MINERALOGICAL CHARACTERIZATION AND CHEMICAL PROPERTIES OF SOILS AS A CONSIDERATION FOR ESTABLISHING SUSTAINABLE SOIL MANAGEMENT STRATEGIES

Karakterisasi Mineral dan Sifat Kimia Tanah Sebagai Dasar untuk Mengembangkan Strategi Pengelolaan Tanah Berkelanjutan

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ABSTRACT

Problems of soil limiting factors affecting crop growth were not fully understood owing to little attention has been given to soil mineralogy and its association to soil chemical properties. The objective of the study was to assess soil mineralogical and chemical properties of seven soils derived from different parent materials as an integrated strategic consideration to establish soil management. Field study was carried out in 2009. Soils were sampled from each horizon of profiles. Results showed that primary and secondary minerals had a strong effect on soil chemical properties. The sand fraction of soils derived from basalt, gabbro, mica schist and serpentinite was dominated by resistant minerals (quartz or opaques), leading to very limited, if any, nutrients released from parent materials. The clay fraction was dominated by kaolinite for soils derived from basalt, mica schist and gabbaro, and by amorphous materials for the soil derived from serpentinite resulting in low soil cation exchange capacity (CEC). For other three soils derived from volcanic tuff, volcanic basaltic andesite and volcanic ash, the easily weatherable minerals (feldspar and ferromagnesian) were dominant, suggesting the high reserved nutrients. The presence of halloysite and smectite minerals in the soil derived from volcanic tuff resulted in high soil CEC, while the dominance of amorphous materials in soils derived from volcanic basaltic andesite and volcanic ash was responsible for the low CEC. For soils derived from basalt, serpentinite, mica schist and gabbro, therefore, the strategic management should be directed to restore soil CEC, pH, exchangeable cations and P content. For soils derived from volcanic tuff, volcanic basaltic andesite and volcanic ash, the presence of easily weatherable minerals indicated many reserved nutrients; hence the soil management is directed for replenishment of nutrients removed by crops.

[*Keywords*: Soil chemical properties, mineralogical characteristics, primary minerals, clay minerals, soil management]

ABSTRAK

Faktor-faktor pembatas pertumbuhan tanaman yang berkaitan dengan sifat-sifat tanah belum sepenuhnya dapat dipahami karena terbatasnya informasi tentang kandungan mineral tanah yang berkaitan dengan berbagai sifat kimia tanah. Tujuan penelitian ini adalah mempelajari komposisi mineral dan sifat kimia tujuh tanah yang terbentuk dari bahan induk berbeda sebagai dasar pertimbangan untuk menyusun strategi pengelolaan tanah berkelanjutan. Penelitian lapangan dilakukan pada tahun 2009. Contoh tanah diambil dari tiap horison masing-masing profil tanah. Hasil penelitian menunjukkan bahwa komposisi mineral primer dan sekunder sangat memengaruhi sifat kimia tanah. Fraksi pasir tanah yang terbentuk dari batuan basal, gabro, skis mika, dan serpentin didominasi oleh mineral tahan pelapukan (kuarsa atau opak) sehingga hara yang dilepaskan sangat terbatas. Fraksi liat didominasi oleh mineral kaolinit pada tanah yang terbentuk dari batuan basal, skis mika, dan gabro, sedangkan tanah dari batuan serpentinit didominasi bahan amorf sehingga kapasitas tukar kation (KTK) rendah. Tanah yang terbentuk dari tufa volkan, volkan andesit basal, dan abu volkan didominasi oleh mineral primer mudah lapuk (feldspar dan ferromagnesian) sehingga kandungan cadangan hara tinggi. Tanah yang terbentuk dari tufa volkan mempunyai mineral haloisit dan semektit sehingga KTK-nya tinggi, sedangkan tanah yang terbentuk dari volkan andesit basal dan abu volkan didominasi oleh bahan amorf sehingga KTK-nya rendah. Oleh karena itu, strategi untuk pengelolaan tanah-tanah dari bahan induk basal, serpentin, mika, dan gabro diarahkan untuk memulihkan KTK, pH, kation tukar, dan kandungan P, sedangkan pada tanah-tanah dari bahan volkan (tufa, andesit basal, dan abu) yang masih mempunyai banyak cadangan hara, pengelolaannya diarahkan untuk mengganti hara yang terangkut panen tanaman.

[*Kata kunci*: Sifat kimia tanah, karakteristik mineral tanah, mineral primer, mineral liat, pengelolaan tanah]

INTRODUCTION

To fully understood soil properties affecting agricultural practices, the approach needs an integrated consideration of various soil components to allow predictions of soil behavior, use and management. Composition of primary minerals (sand fractions)

played the key role in controlling reserved nutrients in soils and that secondary minerals (clay fractions) determined the soil capability to retain various cations and anions released from the weathering of primary minerals. However, primary and secondary minerals of soils very often received little attention, while chemical and physical properties received a lot. This could be due to expensive analysis problems and the availability of instruments, which are beyond the capability of many laboratories. Consequently, interpretation of soil properties was not supported by sufficient data required to predict potential availability of various reserved elements that affect soil fertility and its management.

The effect of soil mineralogical compositions (primary and secondary minerals) on chemical properties is crucial in anticipating soil management practices. From pedological view points, it is well understood that parent materials containing various easily weathered minerals with high amounts of reserved potential nutrients produced more fertile soils.

Serpentinite is one of the ultrabasic rocks (containing magnesium-silicate as dominant minerals) that rapidly weathered in soils (Bonifacio *et al*. 1997; Lee *et al*. 2004; Wilson 2004). The content of Mg in soils derived from ultrabasic rocks is exceptionally higher than other cations. In soil taxonomy, soils dominated by magnesium-silicate minerals, such as serpentine, talc, olivines, Mg-rich pyroxenes and Mg-rich-amphiboles in the fine earth fraction were recognized at the family mineralogical level as magnesic (Soil Survey Staff 2010) to allow an appropriate interpretation of soil use and management.

Mineral composition of basalt composed of plagioclase feldspar, olivine, pyroxene, magnetite, augite, orthoclase, apatite and glass minerals (Gillman *et al*. 2002; Chorover *et al*. 2004), which are all rapidly weathered. Gabbro is a coarse grain (intrusive rock) equivalent to basalt, both having relatively similar properties. Basalt released high amounts of cations (Ca, Mg and Na) (Chorover *et al*. 2004). According to Rasmussen *et al*. (2010), clay minerals of soil developed from basalt were dominated by kaolinite and dehydrated halloysite, followed by crystalline Fe-oxyhydroxides.

In Indonesia, most soils derived from volcanic materials have good fertility. Van Ranst *et al*. (2008) showed that the primary minerals of Andosols in Dieng Tephra (airborne volcanic particulate matter), Indonesia, were mainly alkali-feldspar, Ca-feldspar, volcanic glass and minor amounts of hornblende, hypersthene, augite and olivine. These minerals are rapidly weathered in soils to release new nutrients.

Hepper *et al*. (2006) studied 24 topsoils (0-20 cm) for Argentinean soils with different volcanic ash contents and reported that clay minerals were dominated by amorphous minerals and less crystallized smectite in enriched volcanic ash soils and by illite in volcanic ash free soils.

Mica schist is the parent rocks containing mainly biotite and muscovite minerals. Biotite is the major source of K for plant nutrient and Fe and Mg in ground water (Berner and Berner 1996). Anda *et al*. (1997) reported transformation of mica schist to illite and smectite during formation of the red soil profile (Natrixeralf) in the Monarto area, South Australia. Based on dissolution processes of biotite in the laboratory and in nature, Murakami *et al*. (2003) reported that the formation of vermiculite layers between biotite layers occurred when biotite is not Fe-rich, while vermiculite was rarely formed when biotite Fe-rich due to lack of Mg.

Feldspars are potential Ca-, K- and Na-bearing minerals and occurred at varying proportions for different rocks. Zhang and Lüttge (2009) stated that the mechanism of plagioclase feldspar dissolution was dominated by an interfacial dissolution-reprecipitation. Feldspar dissolution mechanism is leaching of Ca, Mg, Na, K and Al from crystal structures. In the plagioclase solid series, the Al content increased linearly from albite ($NaAlSi_3O_8$) to anorthite ($CaAl_2Si_2O_8$) end members, corresponding to the increase in dissolution rates under acid pH conditions (Zhang and Lüttge 2009). The released cations from weatherable minerals in fresh rocks play a crucial role in supplying cations to replenish cation losses from the soils. The objective of the study was to assess soil mineralogy in association with chemical properties of seven soils (representing soils mostly used for agriculture in Indonesia) derived from different parent materials as a strategic consideration to establish soil management for sustainable agricultural practices.

MATERIALS AND METHODS

Seven soils developed from different parent materials, viz., basalt, gabbro, serpentinite, volcanic basaltic andesite, volcanic tuff, volcanic ash and mica schist were studied to represent soils on various landscapes and parent materials. Locations of seven soils and associated environmental conditions are summarized in Table 1. The parent materials had different geological formations. The basalt rock occurred on a Pleistocene volcanic plain (Mangga *et*

Table 1. Location of seven soils and their related parent materials and relieves.

Soil	Location	Parent material	Relief	Longitude/latitude
MA1	Negara Ratu Village, Batang Hari District, Lampung Timur Regency, Lampung	Basalt	Undulating	55°21'71" E/ 04°35'05" S
MA6	Giritirto Village, Karanggayam District, Kebumen Regency, Central Java	Gabbro	Hilly	109°39'49.1" E/ 07°30'25.6" S
MA3	Lapa-Lapa Village, Kolaka District, Kolaka Regency, Southeast Sulawesi	Serpentinite	Undulating	121°35'36" E/ 04°13'5" S
MA5	Ladatundu Village, Ubud District, Gianyar Regency, Bali	Volcanic tuff	Undulating	115°15'15.6" E/ 08°32'52.5" S
MA8	Kaliadem Village, Cangkringan District, Sleman Regency, Yogyakarta	Volcanic ash	Straight gentle slope	110°26'55" E/ 07°34'55.3" S
MA7	Garung Village, Garung District, Wonosobo Regency, Central Java	Basaltic andesite	Hilly	109°55'38.9" E/ 07°17'50.4" S
MA4	Laloeeha Village, Kolaka District, Kolaka Regency, Southeast Sulawesi	Mica schist	Hilly	121°36'93" E/ 04°03'32" S

al. 1993) with undulating relief. The basalt is a lava flow with ground mass of plagioclase and olivine, containing 5% phenocrysts of olivine. For the serpentinite, it was part of an ultrabasic formation from the Cretaceous (Simanjuntak *et al.* 1993) in rolling to hilly areas. The serpentinite has greenish color. The pale green gabbro sample was a part of basic rocks occurring in a hilly area with early Cretaceous age (Condon *et al.* 1996). For the mica schist, it was a Pompangeo complex formation from the Paleocene (Simanjuntak *et al.* 1993) in a hilly area. The mica schist is low grade metamorphic rock dominated by mica mineral resulting from regional metamorphism. Quartz as vein and feldspar are two minerals which are always found together with mica.

Volcanic tuff, volcanic basaltic andesite and volcanic ash are extrusive volcanic materials. The volcanic tuff was quaternary volcanic rock (Hadiwijojo *et al.* 1998) in a volcanic area. The tuff was formed by sedimentation of volcanic eruption materials by water or wind. The volcanic basaltic andesite rock was sampled in the Sindoro volcano formation from the Holocene (Condon *et al.* 1996) and occurred at a middle slope position. Basaltic andesite is flowed breccia and lahar, containing augite-hypersthene andesitic and augite-olivine basaltic lava. The volcanic ash material was a recent Merapi volcano eruption occurring in March 2006. Lavas from previous eruptions of Merapi were calcic-alkaline, with SiO_2 content ranging from 49.5% to 60.5% (w/w), and basaltic andesites represent about 90% of Merapi lavas (Camus *et al.* 2000).

Field observation of soils was carried out by digging a pit with a 1.5 m by 1.5 m by 0.7-1.7 m dimension (length by breadth by depth). The depth depended on thickness of soils to the parent materials and 1 kg sample representing each horizon was taken for mineralogical and chemical analyses. Soil samples were air-dried, ground and passed through a 2 mm sieve. The mineralogical compositions of the sand fractions of soils were identified using a polarizing microscope (PM). The 300 grains of 50-250 μm were counted by line count traverses. The mineralogical composition of clay fractions was determined using X-ray diffraction (XRD) of a Philip PW 3020 X-ray diffractometer with CuK-alpha radiation target, operated at 30 kV and 25 mA. The specimens were scanned from 3 to 40° 2θ at 1° minute[-1]. XRD data were collected and stored by IBM compatible PC. Differential thermal analysis (DTA) of the clay fraction (< 2 μm) was carried out using a Thermal Analyzer (Simatzu, Kyoto, Japan) and Al_2O_3 powder as a reference material. The clay fraction was saturated with 0.1 M $CaCl_2$ (Tan *et al.* 1986) and the excess of electrolyte was washed with alcohol (98%), air-dried and oven-dried at 50° C prior to regrinding. The sample was weighed (28.41 ± 0.1 mg) and heated from ambient temperature (35°C) to 1000°C at 20°C minute[-1] under N_2 gas flow.

Soil pH was measured in H_2O and 1 M KCl at a solution ratio of 1:2.5 after 30 minutes of equilibration (Soil Survey Staff 1992). Particle size analyses were obtained by using sedimentation methods. Exchangeable cations were extracted by 1N NH_4OAc, pH 7.0 (Soil Survey Staff 1992) and the cation was measured using atomic absorption spectrophotometry (AAS). The CEC was measured in 1M NH_4OAc (buffered at pH 7.0) after extraction of NH_4^+ by NaCl. Aluminum, Fe and Si associated with active amorphous constituents were extracted by ammonium

oxalate (Van Reeuwijk 1993) and were referred to as Al_o, Fe_o and Si_o, respectively. Free iron was extracted by sodium dithionite (Mehra and Jackson 1960). P retention was determined using the method of Blackmore *et al.* (1981).

RESULTS

Weatherable Minerals in Sand Fractions of Soils

Composition of weatherable minerals in sand fractions of soil profiles developed from different parent materials is given in Tables 2 and 3. The easily weatherable minerals of various parent materials consisted of feldspar mineral group (anorthite, bytownite, labradorite, andesine and orthoclase), ferromagnesian mineral group (hornblende, augite, hypersthene, olivine, pyroxene, enstatite and serpentine), and volcanic glass. These easily weatherable minerals are potential sources of reserved nutrients for a long period of time in soils. On the other hand, the resistant minerals are opaque and quartz. These resistant minerals have no potential reserved nutrients.

Based on the primary mineral composition, the seven soils were separated into four groups. Group one is soils dominated by feldspar and ferromagnesian minerals. This includes soils developed from volcanic tuff (MA5), volcanic basaltic andesite (MA7), and volcanic ash (MA8). They had relatively similar composition of feldspar and ferromagnesian minerals. Feldspars were mainly labradorite (20-39%) with minor amounts of andesine, bytownite and anorthite (< 5% each) (Table 2). Ferromagnesian minerals present in intermediate proportion composed of augite, hypersthene and hornblende. In addition, volcanic glass mineral occurred in a minor proportion, varying mostly from 5% to 15% with the order of decreasing magnitude was MA8 > MA7 > MA5 soils. The resistant mineral observed was opaque, varying from 10% to 25% for three soils. Group two is soils dominated by resistant mineral of quartz with trace amounts of feldspar and ferromagnesian minerals (Table 3). This includes soils derived from basalt (MA1) and gabbro (MA6), where the magnitude of quartz content was considerably higher in the former soil. Group three is a soil dominated by resistant mineral of opaque (iron oxyhydroxides 53-63%) accompanied by significant amount of enstatite (20-32%). This was only observed in the MA3 soil.

Table 2. Mineralogical composition of fine sand fractions (50-250 μm) in soils developing from volcanic tuff, volcanic basaltic, andesite and volcanic ash parent materials.

Profile/ horizon	Depth (cm)	Mineralogical composition (%)																		
		Op	Qt	Lm	Wm	Rf	Vg	Og	An	Lb	Bw	An	Or	Sn	Mv	Hb	Au	Hp	En	Total
MA5 Profile developed from volcanic tuff																				
Ap	0-14	11	4	1	3	5	6	-	5	39	<1	-	-	-	-	6	4	16	-	100
Bw1	14-37	13	4	1	2	4	5	-	3	39	<1	<1	-	<1	-	4	7	18	-	100
Bw2	37-50	22	3	<1	5	5	3	1	3	39	<1	<1	<1	-	-	5	5	9	-	100
Bw3	50-70	22	32	<1	4	4	7	1	4	20	-	-	-	-	-	<1	2	3	-	100
MA7 Profile developed from volcanic basaltic andesite																				
Ap	0-12	25	-	-	<1	5	9	-	3	31	<1	-	-	-	-	2	16	9	-	100
Bw1	12-32	21	-	-	<1	7	7	-	2	35	1	-	-	<1	-	4	15	8	-	100
Bw2	32-65	21	-	<1	<1	8	12	-	2	34	<1	-	-	-	-	1	13	9	-	100
Bw3	65-101	15	-	-	<1	10	8	-	2	35	<1	<1	-	-	-	3	19	8	-	100
Bw4	101-110	19	-	-	-	8	11	-	2	36	<1	-	-	<1	-	2	16	6	-	100
BC	110-120	16	-	-	-	6	9	-	3	37	1	<1	-	<1	-	2	15	11	-	100
MA8 Profile developed from counter part of freshly sampled volcanic ash[1]																				
Ap	0-11	22	-	-	<1	7	7	-	1	37	2	<1	-	-	-	2	17	5	-	100
Bw1	11-25	20	-	-	-	8	10	-	<1	39	1	<1	-	-	-	1	15	6	-	100
Bw2	25-58	10	-	-	-	13	12	-	1	36	3	1	-	-	-	1	16	7	-	100
Bw3	58-75	13	-	<1	-	14	13	-	<1	35	2	<1	-	-	-	<1	17	6	-	100
Bw4	75-100	17	-	-	-	15	15	-	1	28	1	-	-	-	-	<1	20	3	-	100

- = not detected

[1]MA8 profile developed from previous volcanic material eruption, a counter part of freshly sampled volcanic ash.

Op = opaque, Qt = quartz, Lm = limonite, Wm = weathered mineral, Rf = rock fragment, Vg = volcanic glass, Og = oligoclase, An = andesine, Lb = labradorite, Bw = bytownite, An = anorthite, Or = orthoclase, Sn = sanidine, Mv = muscovite, Hb = hornblende, Au = augite, Hp = hypersthene, En = enstatite.

Table 3. Mineralogical composition of fine sand fractions (50-250 μm) in soils developing from basalt, serpentinite, mica schist and gabbro parent materials.

Profile/ horizon	Depth (cm)	Mineralogical composition (%)																		
		Op	Qt	Lm	Wm	Rf	Vg	Og	An	Lb	Bw	An	Or	Sn	Mv	Hb	Au	Hp	En	Total
MA1 Profile developed from basalt																				
Ap	0-19	10	64	<1	4	6	5	<1	1	6	<1	-	-	1	-	-	1	<1	-	100
Bo1	19-44	14	79	<1	5	1	<1	<1	<1	<1	-	-	-	1	-	-	-	<1	-	100
Bo2	44-81	15	81	<1	3	1	<1	<1	<1	<1	-	-	-	<1	-	-	<1	<1	-	100
Bo3	81-126	17	80	<1	1	2	<1	<1	-	<1	-	-	-	<1	-	-	-	<1	-	100
Bo4	126-170	21	71	1	5	1	<1	-	-	-	-	-	-	<1	-	<1	-	<1	-	100
MA3 Profile developed from serpentinite																				
A	0-18	62	13	<1	2	1	<1	-	-	-	-	-	-	<1	-	-	-	-	20	100
Bo1	18-48	63	13	<1	1	1	<1	-	-	-	-	-	-	-	-	-	<1	-	22	100
Bo2	48-87	53	12	<1	3	3	-	-	-	-	-	-	-	-	-	-	-	-	28	100
Bo3	87-100	54	8	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	32	100
MA4 Profile developed from mica schist																				
Ap	0-16	2	72	1	<1	24	-	-	-	-	-	-	-	-	<1	-	-	-	-	100
Bt1	16-45	2	59	3	-	34	-	-	-	-	-	-	-	-	2	-	-	-	-	100
Bt2	45-78	<1	67	2	-	31	-	-	-	-	-	-	-	-	<1	-	-	-	-	100
Bt3	78-91	<1	64	2	1	33	-	-	-	-	-	-	-	<1	<1	-	-	-	-	100
Bt4	91-98	<1	60	1	<1	39	-	-	-	-	-	-	-	-	<1	-	-	-	-	100
WR[1]	98-105	<1	22	1	29	19	-	-	-	-	-	-	-	-	29	-	-	-	-	-
MA6 Profile developed from gabbro																				
Ap	0-15	10	19	5	1	31	1	-	-	10	-	-	<1	<1	-	8	9	3	-	100
Bw1	15-33	-	23	7	1	68	-	-	-	-	-	-	-	<1	-	<1	-	-	-	100
Bw2	33-59	<1	60	6	1	33	-	-	-	<1	-	-	-	<1	-	-	<1	-	-	100
Bw3	59-98	<1	51	9	-	40	<1	-	-	-	-	-	-	<1	-	-	<1	-	-	100
BC	98-120	1	43	8	<1	45	-	-	-	-	-	-	<1	3	-	<1	-	-	-	100
C	120-150	<1	42	<1	<1	55	-	-	-	<1	-	-	1	<1	-	<1	-	-	-	100

- = not detected

[1] Weathered mica schist

Op = opaque, Qt = quartz, Lm = limonite, Wm = weathered mineral, Rf = rock fragment, Vg = volcanic glass, Og = oligoclase, An = andesine, Lb = labradorite, Bw = bytownite, An = anorthite, Or = orthoclase, Sn = sanidine, Mv = muscovite, Hb = hornblende, Au = augite, Hp = hypersthene, En = enstatite.

Group four is a soil dominated by quartz (mostly 60-72%) with trace amount of muscovite, occurring only in the soil developed from mica schist (MA4). The high quartz was due to the presence of quartzite as a vein in the mass of mica schist rock and was preserved and concentrated during the weathering of muscovite and biotite.

Mineralogical Composition of Clay Fractions

Clay mineral (secondary mineral) composition of soils developed from volcanic tuff, volcanic basaltic andesite, volcanic ash, basalt, serpentinite, mica schist and gabbro parent materials was divided into four groups, corresponding to groups of primary minerals as mentioned previously. Group one is clay mineral composition of soils (MA5, MA7 and MA8) dominated by primary minerals of feldspar and ferromagnesian. Soils of MA7 and MA8 have similar clay mineralogical composition but differ from the MA5 soil. The MA7 and MA8 soils respectively developed from volcanic basaltic andesite and volcanic ash, the clay fractions were dominated by short range order mineral (SROM) with trace amount of feldspar (labradorite). Since XRD peaks for all horizons of MA7 and MA8 soils were similar and were not clearly indentified by XRD (e.g. Fig. 1 shows no observable peaks at the left hand side of 22° 2θ), a selected horizon (Bw2 of MA7) was subjected to thermal analysis to represent other layers for further detail of mineral confirmation. The differential thermal analysis (DTA) showed only a broad endothermic peak between 50 and 300°C with the main peak at 122°C, confirming the presence of short range order mineral (see MA7 in Fig. 2). According to Harsh *et al.* (2002), DTA peaks of short range order mineral
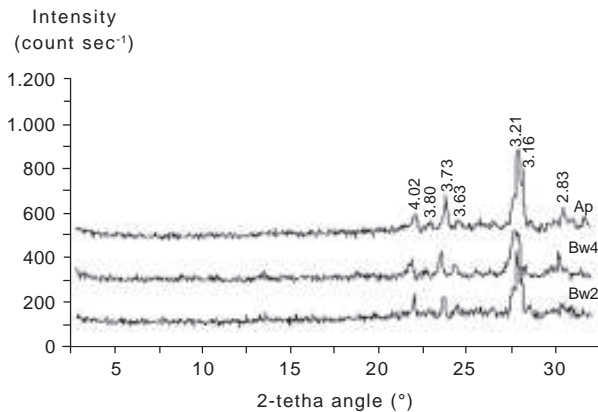
Fig. 1. X-ray diffraction patterns of soils developed from volcanic basaltic andesite (MA7). All peaks unit in Å.

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Fig. 2. Differential thermal analysis curves of the clay fractions of a selected horizon of MA3, MA5, MA6 and MA7 profiles.

(allophone and imogolite) exhibit large endothermic peak between 50 and 300°C resulting from removal of adsorbed water. This agrees well with the observation in this study. For the MA5 soil developed from volcanic tuff, the clay minerals were dominated by halloysite and smectite within the upper three layers (0-50 cm) and by halloysite and illite in the lowest layer (Table 4).

Group two is clay mineral composition of soils (MA1 and MA6) dominated by primary minerals of quartz with trace amounts of feldspar and ferromagnesian. The MA1 and MA6 soils had different clay mineral compositions. For the MA1 soil, the clay fraction was dominated by kaolinite accompanied by minor proportion of goethite and hematite (Table 4). The presence of only kaolinite, goethite and hematite minerals indicated highly weathered soils such as Oxisols (Charlet and Sposito 1987; Fontes *et al.* 1992; Melo *et al.* 2001; Anda *et al.* 2008a). According to pedological view, the MA1 soil has achieved an advanced weathering stage or infertile soil in respect to soil management. For the MA6 soil, the XRD results showed that the clay mineralogy was mainly haloysite. A selected horizon (Bw2) subjected to thermal analysis (DTA) indicated dehydration and dehydroxylation at 94 and 495°C endothermic peaks, confirming the presence of halloysite (see MA6 in Fig.2). These endothermic peaks were considerably lower than the common temperature for halloysite, indicating the less crystalline minerals.

Group three is clay mineral composition of the soil (MA3) dominated by primary minerals of opaque with
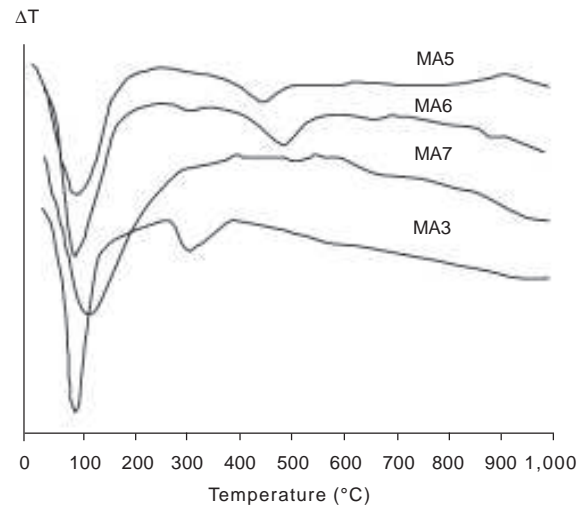
some enstatite. The soil clay fraction is mainly short range order mineral with trace amounts of goethite and hematite. DTA curves showed dehydration and dehydroxylation at 99 and 312°C endothermic peaks, confirming the presence of short range order mineral and goethite, respectively (MA3 in Fig.2). The 312°C endothermic peak was considerably lower than the common temperature for goethite dehydroxylation, indicating less crystallinity. This interpretation is further supported by considerable amount of short range order mineral extracted by NH_4-oxalate (1.35% Fe_o) (Table 6). According to Jackson *et al.* (1986), the differential endotherm of goethite varies from 300 to 350°C and that typically high crystalline occurred at 400°C. They also stated that the diagnostic properties of the hydrous oxides, as measured by thermal analysis, vary greatly depending on variation in particle size and degree of crystallinity. Anda *et al.* (2008a) observed differential endotherm of goethite for heavy clay Oxisols in Malaysia which varied between 343 and 368°C owing to differences in crystallinity (as revealed by XRD) and grain sizes (as shown by SEM), in which the lesser crystallinity and finer particle sizes, the lower dehydroxylation temperature. Similar results were reported by Singh and Gilkes (1992) for Australian soils.

Group four is clay mineral composition of the soil (MA4) dominated by primary minerals of quartz with trace muscovite. The clay fraction of this soil was dominated by kaolinite accompanied by moderate amounts of illite and vermiculite, and minor gibbsite minerals.

Table 4. Mineralogical composition of clay fractions of selected horizons of seven soils developing from diffrent materials.

Profile/ horizon	Depth (cm)	Mineralogical composition[1]									
		Ka	Ha	SROM	Sm	Il	Vm	Gb	Gt	Hm	Lb
MA1 Soil developed from basalt is classified into a Kandiudalfic Eutrudox[2]											
Ap	0-19	+++	-	-	-	-	-	-	+	+	-
Bo2	44-81	+++	-	-	-	-	-	-	+	+	-
Bo4	126-170	+++	-	-	-	-	-	-	+	+	-
MA3 Soil developed from serpentinite is classified into a Rodic Eutrudox											
A	0-18	-	-	+++	-	-	-	-	+	+	-
Bo2	48-87	-	-	+++	-	-	-	-	+	+	-
Bo4	87-100	-	-	+++	-	-	-	-	+	+	-
MA4 Soil developed from mica schist is classified into a Typic Hapludult											
Ap	0-16	+++	-	-	-	++	+	+	-	-	-
Bt2	45-78	++	-	-	-	++	++	+	-	-	-
Bt4	91-98	+++	-	-	-	++	++	+	-	-	-
MA5 Soil developed from volcanic tuff is classified into a Vitrandic Hapludol											
Ap	0-14	-	++	-	++	-	-	-	-	-	-
Bw2	37-50	-	++	-	++	-	-	-	-	-	-
Bw3	50-70	-	++	-	-	++	-	-	-	-	-
MA6 Soil developed from gabbro is classified into a Dystric Eutrudept											
Ap	0-15	-	++++	-	-	-	-	-	-	-	-
Bw2	33-59	-	++++	-	-	-	-	-	-	-	-
Bw4	98-120	-	++++	-	-	-	-	-	-	-	-
MA7 Soil developed from volcanic basaltic andesite is classified into a Vitric Hapludand											
Ap	0-12	-	-	++++	-	-	-	-	-	-	+
Bw2	32-65	-	-	++++	-	-	-	-	-	-	+
Bw4	101-110	-	-	++++	-	-	-	-	-	-	+
MA8 Soil developed from volcanic ash is classified into a Vitrandic Eutrudept											
Ap	0-11	-	-	++++	-	-	-	-	-	-	+
Bw2	25-58	-	-	++++	-	-	-	-	-	-	+
Bw4	75-100	-	-	++++	-	-	-	-	-	-	+

[1]Ka = kaolinite, Ha = meta-halloysite, SROM = short range order mineral, Sm = smectite, Il = illite, Vm = vermiculite, Gb = gibbsite,
 Gt = goethite, Hm = hematite, and Lb = labadorite

[2]Soils are classified according to Soil Taxonomy (Soil Survey Staff 2010).

++++ = predominant, +++ = dominant, ++ = moderate, + = minor, - = not detected

Chemical Properties of Seven Soils

Chemical properties of seven soils are divided into four groups, corresponding to primary and secondary mineral groups as aforementioned. The four groups include (1) soils dominated by feldspar and ferromagnesian minerals, (2) the soil dominated by opaques with some enstatite, (3) soils dominated by quartz with trace feldspar and ferromagnesian, and (4) the soil dominated by quartz with trace muscovite. Chemical properties of seven soils are shown in Tables 5 and 6.

Soils dominated by feldspar and ferromagnesian minerals

The soil group includes MA5, MA7 and MA8. Particle size of soils showed the magnitude of the sand fraction decreased in the order of MA8 > MA7> MA5 (Table 5). The sand content in the MA8 soil ranged from 75% to 86% and in the MA5 from 32% to 45%. The CEC and sum of cations were the highest in the MA5 followed by MA7 and MA8 soils, respectively. Sum of cations (Ca, Mg, K, Na) in the MA5 soil achieved 19-30 $cmol_c$ kg^{-1}. This high value is due to the presence of easily weatherable minerals (e.g. labradorite, andesine, volcanic glass, augite) to release cations and the higher CEC value attributed by high clay fractions with meta-halloysite and smectite minerals to retain released cations from primary minerals. The high CEC values correspond to the high effective cation exchange capacity (ECEC) and more negativity of ΔpH values (pH_{KCl}-pH_{H2O}). This indicates that the MA5 soil falls into the so called a permanent charge soil (the CEC value is not dependent on soil pH). Comparing the MA7 and MA8

Table 5. Particle size, pH, organic matter, cation saturation and CEC of seven soils developing from different parent materials.

Profile/ horizon	Particle size			pH			Ca	Mg	K	Na	Organic		CEC	Al	ECEC	ECEC/ CEC
	Sand	Silt	Clay	H_2O	KCl	ΔpH[1]					C	N				
	.... (%)						.... $(cmol_c \ kg^{-1})$				.... (%)		.... $(cmol_c \ kg^{-1})$			
MA1 Profile developed from basalt is classified into a Kandiudalfic Eutrudox[2]																
Ap	10	40	50	5.6	5.1	-0.5	8.14	3.41	0.25	0.20	2.62	0.19	16.8	nd	12.0	0.72
Bo1	5	23	72	5.2	4.9	-0.3	3.79	1.53	0.25	0.18	0.75	0.06	9.6	nd	5.8	0.60
Bo2	2	21	77	5.1	5.0	-0.1	3.48	1.92	0.17	0.18	0.44	0.04	8.7	nd	5.8	0.66
Bo3	2	21	77	4.9	4.7	-0.2	2.89	1.93	0.08	0.25	0.29	0.03	9.1	nd	5.2	0.57
Bo4	1	19	81	4.6	4.6	0	1.88	1.69	0.03	0.75	0.23	0.02	8.3	nd	4.4	0.72
MA 3 Profile developed from serpentinite is classified into a Rodic Eutrudox																
A	7	73	20	5.3	5.2	-0.1	0.55	4.19	0.08	2.40	1.85	0.15	11.6	nd	7.2	0.62
Bo1	8	76	16	5.5	5.4	-0.1	0.32	4.73	0.03	1.23	1.28	0.11	11.0	nd	6.3	0.57
Bo2	10	75	15	5.8	5.7	-0.1	0.32	4.05	0.04	1.19	0.86	0.07	11.2	nd	5.6	0.51
Bo3	10	75	15	5.9	5.9	0	0.32	4.79	0.03	0.68	0.91	0.07	10.1	nd	5.8	0.58
MA 4 Profile developed from mica schist is classified into a Typic Hapludult																
Ap	41	44	15	4.2	3.7	-0.5	0.32	0.69	0.16	0.92	1.05	0.09	7.9	3.6	5.7	0.72
Bt1	42	31	27	4.1	3.7	-0.4	0.27	0.76	0.14	1.04	0.47	0.04	8.7	5.3	7.5	0.87
Bt2	42	27	31	4.5	3.6	-0.9	0.23	0.46	0.19	0.22	0.22	0.02	10.6	6.5	7.6	0.71
Bt3	41	31	28	4.5	3.6	-0.9	0.27	0.33	0.19	0.15	0.27	0.02	11.6	6.9	7.9	0.68
Bt4	41	25	34	4.5	3.6	-0.9	0.09	0.31	0.19	0.22	0.20	0.02	9.4	7.4	8.2	0.87
C/R	19	52	29	4.5	3.7	-0.8	0.18	0.24	0.11	0.57	0.20	0.02	5.1	2.8	3.9	0.75
MA 5 Profile developed from volcanic tuff is classified into a Vitrandic Hapludol																
Ap	32	29	39	5.9	5.0	-0.9	15.30	7.83	1.14	0.41	1.64	0.13	27.2	nd	24.7	0.91
Bw1	30	27	43	6.1	5.1	-1.0	16.20	8.56	0.62	0.95	1.05	0.09	27.1	nd	26.3	0.97
Bw2	40	29	31	6.2	5.2	-1.0	18.00	9.56	0.59	1.27	0.59	0.05	31.6	nd	29.5	0.93
Bw3	45	28	27	6.1	5.1	-1.0	10.59	5.69	0.56	1.91	0.21	0.02	20.8	nd	18.8	0.90
MA 6 Profile developed from gabbro is classified into a Dystric Eutrudept																
Ap	5	39	56	4.8	4.2	-0.6	9.63	6.73	0.11	0.99	0.81	0.07	17.3	0.4	17.8	1.03
Bw1	5	48	47	5.0	4.1	-0.9	9.85	9.54	0.06	0.51	0.37	0.03	22.8	0.7	20.6	0.90
Bw2	22	42	36	5.2	4.0	-1.2	8.94	10.68	0.06	0.51	0.31	0.03	23.8	0.8	21.0	0.88
Bw3	16	45	39	4.9	4.0	-0.9	8.48	11.40	0.08	0.52	0.19	0.02	20.8	0.8	22.4	1.08
BC	15	50	35	4.9	3.9	-1.0	8.84	13.65	0.03	0.56	0.20	0.02	25.8	0.9	25.6	0.99
C	57	26	17	4.9	4.0	-0.9	7.75	11.67	0.06	0.76	0.14	0.01	23.8	0.8	21.1	0.89
MA 7 Profile developed from volcanic basaltic andesite is classified into a Vitric Hapludand																
Ap	60	31	9	5.2	5.0	-0.2	2.86	0.33	0.12	0.70	5.38	0.35	18.8	nd	4.0	0.21
Bw1	41	53	6	5.3	5.2	-0.1	2.48	0.34	0.09	0.68	5.00	0.33	19.6	nd	3.6	0.18
Bw2	56	35	9	5.4	5.2	-0.2	2.65	0.34	0.06	0.26	4.40	0.31	17.6	nd	3.3	0.19
Bw3	50	44	6	5.4	5.2	-0.2	3.15	0.58	0.12	0.42	4.34	0.38	18.6	nd	4.3	0.23
Bw4	44	48	8	5.4	5.2	-0.2	3.87	0.82	0.11	0.43	3.40	0.35	14.3	nd	5.7	0.40
BC	62	27	11	5.5	5.3	-0.2	3.39	0.59	0.09	0.46	3.09	0.23	19.0	nd	4.5	0.24
MA 8 Profile developed from a counter part of freshly sampled volcanic ash is classified into a Vitrandic Eutrudept[3]																
Ap	82	16	2	5.5	5.1	-0.4	2.54	0.14	0.08	0.40	1.51	0.13	4.9	nd	3.2	0.64
Bw1	86	13	1	5.6	5.3	-0.2	1.77	0.31	0.05	0.37	1.36	0.11	3.5	nd	2.5	0.71
Bw2	75	16	9	5.7	5.4	-0.3	1.99	0.22	0.05	0.57	0.72	0.05	2.2	nd	1.8	0.82
Bw3	78	15	7	5.7	5.4	-0.3	2.36	0.26	0.05	0.57	1.24	0.09	3.6	nd	3.2	0.89
Bw4	77	17	6	5.7	5.4	-0.3	2.92	0.55	0.08	1.72	1.47	0.11	5.3	nd	5.3	0.99

[1] $pH_{KCl} - pH_{H2O}$

[2] Soils are classified according to Soil Taxonomy (Soil Survey Staff 2010).

[3] MA8 profile developed from previous volcanic material eruption, a counter part of freshly sampled volcanic ash.

soils showed much higher CEC values in the former than the latter (14-20 $cmol_c \ kg^{-1}$ vs < 5 $cmol_c \ kg^{-1}$) due to the coarser texture of the MA8 soil. However, the CEC values were much higher than the ECEC values for the MA7 soil in addition to the less in negativity of pH values, suggesting the soil falls into the so called the variable charge soil (the CEC value increased with increasing soil pH).

Table 6. Total P, P retention, and selected extraction of Fe, Si, Al and Mn of seven soils developing from different parent materials.

Profile/ horizon	Depth (cm)	Total$_{HCl\ 25\%}$ P$_2$O$_5$ (mg 100 g^{-1})	K$_2$O	P reten- tion (%)	DCB Fe$_d$ (%)	Al$_d$	Mn$_d$	Fe$_o$:Fe$_d$ ratio	Ammonium oxalate Fe$_o$	Al$_o$	Si$_o$ (%)	Al$_o$+0.5Fe$_o$
MA1 Profile developed from basalt is classified into a Kandiudalfic Eutrudox[1]												
Ap	0-19	24	23	12.1	6.35	0.80	4.28	0.11	0.72	0.48	0.13	0.84
Bo1	19-44	15	13	14.7	6.44	0.79	2.39	0.12	0.78	0.36	0.12	0.75
Bo2	44-81	17	9	17.6	6.47	0.75	1.52	0.12	0.80	0.35	0.11	0.75
Bo3	81-126	23	4	19.4	6.55	0.71	1.29	0.14	0.90	0.36	0.12	0.80
Bo4	126-170	27	2	22.6	6.64	0.76	1.29	0.14	0.94	0.38	0.11	0.85
MA 3 Profile developed from serpentinite is classified into a Rodic Eutrudox												
A	0-18	2	6	24.9	7.13	0.49	5.09	0.17	1.22	0.23	0.12	0.84
Bo1	18-48	3	3	25.9	6.82	0.46	5.28	0.18	1.26	0.24	0.15	0.87
Bo2	48-87	2	3	28.1	6.78	0.43	5.62	0.20	1.35	0.24	0.19	0.91
Bo3	87-100	2	2	28.2	6.77	0.45	5.80	0.15	1.04	0.23	0.17	0.75
MA 4 Profile developed from mica schist is classified into a Typic Hapludult												
Ap	0-16	5	25	3.1	1.49	0.10	0.20	0.12	0.18	0.12	0.00	0.21
Bt1	16-45	4	26	4.1	1.84	0.17	0.22	0.10	0.19	0.14	0.00	0.23
Bt2	45-78	5	24	5.7	2.04	0.18	0.08	0.10	0.21	0.14	0.00	0.25
Bt3	78-91	6	21	6.7	2.48	0.21	0.11	0.08	0.21	0.14	0.00	0.24
Bt4	91-98	7	24	6.5	2.79	0.23	0.15	0.06	0.16	0.15	0.00	0.23
C/R	98-105	5	16	0.7	1.96	0.11	0.04	0.03	0.06	0.05	0.00	0.08
MA 5 Profile developed from volcanic tuff is classified into a Vitrandic Hapludol												
Ap	0-14	31	109	15.3	2.62	0.20	1.82	0.64	1.69	0.55	0.29	1.39
Bw1	14-37	25	63	16.7	2.79	0.15	1.73	0.66	1.84	0.50	0.30	1.41
Bw2	37-50	34	59	18.9	3.01	0.11	2.60	0.58	1.75	0.49	0.31	1.37
Bw3	50-70	36	55	10.9	3.14	0.28	2.61	0.41	1.29	0.34	0.24	0.99
MA 6 Profile developed from gabbro is classified into a Dystric Eutrudept												
Ap	0-15	15	6	19.0	5.75	0.74	1.15	0.12	0.69	0.44	0.08	0.79
Bw1	15-33	14	3	16.9	6.05	0.75	1.43	0.10	0.63	0.37	0.08	0.68
Bw2	33-59	8	3	15.9	4.90	0.57	1.30	0.10	0.51	0.36	0.08	0.61
Bw3	59-98	8	4	15.2	4.45	0.54	1.39	0.10	0.47	0.35	0.07	0.59
BC	98-120	9	2	17.9	4.82	0.62	1.66	0.11	0.54	0.42	0.08	0.69
C	120-150	31	3	15.3	5.57	0.72	1.44	0.09	0.53	0.39	0.09	0.65
MA 7 Profile developed from volcanic basaltic andesite is classified into a Vitric Hapludand												
Ap	0-12	114	6	70.0	2.06	1.55	0.59	0.80	1.66	4.39	1.28	5.22
Bw1	12-32	49	5	83.1	2.32	1.83	0.68	0.80	1.84	5.28	1.67	6.20
Bw2	32-65	48	3	77.1	2.01	1.46	0.58	0.77	1.55	4.37	1.46	5.15
Bw3	65-101	41	6	72.7	2.05	1.48	0.73	0.88	1.80	4.35	1.37	5.24
Bw4	101-110	88	7	70.8	1.96	1.27	0.76	0.73	1.44	3.95	1.54	4.67
BC	110-120	57	6	79.6	2.29	1.57	0.82	0.68	1.56	3.75	1.42	4.53
MA 8 Profile developed from a counter part of freshly sampled volcanic ash is classified into a Vitrandic Eutrudept[2]												
Ap	0-11	169	5	16.6	0.55	0.33	0.14	2.32	1.27	0.88	0.32	1.52
Bw1	11-25	152	4	11.1	0.52	0.29	0.11	2.70	1.41	0.79	0.31	1.50
Bw2	25-58	173	5	13.2	0.55	0.25	0.10	2.50	1.37	0.80	0.32	1.48
Bw3	58-75	151	4	19.0	0.52	0.36	0.20	1.86	0.97	0.98	0.43	1.46
Bw4	75-100	147	6	24.6	0.68	0.42	0.19	1.39	0.94	1.36	0.62	1.83

[1]Soils are classified according to Soil Taxonomy (Soil Survey Staff 2010).

[2]MA8 profile developed from previous volcanic material eruption, a counter part of freshly sampled volcanic ash.

The soil dominated by opaque with some enstatite

The group is represented by the MA3 soil. This soil contained low sand fractions ($\leq 10\%$), but its CEC values were low, except for the topsoil where the CEC value was considerably higher due to the higher organic matter (Table 5). This reflects that the CEC of the soils can be increased by applying organic matter. Values of ECEC (sum of cations plus Al) in the subsoil were about 6 cmol$_c$ kg^{-1}, which was considerably lower than the corresponding CEC values of

about 11 cmol$_c$ kg^{-1} (as determined by NH$_4$OAc at pH7).

Exchangeable cations of Ca, K and Na were low, while Mg was high (4-5 cmol$_c$ kg^{-1}) in the subsoil due to the presence of Mg-bearing minerals (serpentine and enstatite). The presence of enstatite mineral in considerable amount (20-32% in the sand fractions) is owing to (i) enstatite mineral was relatively and slowly weathered, leading to its selective preservation among other easily weathered minerals, and (ii) exchange sites were saturated with Mg (58-82% exchangeable Mg; Table 5) to maintain equilibrium with Mg-interface minerals retarding dissolution of Mg from mineral surfaces into the soil. Hence, enstatite was still remaining in considerable amount as Mg-reserved-bearing mineral.

Furthermore, the low in CEC values and cation summation satisfies the so called an oxic horizon of soil taxonomy (Soil Survey Staff 2010), indicating a highly weathered soil or infertile soil. Values of ΔpH were less in negativity even became zero at the lowest horizon, indicating limited amounts of negative charge as a characteristic of variable charge soils in addition to low CEC and ECEC values (Anda *et al.* 2008b). This variable charge soil was also indicated by the high Fe$_d$ content (~7%) (Table 6). Examination of mineralogical composition of sand fraction showed that easily weatherable minerals had been depleted from the soil as revealed by the only trace, if any, easily weatherable minerals (Table 3). On the other hand, the resistant mineral (opaque) left behind was high (53-63%), which contained no reserved nutrients. All these chemical properties indicate a severe soil chemical degradation.

Soils dominated by quartz with trace feldspar and ferromagnesian

The group includes MA1 and MA6 soils. Soil texture showed much high clay content in the MA1 (50-81%) than MA6 soils (35-56%). The CEC values in the topsoil were relatively similar for two soils and two times higher for the MA6 than MA1 in the subsoil. The magnitude of CEC values and sum of cations were only slightly different in the MA6, but were much high differences in the MA1 soil. Values of ΔpH were more negativity in the MA6 and were very small in the MA1 accompanied by high Fe$_d$ content. All these chemical properties showed variable charge for the MA1 soil and permanent charge for the MA6 soil. The two soils showed low content of short range order mineral (Fe$_o$, Al$_o$, and Fe$_o$), resulting in low P

retention. The pH of the two soils was acidic and relatively similar, except for the topsoil of the MA1 was slightly higher. Based on their chemical properties, the MA6 soil provides more favorable conditions for crop growth, while the MA1 experiences chemical degradation, resulting in many limiting factors for crop development.

The soil dominated by quartz with trace muscovite

The soil is represented by MA4 derived from mica schist. The soil had clay texture for the uppermost two horizons and clay loam for other subsurface horizons (Table 5). The CEC values were low (9-11 cmol$_c$ kg^{-1}) with very acid soil reaction (pH < 4.5) and extremely high exchangeable Al (63-90% Al saturation). All exchangeable cations and total P were very low. All these chemical properties showed the MA4 soil has also experienced severe chemical degradation. In addition, all weatherable minerals in the MA4 have been depleted from the soil, while the resistant mineral (quartz) was accumulated in high amount (59-72%) (Table 3). This soil has many limiting factors for crop growth and is comparable to MA1 and MA3 soils.

DISCUSSION

Seven soils studied showed variation in amounts of easily weatherable minerals and resistant minerals in their sand fractions. This indicates that some soils have high reserved nutrients, while others experience nutrient depletion. Similarly, the clay fractions have different mineralogical composition among the soils. Hence, some soils have high capacity to retain cations, while others have very limited, depending on type of clay mineral present. For a given soil, the information on high reserved sources of nutrients or depletion of potential nutrient sources in soils is only known from mineralogical analysis of sand fractions. This information and its association with soil chemical properties provide more integrated understanding in assessing and predicting soil limiting factors for plant growth and their anticipation to establish the strategic soil management for a longer period of time (sustainable production).

Sand fractions of MA7, MA8 and MA5 soils still contain appreciable amounts of feldspars, ferromagnesians and volcanic glass minerals suggesting that the three soils have sufficient reserve of potential

nutrient sources (Table 2). Hence, the three soils could have a good fertility in a long period of time owing to continuous supply of nutrients from easily weatherable minerals. In fact this is the case in which total P_2O_5, Ca, Mg and K contents are high in soils (Tables 5 and 6). For management practices, these soils need low rate of fertilizer or ameliorant since the application rate is only as a supplement to the content of initial nutrients in soils to obtain high yields. The only problem that should receive attention is the high short range order mineral in the MA7 soil, resulting in a high P fixation as shown by 70-83% P retention (Table 6). Therefore, P-fertilizer is needed at a high rate to satisfy crop requirement.

Interesting findings in this study are different P retentions of soils dominated by short range order mineral, and the presence of considerable amount of enstatite mineral and the high Cr and Ni heavy metals in a highly weathered soil (MA3). Three (MA7, MA8 and MA3) out of seven studied soils contained mainly short range order mineral in the clay fractions (Table 4). Hence, one may expect that three soils would have a high P fixation. However, only the MA7 soil showed a high P retention (70-83%), while the MA3 and MA8 soils had low P retention, viz., 25-28% and 11-25%, respectively (Table 6). The plausible explanation may be related to the size and magnitude of short range order mineral, initial soil P content, particle sizes of fine earth fraction, and soil pH. Comparison of sand fractions and initial P content among soils showed the order of decreasing magnitude of MA8 >> MA7>> MA3. On the other hand, the order of $Al_o+0.5 Fe_o$ (representing short range order mineral) content was MA7 >> MA8 > MA3. It seems that the high P retention in the MA7 is owing to the high short range order mineral composition (indicating by XRD, DTA and $Al_o+0.5Fe_o$ analyses) with small particle sizes and low pH value (< 5.4). The small particle size of the short range order mineral is revealed by very broad endothermic peaks of DTA (see MA7 vs MA3 in Fig. 2) leading to large surface areas with very reactive surfaces to adsorb P in the MA7 soil. The lower P retention in the MA8, although it has considerable short range order mineral composition (1.5-1.8% of $Al_o+0.5Fe_o$), was attributed to the coarse texture (75-86% sand) resulting in smaller surface areas compared to MA3 (containing 7-10% sand).

The initial total P_2O_5 content of the MA8 was already high, which may also account for its lowest P retention compared to MA3 and MA7 soils (Table 6). Although the MA7 contained higher sand fraction compared to the MA3 soil (41-60% vs 7-10%), the P

retention was lower in the MA3 due to the coarser size of short range order mineral as shown by sharp endothermic peaks of DTA (MA3 in Fig. 2) and lower content of short range order mineral (0.8-0.9% of $Al_o+0.5Fe_o$). This implies the three soils need different management practices in respect to P fertilizer. In other words, the MA7 soil needs a higher P fertilizer rate followed by MA3 and MA8 soils, respectively. This different P fixation is only detected and taken into account in establishing soil management practices if the mineralogical composition of the soils is available. Organic matter application may help to form complexes with Al and Fe metals, which in turn reducing P fixation and becomes available for crops.

From mineralogical perspective, the major problems in MA1, MA3, and MA4 soils are the dominance of resistant minerals to weathering, i.e. quartz for MA1 and MA4 soils, and opaque for the MA3. In contrast, easily weatherable minerals (feldspars and ferromagnesians) have been depleted, except for appreciable amount of enstatite in the MA3 soil. This evidence suggested the total depletion of potential nutrient sources in MA1 and MA4 soils. Since the chemical properties of the three soils are variable charge, viz., low content of cations and the ability of soils to retain cations depends solely on pH values (increased ability with increasing pH values), the agricultural practices in those soils are mainly relied on technology intervention to alleviate various soil limiting factors (including low in CEC, various cations, N, and P) for crops. These limiting factors have a crucial implication on soil management by applying ameliorants (e.g., lime, finely ground basalt, organic matter) and fertilizers to restore the CEC, exchangeable cations, N, and P. In addition, the ameliorant was needed to suppress the high Al content in the MA4 soil. Gillman *et al.* (2002) showed that finely ground basalt is potential ameliorant to be used to increase exchangeable cations, pH and CEC of highly weathered Australian soils. Similarly, Anda *et al.* (2009) reported that finely ground basalt was able to suppress Al and Mn to a non-toxic level, in addition to increase exchangeable cations for highly weathered Malaysian soils.

Potential risk of heavy metals for human health was observed in the soil derived from serpentinite (MA3). The XRD analysis of soil sand fraction showed peaks at 14.54, 7.21, 4.78 and 2.42 Å, indicating the presence of kämmererite [$(MgCr)_3 (CrSi_3O_{10}) (OH)_2 (Mg_3(OH)_6$], and that 7.26, 3.60, and 2.42 Å peaks indicating garnierite [$(Ni,Mg)_3)Si_2O_5) (OH)_4$] (Fig. 3). The presence of kämmererite and garnierite minerals in serpentinite potentially release Ni and Cr heavy
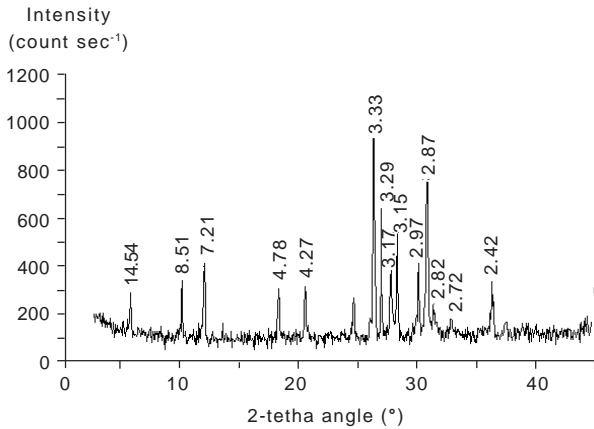
Intensity
(count sec⁻¹)

Fig. 3. X-ray daffraction patterns of the sand fractions of the selected horizon of the MA3 profile developed from serpentine rocks. All peaks unit in Å.

metals, which may result in plant toxicity and human health risk. This potential heavy metal risk would not have been identified without mineralogical analysis. Soils with heavy metals need a specific use and management to avoid heavy metal risk. In the previous paper, it has been shown that the soil derived from serpentinite contained high Cr and Ni heavy metals and that Cr has exceeded the maximum threshold limit (> 600 mg kg⁻¹) (Anda 2012). The Cr^{6+} was highly mobile, while Cr^{3+} was less mobile (McGrath 1995) and that Cr^{6+} was more toxic than Cr^{3+} to plants (Bartlett and James 1979). The solubility of Cr^{3+} form decreases at above pH 4 and is completely precipitated at above pH 5.5 (McGrath 1995). The $Ni(OH)^{1+}$ and Ni^{2+} are the major forms in the soil solution at over pH 8, while in acid condition is Ni^{2+}, $NiSO^{0}$, and $NiHCO_3^{+}$ (McGrath 1995). The Ni is readily absorbed by plants as reflected by the high concentration of Ni in plant corresponding to the high concentration in soils (McGrath 1995). A strategic management for this soil is the soil should not be used for food crops to avoid Cr and Ni heavy metal risk for health. Instead the soil could be used for non-edible crops (e.g. rubber, ornamental or pulp crops).

The integral considerations of soil mineralogical constituents and chemical properties showed that the soils developed from volcanic tuff (MA5) with high in easily weatherable minerals, various cations, CEC and slightly acid (pH ~ 6.0) have no considerable limiting factors that reduce yield of many crops. In soil management practice, only low input is needed to obtain an optimal yield of a given crop.

Composition of primary minerals in soils provides invaluable information on the reservation or depletion of potential nutrient supply for a long period of time

and that clay mineral composition dictates the capacity of the soil to retain various cations released from easily weatherable minerals and to control various soil chemical properties. Hence, soil secondary mineralogy (clay minerals) plays a key role in providing information on soil CEC, being high for 2:1 minerals and low for 1:1 and oxi-hydroxide minerals.

Since weatherable minerals disappeared in MA1, MA3 and MA4 soils, the strategy for soil management in a longer period of time is solely and continuously remained relying on the input application to alleviate various soil limiting factors for a given crop. The high cost is needed for soil ameliorant and fertilizers to create favorable conditions for crop growth. On the other hand, the MA5, MA7 and MA8 soils contained considerable amount of easily weatherable minerals, as reserved nutrients and may be released to replenish nutrient loss or removed by plants. This implies low cost is needed to obtain desired yields.

CONCLUSION

The dominance of resistant minerals (primary minerals) accompanied by trace amounts of weatherable minerals in the soils derived from basalt, serpentine, mica schist and gabbro indicated very limited nutrients released from parent materials into the soils. In contrast, the dominance of easily weatherable minerals (feldspars and ferromagnesians) in soils derived from volcanic tuff, basaltic andesite and volcanic ash indicated the availability of highly reserved nutrients for a longer period of time.

Clay mineral compositions of seven soils derived from different parent materials were different. It was mainly kaolinite for the soil derived from basalt, halloysite for the soil from gabbro, short range order mineral with goethite and hematite for the soil from serpentinite, meta-halloysite and smectite for the soil from volcanic tuff, short range order mineral for soils from volcanic basaltic andesite and volcanic ash, and kaolinite followed by vermiculite or illite for the soil from mica schist. The difference in clay mineral compositions among soils resulted in the difference in soil chemical properties.

Soils derived from basalt, serpentine, and mica schist were low in exchangeable cations, CEC and pH. High exchangeable Al for the soil derived from mica schist, reflecting a severe chemical degradation. This agrees well with the depletion of easily weatherable minerals in soils, suggesting that these three soils have severe natural limiting factors that reduce crop

growth. Therefore, soil management should be established to restore exchangeable cations, CEC and pH, and to decrease exchangeable Al.

Soils derived from volcanic ash and basaltic andesite both contained high easily weatherable minerals but had low exchangeable cations and pH. However, soil from basaltic andesite had much higher P retention (70-83%) due to the higher short range order mineral. This implies that these two soils need different management practices, i.e. the soil from basaltic andesite needs a higher P fertilizer rate than that from volcanic ash.

The soils deriving from basalt, serpentine, and mica schist are mainly rely on external input of nutrients since only little nutrient is potentially released from parent materials. Restoration of chemical properties using ameliorants, organic matter and fertilizer is necessary. Soil derived from serpentine needed a specific strategic management since it contains heavy metal-bearing minerals that release Cr and Ni. The soil is wisely used for non-edible crops to avoid Cr and Ni health risk. For other soils since they have sufficient easily weatherable minerals to release nutrients naturally, the management is directed as maintenance to replenish nutrients removed by crops.

ACKNOWLEGEMENTS

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