++
Bw1	25-51	39	37	37	CL	7,5 YR 3/3	0.95	+++
Bw2	51-82	45	33	33	CL	7,5 YR 3/3	-	+++
Bw3	82-131	44	34	34	CL	7,5 YR 4/3	-	+++
Bw4	131-170	49	38	38	SiCL	7,5 YR 4/4	-	+++
BC	170-200	46	29	29	CL	10 YR 4/4	-	+++
KM-04 derived from old pyroclastic fall, 880 m asl, was classified as Andic Dystrudepts								
Ap	0-21	37	36	27	CL	7,5 YR 4/2	0.87	++
Bw1	21-42	33	39	28	CL	7,5 YR 4/3	0.93	++
Bw2	42-71	41	34	25	L	7,5 YR 3/3	-	-
Bw3	71-95	25	42	33	CL	7,5 YR 3/4	-	-
2Bw4	95-125	16	35	49	C	7,5 YR 3/4	-	-
2BC	125-170	14	38	48	C	10 YR 4/6	-	-
2CR	>170	-	-	-	-	-	-	-

SL = Sandy Loam, SCL = Sandy Clay Loam, CL = Clay Loam, SiCL = Silty Clay Loam, C = Clay, , ++ = clear, +++ = very clear, - = no data.

The unexpected result in this study was that KM-03 derived from old lava contained abundant NRM (80- 82%) with the proportion of hypersthene>augite>labradorite. The different conditions occurred at KM-04 soil where RM was more dominant than NRM. KM-04 soil was dominated by opaque (53 - 62%), while NRM was only around 33 - 38% which was dominated by hypersthene with little proportion of augite and labradorite. KM-03 soil also still contained 3 - 6% TVG, while KM-04 soil completely lost all TVG. Therefore, KM-04 derived from old pyroclastic fall is more weathered than KM-03 soil. This is supported through the higher WF proportion in KM-04 soil. Based on the composition of sand fraction, KM-03 soil still has high potential

nutrient sources, while the potential of nutrient sources in KM-04 soil has begun to be limited.

Mineral composition in the clay fraction

Clay composition in the surface horizon of KM-01 soil was relatively dominated by amorphous minerals and a small amount of cristobalite (Figure 1). The dominance of amorphous mineral is shown by the shape of the convex diffraction peak. The convex peak exhibited that non-crystalline minerals had low crystallinity. The composition of clay minerals in A horizon from KM-02, KM-03, and KM-04 soils were similar. X-Ray analysis detected the presence of amorphous mineral, gibbsite, halloysite, and cristobalite in minor proportion.

Table 3. The mineral composition of the selected pedon sand fraction.

Horizon	The mineral composition (%)																
	Opq	Tq	Cq	Ic	Wm	Gf	Gv	Lab	Bit	Gh	Aug	Hyp	Olv	TVG	RM	NRM	WF
KM-01 derived from young lava, 757 m asl, was classified as Typic Udivitrands																	
Ap	2	-	-	-	1	33	1	22	sp	sp	25	12	1	34	2	61	1
Bw1	5	-	-	-	sp	39	sp	18	sp	sp	26	10	sp	39	5	54	0
2Bw2	7	sp	-	-	1	37	sp	17	-	-	25	11	sp	37	7	53	1
2BC	4	1	sp	-	sp	44	sp	15	sp	-	24	10	1	44	5	50	0
KM-02 derived from young pyroclastic fall, 664 m asl, was classified as Typic Udivitrands																	
Ap	13	sp	-	-	6	11	3	21	-	-	22	19	3	14	13	68	6
Bw1	15	1	-	-	5	9	2	25	-	-	26	15	1	11	16	69	5
Bw2	14	sp	sp	-	5	9	2	24	-	-	28	16	1	11	14	71	5
Bw3	15	sp	sp	-	3	10	1	22	-	-	31	15	1	11	15	70	3
KM-03 derived from old lava, 1094 m asl, was classified as Typic Hapludands																	
Ap	13	sp	sp	1	1	3	sp	21	-	4	27	28	sp	3	13	80	2
Bw1	12	sp	sp	1	sp	5	sp	22	-	3	25	31	sp	5	12	81	1
Bw2	12	-	sp	sp	1	6	sp	17	-	5	25	34	sp	6	12	81	1
Bw3	11	sp	-	1	1	4	sp	17	-	4	24	37	-	4	11	82	2
Bw4	14	-	-	1	sp	4	sp	20	-	2	21	38	-	4	14	81	1
BC	15	-	-	sp	sp	3	-	19	-	2	24	37	-	3	15	82	0
KM-04 derived from old pyroclastic fall, 880 m asl, was classified as Andic Dystrudepts																	
Ap	53	-	-	1	5	sp	sp	4	sp	sp	8	25	sp	-	53	37	6
Bw1	54	-	-	sp	6	sp	-	3	sp	sp	8	26	sp	-	54	37	6
Bw2	56	-	-	1	7	sp	-	5	sp	1	5	22	sp	-	56	33	8
Bw3	58	-	-	sp	3	sp	sp	5	sp	sp	7	26	sp	-	58	38	3
2Bw4	59	-	-	1	3	sp	sp	4	-	1	4	27	sp	-	59	36	4
2BC	62	-	-	sp	4	sp	-	4	-	sp	4	25	sp	-	62	33	4

Note : Opq = Opaque, Tq = Turquoise Quartz, Cq = Clear Quartz, Ic = Iron Concretion, Wm = Weathering Minerals, Fg = Glass Fragment, Gv = Volcanic Glass, Lab = Labradorite, Bit = Bytownite, Gh = Green Hornblende, Aug = Augite, Hyp = Hypersthene, Olv = Olivine, TVG = Total Volcanic Glass, RM = Resistant minerals, NRM = Nutrient Reserves Minerals, WF = Weathered Fractions.

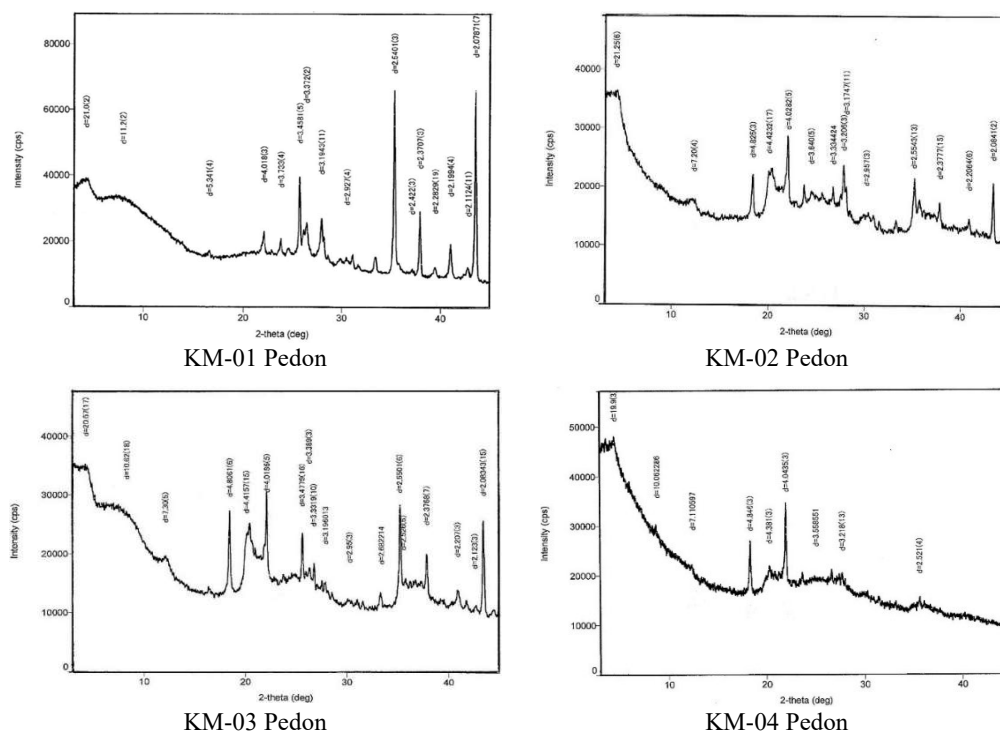


Figure 1. Diffractogram analysis of the clay minerals studied.

Halloysite ($\text{Al/Si} = 1$) was indicated by the diffraction peak at $7 \text{ \AA}$, while gibbsite ($\text{Al/Si} = \sim$) was indicated by the diffraction peak at $4.85 \text{ \AA}$ (Figure 1). Sharp peaks exhibited that halloysite and gibbsite had crystalline structures. Halloysite formation requires conditions that support the accumulation of silica in soil solutions so that the ratio of Al and Si becomes balanced ($\text{Al/Si} = 1$) (Parfitt, 2009; Churchman and Lowe, 2012). The formation of gibbsite is related to the removal of Si out of the soil solum due to leaching, leaving a large amount of Al hydroxy to crystallize ($\text{Al/Si} = \sim$) (van Breemen and Buurman, 2002). Thus, the presence of halloysite and gibbsite indicates the dynamics of the release, removal, and accumulation of Si in the soil. The processes are most likely to occur in areas with high rainfall and precipitation, good drainage, and steep slopes. These minerals did not form on KM-01 soil, presumably because the profile position was not in a steep area (slope level was 10%).

Characteristics of non-crystalline minerals

The $\text{Al}_0 + 1/2 \text{ Fe}_0$ value was higher in the sub-surface horizon than the surface horizon for all pedons (Table 4). The order of magnitude on the surface horizon was $\text{KM-03} > \text{KM-01} = \text{KM-02} > \text{KM-04}$. Takahashi and Dahlgren (2016) explained the low amorphous material on the surface horizon was related to the ability of a humic substance to

form a chelate with Al/Fe, which prevented the formation of non-crystalline minerals. In line with $\text{Al}_0 + 1/2 \text{ Fe}_0$ value, the highest amount of allophane was found in KM-03 soil, represented 33 - 44 %. Allophane content in the KM-01 and KM-02 soil surface layers were similar (10 %), while the surface layer of the KM-04 soil contained the lowest amount of allophane (8 %). There was a sharp increase in the buried horizon of KM-01 soil and KM-04 soil.

The highest $\text{Al}_0 + 1/2 \text{ Fe}_0$ value confirmed that KM-03 soil was a well-developed Andisol. This soil was classified as Typic Hapludands. This result was different from the appearance of XRD peaks which showed amorphous mineral in KM-03 soil was minor (Figure 2). In contrast, the XRD successfully demonstrated the dominance of amorphous minerals in KM-01 soil (Figure 2). A report from Anda et al. (2012) also showed XRD analysis that was not representative in MA-7 soil (Vitric Hapludands derived from basalt andesite) which contained high amounts of non-crystalline minerals.

The detailed morphology of non-crystalline minerals was taken using a Scanning Electron Microscope (SEM). Figure 2 shows the predominance of allophane (A) in KM-01. Allophane had a spherical morphology at 1,000 times magnification and was increasingly visible at 10,000 times magnification. Clay minerals in KM-

03 soils were allophane (A), imogolite (B), halloysite covered by allophane (C), and gibbsite covered by allophane (D). Allophane was dominated and seemed to form aggregates at 1000 times magnification. Imogolite had a tubular shape and was seen after 10,000 times magnification. Parfitt and Hemni (1980) described allophane

having a circular shape with an external diameter of 35 - 50 Å. Furthermore, imogolite had a tubular shape with a diameter of 50 - 100 Å, while the halloysite was also had a tubular shape with a larger diameter (200 Å) and a longer size (800 Å). The descriptions are similar to the results of this study.

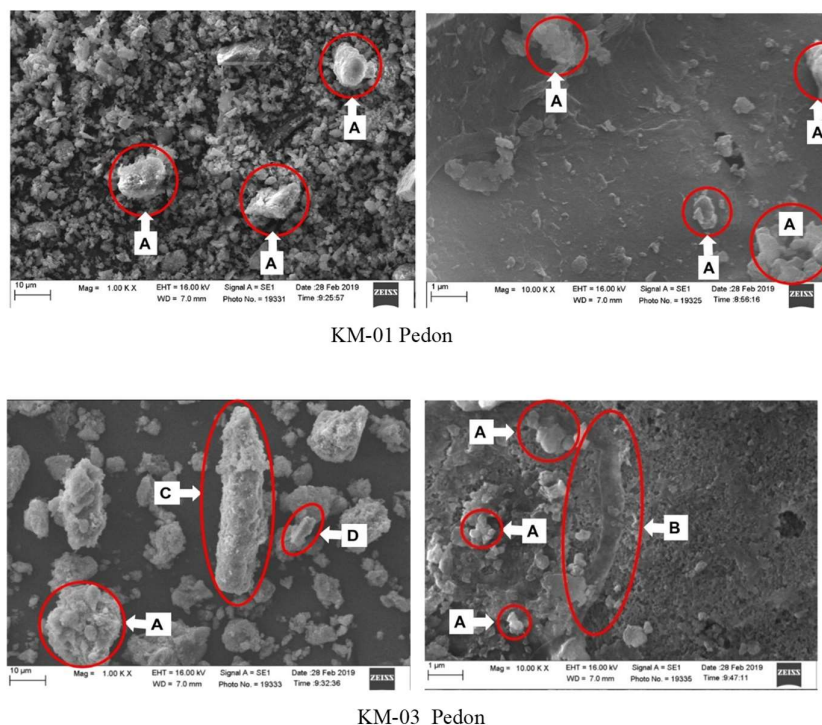


Figure 2. Scanning Electron Microscope (SEM) image results from volcanic soil formed from young parent material (KM-01) and volcanic soil formed from older parent material (KM-03).

The type of allophane was dominated by Al-rich allophane ($Al/Si \approx 2$) for all profiles. The lowest Al/Si ratio (1.4) found in the Bw2 horizon of KM-02 (at a depth of 57 cm). This type of allophane has additional silanol (Si-OH) which is weakly bound to the basic structure of allophane (Parfitt, 2009). Allophane with additional silanol was formed due to an increase of Si concentration in the soil solution. The highest allophane ratio was 3.33 and was found on the Bw2 horizon of KM-04 (at a depth of 42 cm). This allophane has an excess of aluminols (Al-OH) on its surface (Parfitt, 2009). In fact, allophane in the surface layer of the KM-03 soil had an Al / Si ratio > 3 . This fact shows that the KM-03 soil has experienced intense Si leaching. The Al/Si ratio of allophane tends to decrease significantly with depth for soils derived from pyroclastic falls. Meanwhile, soils derived from lava show no significant change in Al/Si ratio of allophane, except for the BC horizon from KM-03 soil. Therefore, in mountainous terrain, we

suspect that Si leaching is more active in soils derived from pyroclastic falls than soils derived from lava. Ferrihydrite from old volcanic soil was higher than young volcanic soils (4 - 9 % vs 3 - 4 %). Ferrihydrite occurred through a process of reduction that pushes Fe from the mineral structure, into the form of Fe(II)-containing water, then rapidly oxidizes to form Fe(III) (McDaniel et al., 2012). Old volcanic soils have experienced weathering over a longer period, causing more ferromagnesian minerals (mainly augite and hypersthene) to transform into ferrihydrite.

All volcanic soils in this study had $Al_o + 1/2 Fe_o$ values higher than 2%. The consequence is that nutrient management for crops must deal with the presence of these minerals. Non-crystalline minerals have pH-dependent properties and high reactivity to phosphate. Both of these properties are promoted by active surface groups, namely aluminol (Al-OH) and ferrol (Fe-OH) (Wada, 1986).

Table 4. Characteristics of non-crystalline minerals in selected pedons.

Horizon	Depth (cm)	Oxalate (%)		Pyrophosphate (%)		Al _o +	Alp	Fer	Al _o /Si _o Alp	
		Fe _o	Al _o	Si _o	Fe _p	Al _p				1/2 Fe _o
KM-01 derived from young lava, 757 m asl, was classified as Typic Udivitrands										
Ap	0-19	1.60	3.35	1.26	0.07	0.71	4.15	10	3	2.1
Bw1	19-41	1.85	3.86	1.69	0.05	0.81	4.79	12	3	1.8
2Bw2	57-91	2.01	4.90	1.91	0.08	1.03	5.90	15	3	2.0
2BC	91-110	2.64	8.60	3.37	0.06	0.93	9.92	29	4	2.3
KM-02 derived from young pyroclastic fall, 664 m asl, was classified as Typic Udivitrands										
Ap	0-24	1.84	3.11	1.27	0.08	0.59	4.03	10	3	2.0
Bw1	24-57	1.79	3.17	1.26	0.08	0.56	4.06	10	3	2.1
Bw2	57-91	1.91	3.34	1.90	0.08	0.66	4.29	12	3	1.4
Bw3	91-110	1.93	4.23	2.22	0.07	0.86	5.20	14	3	1.5
KM-03 derived from old lava, 1094 m asl, was classified as Typic Hapludands										
Ap	0-25	2.36	9.47	4.41	0.08	0.74	10.65	33	4	2.0
Bw1	25-51	2.39	9.44	4.45	0.08	0.75	10.64	33	4	2.0
Bw2	51-82	2.37	9.77	4.45	0.06	0.70	10.95	34	4	2.0
Bw3	82-131	3.22	12.21	6.35	0.06	0.89	13.82	44	5	1.8
Bw4	131-170	3.81	11.93	6.20	0.08	0.79	13.84	44	6	1.8
BC	170-200	3.26	10.53	3.66	0.36	0.79	12.16	37	6	2.7
KM-04 derived from old pyroclastic fall, 880 m asl, was classified as Andic Dystrudepts										
Ap	0-21	1.88	2.47	0.58	0.15	0.59	3.40	8	3	3.2
Bw1	21-42	1.89	2.47	0.68	0.08	0.45	3.42	8	3	3.0
Bw2	42-71	1.94	2.55	0.61	0.12	0.55	3.52	9	3	3.3
Bw3	71-95	2.43	3.06	0.88	0.22	0.69	4.27	9	4	2.7
2Bw4	95-125	4.21	4.07	1.13	0.71	1.32	6.18	10	7	2.4
2BC	125-170	5.37	7.48	3.43	0.06	0.69	10.16	26	9	2.0

Soil chemical properties

In general, there were significant differences in actual acidity (pH H₂O) and exchangeable Al in surface horizons between young volcanic soils and old volcanic soils (Table 5). Furthermore, the acid reaction and the presence of exchangeable Al convinced that KM-04 was the most developed soil. This was also supported by the highest WF content compared to other soils, accompanied by a decreasing proportion of NRM. The pH NaF was relatively similar for all soils, both read after 1 minute and 60 minutes. These results showed the strong influence of non-crystalline minerals through the consumption of F⁻ by aluminol (Al-OH) and ferrol (Fe-OH) groups. The value of ΔpH on all soils showed a negative value with a wide enough interval (> -0.5). This indicated that the volcanic soils on Mount Ceremai are negatively charged.

The total N content of young volcanic soils was moderate, while the old volcanic soils were low to moderate. Interestingly, the total N content was positively correlated with soil organic content (Figure 3). This reflects that nitrogen content can be increased by applying organic matter. All surface horizons had total P (HCl 25%) as high (young volcanic soils) to very high (old volcanic soils). Total P decreased with the depth in all soils. Phosphate had accumulated in the surface layers due to strong retention by non-crystalline minerals.

KM-03 soil containing the highest non-crystalline minerals had the highest P Retention (PR) value (89.97 - 95.1%). The order of magnitude of PR values on the surface layer was KM-03 > KM-01 = KM-04 > KM-02. An unexpected result was found in the PR value of the KM-04 soil. Although this soil had a lower Al_o + 1/2 Fe_o value compared to KM-02, the PR value in the KM-04 surface layer was slightly higher than KM-02.

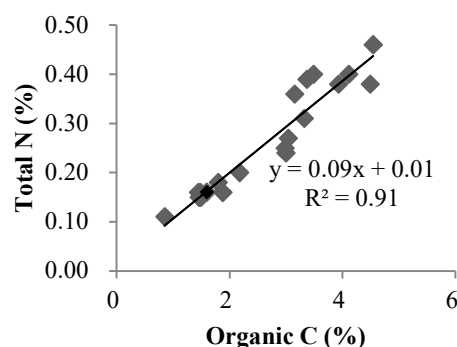


Figure 3. Relationship of soil organic carbon with total N.

This was due to the fact that the surface layer of KM-04 contained allophane with an Al/Si ratio > 3 so it had the addition of aluminol to the allophane

structure. A comprehensive study on phosphate adsorption by allophane from Johan et al. (1997) concluded that the higher Al/Si ratio in allophane supported more ligand exchange between aluminol and phosphate on the surface of allophane. The effect of excess aluminol on allophane (possibly also from gibbsite) further increases P retention in KM-04 soils if soil pH decreases. Since KM-04 has lost large amounts of NRM due to weathering and base cation has been leached, reducing P retention in this soil should consider adding ameliorant which is able to maintain soil pH. It must be noted Blackmore method gives overestimated PR values if it used for agronomic purposes. The Blackmore method use extracts with pH value <3, causing an increase in the amount of positive charge on the surface groups of aluminol (Al-OH) and ferrol (Fe-OH). This increase will be followed by an increase in the amount of phosphate absorbed by the surface group of non-crystalline minerals.

Table 5 also shows the order of exchangeable cations with the highest to lowest content in the surface horizon was Ca>Mg>K>Na for all profiles. The order changed to Ca>Mg>Na>K in the sub-surface horizons. The dominance of exchangeable Ca and Mg corresponded to the proportion of augite, labradorite, and hypersthene which dominate the sand fraction in all soils. The proportion of exchangeable K was the smallest among the other cations. Total K (25% HCl) in all soils was also very low. This is due to the absence of K-bearing mineral in sand fraction.

Critical cation deficiency status developed by Center of Soil Research in Bogor set minimum limits for Ca, Mg, K, and Na, respectively 6 cmol_c/kg, 1.1 cmol_c/kg, 0.4 cmol_c/kg, and 0.4 cmol_c/kg (Pusat Penelitian Tanah, 1983). Based on that criteria, all surface layers in this study were at an insufficient level with respect to plant growth. This does not reflect the potential NRM contained in volcanic soil. The surface layer in soil KM-04 had the lowest exchangeable cations (Σ cations < 1). Low base supply followed by intense leaching resulted in increased acidity and exchangeable Al. This corresponds to the conditions in KM-04 soil.

The low content of exchangeable cations in all volcanic soils was associated with the low cation exchange capacity (CEC) of all volcanic soils. Soil CEC from young volcanic soils ranged from low to moderate (10.96 - 20.08 cmol_c/kg), while old volcanic soils ranged from moderate to high (17.14 - 40.90 cmol_c/kg). The use of ammonium acetate pH 7 gave an overestimated result to the CEC values. Measurements at pH 7 increased artificial negative charges due to the deprotonation process of aluminol and ferrol groups. In contrast, ECEC (Effective Cation Exchange Capacity) for all soil was much lower.

The ECEC values of KM-01 ranged from 3.29 - 3.98 cmol_c/kg, while KM-02 ranged from 2.10 - 4.25 cmol_c/kg. For old volcanic soils, ECEC KM-03 ranges from 3.80 - 7.46 cmol_c/kg, while KM-04 ranges from 4.40 - 13.66 cmol_c/kg.

Sustainable nutrient management

All volcanic soils in Mount Ceremai require regular P₂O₅ and K₂O fertilization considering apatite and potassium bearing minerals as a source of P and K nutrients are not found in all soils. The total P content in all soils was high to very high, while the total K was low. Therefore, P fertilization is needed in relatively small amounts. The focus of P nutrient management is to increase the availability of P absorbed by non-crystalline minerals. From a mineralogical perspective, young volcanic soils contain high nutrient reserves, especially Ca, Mg, and Fe, but have low exchangeable cations and very low capacity to retain nutrients (CEC) due to the low proportion of clay. Therefore, nutrient management is focused on accelerating NRM weathering and improving CEC. Adding organic material such as compost or manure regularly is recommended. Compost or manure contains humic substances and low molecular weight (LMW) organic acids that accelerate NRM weathering (Ismangil and Hanudin, 2005). Both of these substances also reduce phosphate retention and increase the negative charge on allophane surface groups by forming chelates (Hanudin et al., 1999). With this treatment, Ca and Mg fertilizers are not needed for young volcanic soils, while phosphate retention can be reduced.

Two different conditions were identified in old volcanic soils. KM-03 soil that developed from lava still had high nutrient reserves while KM-04 soil that developed from pyroclastic falls experienced nutrient depletion. Both of the soils had clay loam texture dominantly and had low exchangeable cations in surface layers. The KM-03 soil was dominated by allophane with Al/Si ratio = 2. This soil has a serious problem with P retention. The KM-04 soil contains allophane in lower proportions, but the soil has a higher Al/Si allophane ratio (Al/Si = 3). Therefore, nutrient management recommendations are different. KM-03 soil receives the same treatment as young volcanic soils. Adding compost or manure regularly is needed to dissolve NRM and increase the negative charge on the soil. Given the high amount of non-crystalline minerals, relying on the addition of organic matter is not enough to reduce phosphate retention. To improve the efficiency of P fertilization, the utilization of indigenous phosphate solubilizing bacteria combined with the use of phosphate rocks is recommended.

Table 5. Soil chemical properties of studied profiles.

Horizon	Depth cm	pH (1:5)			pH NaF		C	N	C/N	P _{tot}	K _{tot}	PR	Exchangeable Cations							Al _{exc}	H _{exc}	
		H ₂ O	KCl	ΔpH	1'	60'							%.....	Ca	Mg	K	Na	Σ	CEC			ECEC
.....cmol(c)/kg.....																			%			
KM-01 derived from young lava, 757 m asl, was classified as Typic Udivitrands																						
Ap	0-19	5.9	5.0	-0.92	10.8	11.6	4.49	0.38	12	46	10	83.7	2.95	0.34	0.14	0.06	3.49	14.95	3.67	23	0.00	0.18
BC	19-41	6.0	5.0	-0.97	11.0	11.7	2.18	0.20	11	27	5	89.8	2.72	0.31	0.04	0.06	3.13	10.96	3.29	29	0.00	0.16
2Bw2	57-91	6.4	5.4	-0.95	11.1	11.7	4.54	0.46	10	35	5	91.3	3.29	0.38	0.05	0.09	3.81	19.01	3.98	20	0.00	0.17
2BC	91-110	6.4	5.3	-1.15	11.0	11.7	3.93	0.38	10	28	3	94.4	2.74	0.37	0.02	0.05	3.18	16.53	3.37	19	0.00	0.19
KM-02 derived from young pyroclastic fall, 664 m asl, was classified as Typic Udivitrands																						
Ap	0-24	5.8	4.9	-0.93	10.8	11.6	3.00	0.24	13	73	4	80.1	1.54	0.32	0.02	0.04	1.92	14.68	2.10	13	0.00	0.18
Bw1	24-57	5.9	5.0	-0.86	10.7	11.5	2.98	0.25	12	67	4	81.9	2.05	0.41	0.03	0.08	2.57	17.74	2.75	14	0.00	0.18
Bw2	57-91	6.0	5.1	-0.90	10.8	11.5	3.04	0.27	11	55	3	85.3	2.79	0.39	0.02	0.04	3.24	16.76	3.42	19	0.00	0.18
Bw3	91-110	6.3	5.3	-0.96	10.9	11.6	3.37	0.39	9	28	3	85.8	3.58	0.44	0.01	0.02	4.05	20.08	4.25	20	0.00	0.20
KM-03 derived from old lava, 1094 m asl, was classified as Typic Hapludands																						
Ap	0-25	5.3	4.6	-0.69	10.6	11.5	4.11	0.40	10	115	4	93.7	2.93	0.55	0.05	0.03	3.56	29.84	4.55	12	0.69	0.30
Bw1	25-51	5.3	4.7	-0.60	10.6	11.5	3.49	0.40	9	90	3	94.4	2.95	0.50	0.04	0.03	3.52	28.54	4.32	12	0.47	0.33
Bw2	51-82	5.7	5.1	-0.56	10.7	11.6	3.15	0.36	9	49	3	94.2	2.66	0.87	0.04	0.04	3.61	25.82	3.80	14	0.00	0.19
Bw3	82-131	6.1	5.5	-0.61	11.0	11.6	1.45	0.16	9	16	5	94.5	4.06	1.16	0.06	0.08	5.36	21.95	5.57	24	0.00	0.21
Bw4	131-170	6.1	5.5	-0.58	10.8	11.5	1.48	0.16	9	11	5	95.1	4.22	0.79	0.09	0.11	5.21	23.96	5.40	22	0.00	0.19
BC	170-200	6.5	5.7	-0.79	10.5	11.3	0.85	0.11	8	9	5	89.7	5.16	1.84	0.06	0.18	7.24	17.14	7.46	42	0.00	0.22
KM-04 derived from old pyroclastic fall, 880 m asl, was classified as Andic Dystrudepts																						
Ap	0-21	4.9	4.1	-0.74	10.1	11.1	1.88	0.16	12	138	4	83.6	0.57	0.21	0.05	0.04	0.87	25.39	4.61	3	3.15	0.59
Bw1	21-42	5.0	4.2	-0.84	10.1	11.1	1.60	0.16	10	92	5	84.8	0.60	0.23	0.06	0.05	0.94	24.59	4.40	4	2.90	0.55
Bw2	42-71	5.3	4.3	-1.06	10.0	11.1	1.46	0.15	10	65	5	83.5	2.22	0.56	0.07	0.13	2.98	22.69	4.87	13	1.57	0.32
Bw3	71-95	5.7	4.6	-1.08	10.2	11.2	1.80	0.18	10	66	6	83.1	5.53	1.50	0.09	0.11	7.23	27.37	7.45	26	0.00	0.22
2Bw4	95-125	6.1	5.0	-1.06	10.2	11.3	3.32	0.31	11	94	4	85.4	9.32	2.12	0.06	0.16	11.66	40.90	11.91	29	0.00	0.25
2BC	125-170	6.5	5.5	-0.96	10.8	11.5	1.49	0.15	10	39	3	91.8	10.78	2.47	0.05	0.16	13.46	37.81	13.66	36	0.00	0.20

Note: P_{tot} = Total P, K_{tot} = Total K, PR = P retention, Σ = total cation (Ca+Mg+K+Na), ECEC= Effective CEC, BS = bases saturated, Al_{exc} = Exchangeable Al, H_{exc} = Exchangeable H.

On the other hand, liming becomes crucial for nutrient management in KM-04 soil. Lime is needed to maintain soil pH, suppress exchangeable Al in soil solution, and increase Ca availability for crops. Preventing soil acidification is important to reduce the protonation of excess aluminol groups on the surface of allophane. Furthermore, after liming, organic matter is given in very large quantities considering the C-organic in this soil is low. KM-04 soil contains low total N, but a massive addition of inorganic N fertilizer might increase acidity in these soils. This must be avoided so that no protonation occurs in the aluminol group of allophane. Slow-release N fertilizer can be an alternative in maintaining N for crop growth.

Conclusion

Young volcanic soils from Mount Ceremai were dominated by nutrient reserved mineral (NRM), namely augite, labradorite, and hypersthene. There were no apatite and K-bearing minerals found in all volcanic soils, so regular P and K fertilization is recommended. The volcanic soils from Mount Ciremai have a composition of clay minerals dominated by amorphous minerals, and a mixture of amorphous minerals, gibbsite, and halloysite.

Young volcanic soils contained high NRM but had very low exchangeable cation and very low capacity to retain nutrients. Phosphate retention was also a problem. Therefore, adding organic matter regularly should be established to restore CEC, accelerate NRM weathering, and decrease phosphate retention. Soil from old lava had a serious problem with phosphate retention. This soil also had high NRM, but the number of exchangeable cations was relatively low.

Recommended nutrient management for this soil are the addition of organic matter and the use of phosphate rock combined with the utilization of phosphate solubilizing bacteria to restore CEC and P availability for crops. As the most weathered soil, soil from old pyroclastic deposits had several problems such as soil acidity, the presence of exchangeable Al, nutrient depletion, low C-organic and total N, high P retention, and very low amount of exchangeable cations in the surface layer. Therefore, soil restoration required liming, large amounts of organic material, and fertilizing.

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