ABSTRACT

The mineralogy and chemical properties of volcanic ash soils from West Sumatra, Indonesia were studied. The soils under study contain high amounts of organic carbon, a slightly acid to acid pH and low available phosphorus contents although the total phosphorus is high. The low bulk density, the high phosphate retention and more than 2 % of Al + 1/2Fe extracted by ammonium oxalate meet andic soil properties criteria. The clay fraction is composed mainly of allophane, cristobalite, feldspars and halloysite. Gibbsite is only present in the clay fraction of the soils from Mt. Talamau, while opal-A is only found in the clay of the soils from Mt. Marapi.

INTRODUCTION

The Indonesian archipelago is one of the most active volcanic areas in the world. There are many volcanoes and volcanic ash soils widely distributed in this country. These soils have considerable economic importance for subsistence agriculture and cash cropping.

The morphological, physical and chemical properties of the volcanic ash soils are closely related to the nature and behavior of the clay minerals. Poorly ordered clay minerals are common components of the clay-size fraction of volcanic soils. These poorly ordered materials may consist of allophane, imogolite and ferrihydrite on the one hand, or Al/Fe-humus complexes and opaline silica on the other. Allophanes are some of the most reactive components in the volcanic ash soil. Because of their high surface area and reactivity, they strongly retain phosphate and organic matter (Wada, 1980; Farmer et al., 1991; Shoji et al., 1993; Takahashi et al., 1993).
Soils formed from volcanic ash are widespread in the central and northern highlands of West Sumatra. Despite large areas in this region which are affected by volcanic activity, soil data crucial for management strategies are still very scarce or unavailable. The main objective of this study was to determine the mineralogical composition and chemical properties of soils derived from volcanic materials in the vicinity of Mt. Marapi and Mt. Talamau in the West Sumatra province, Indonesia.

MATERIALS AND METHODS

Description of sites and soils

All the soil profiles used in this study were formed from volcanic materials. Two soil profiles are located on the south slope of Mt. Marapi at the altitude of 1000 and 800 m above sea level (a.s.l.) in the Batipuh District, Regency of Tanah Datar. The other two profiles are located on the north slope of Mt. Talamau at the altitude of 325 and 175 m a.s.l. in the Pasaman District, Regency of Pasaman.

Analytical methods

Soil pH (H$_2$O) was measured in a 1:2.5 (soil: suspension) ratio. Total organic carbon content of the soil samples was determined by Walkley-Black method. Available phosphorus was determined by using Bray 1 method. Phosphate retention was determined using the method of Blakemore et al. (1987). CEC was determined with 1 M NH$_4$OAc pH 7 solution, while CEC$_p$ and CEC$_v$ were determined by using BaCl$_2$–TEA method (Tan, 1996). CEC compulsive and AEC were determined by using Gillman and Sumpter (1986) method.

Selective dissolution of non-crystalline and short-range-order materials were performed as follows: (1) acid ammonium oxalate, (2) DCB (dithionite-citrate-bicarbonate), and (3) sodium pyrophosphate (Blakemore et al., 1987).

The clay-size fraction (less than 2 μm) was isolated from field-moist samples by using Na-resin method (Bartoli et al., 1988 and 1991) and dispersion by sonication treatment for 5 minutes. Mineralogical analyses were carried out by XRD. The XRD analysis was performed on oriented clays before and after ammonium oxalate extraction.

RESULTS AND DISCUSSION

Chemical properties

Selected chemical data for the soils are presented in Table 1. The carbon contents are quite high in the upper horizons with values increasing with increase elevation in both volcanoes. Available phosphorus contents are quite low as compared to total P. Phosphate retention is very high (> 95 %) and bulk density is low (< 0.8 Mgm$^{-3}$) in both toposequences; these satisfy the requirements for andic properties. Lower P retention values were observed with decreasing altitude. The high P retention capacity is related to large specific surface areas of these soils (Wada, 1980; Sanyal and Datta, 1991). CEC ranges from 22 to 28 cmol (+) kg$^{-1}$ soil in the soils of Mt. Marapi and from 19 to 30 cmol
(+) kg\(^{-1}\) soil on those of Mt. Talamau. The pH\(_o\) values of the topsoils are lower than those of the subsoils, attributed to higher amount of organic matter in the topsoils.

**Selective dissolution methods**

DCB solution extracted more Fe than acid ammonium oxalate or Na-pyrophosphate (Table 2). The Fe\(_o\)/Fe\(_d\) ratios of the surface horizons of soils from Mt. Talamau are lower compared to those of the Mt. Marapi, indicating that iron oxides in soils from Mt. Talamau are of higher crystallinity. The higher crystallinity and the larger amounts of Fe\(_d\) indicate that soils from Mt. Talamau are more weathered than soils from Mt. Marapi. This is in agreement with Mizota and Van Reeuwijk (1989) who believed that the Fe\(_o\)/Fe\(_d\) ratio can be used as an index for the crystallinity or 'age' of iron oxides. Values for young volcanic ash soils are > 0.75, whereas the older soils have values < 0.75.

The soils from Mt. Marapi show lower Al\(_p\)/Al\(_o\) ratios than the soils from Mt. Talamau (Table 2). This indicates that the soils from Mt. Talamau are more weathered than the soils from Mt. Marapi. The ratio of Al\(_p\) over Al\(_o\) also gives some indications about the occurrence of allophane and imogolite. A lower ratio (close to zero) indicates the presence of allophane and imogolite (Mizota and Van Reeuwijk, 1989). The allophane content is lower in the topsoil than in the subsoil (Table 2). The lower content of allophane in the topsoil is probably due to the higher content of organic matter in the A horizon than the underlying B and C horizons. The allophane content of soils from Mt. Talamau is lower than that of Mt. Marapi. Moisture content also plays an important role in the formation of allophane. Low amounts of annual precipitation that reduce the loss of Si from the soils favor the formation of allophane and imogolite rather than ferrihydrite and/or gibbsite (Parfitt et al., 1988).

**Mineralogical Properties of Clay fraction**

Andisols from Mt. Talamau have more clay content than Andisols from Mt. Marapi (Table 2). Figures 1a and 1b show the XRD patterns of the untreated clay of the soil profiles I and IV. The clay fraction of soil at Mt. Marapi is largely amorphous to X-rays (diffused spectrum) as compared to that of Mt. Talamau which is largely crystalline. The mineralogical composition of the clay fraction of the two soils does not change with depth. The soils are characterized by the presence of cristobalite (0.405 nm), feldspars (0.377, 0.321, 0.315 nm) and halloysite (1.01, 0.405 nm). Opaline silica, which gives a diffuse, broad X-ray spectrum centers at about 0.41 nm, is only observed in profile I from Mt. Marapi. This finding is in agreement with the results obtained by Diakite (1992) who found opaline silica accumulating in the surface horizons of Andisols from Mexico. High amounts of opaline silica are also reported present in the Andisols of Japan. A review of literature shows that opaline silica is found more abundantly in younger volcanic ash soils (< 500 years) than in older ones (4000-7000 years), also in humus-rich A horizon than in underlying B and C-horizons. Therefore, opaline silica is a product of the early stages of weathering of volcanic ash.

Gibbsite (0.485 nm) is detected in the clay fraction of the soils at Mt. Talamau, but absent in the soils from Mt. Marapi. Formation of gibbsite in the clay fraction of Mt. Talamau soil is presumably due to high precipitation. Under high precipitation, Si and basic
ations are leached out of the profiles, leaving aluminium behind to precipitate as aluminium oxide (Parfitt et al., 1988). Weathering of Al-silicates directly to gibbsite or through a 1:1 layer is governed by the intensity of leaching which, in turn, is affected by rainfall, temperature, topography, ground water table and time (Hsu, 1989).

Disappearance of the 0.715 and 0.357-nm reflection peaks after heating at 550°C is indicative of the occurrence of 1:1 layer minerals in the samples. This phenomenon occurred in all the samples. The 1:1 layer silicate is found to be halloysite. The presence of halloysite in the samples is confirmed by the strong reflection at 0.445 nm and the collapse of the 1.01 nm reflection to 0.72 nm after heating at 350°C (Dixon, 1989). The intensity of the halloysite XRD reflections increases with decreasing altitude of the soil profiles and also with increasing soil depth. This suggests that silica is subjected to leaching from the upper topographic areas and accumulates in the lower zones. This is supported by the study of Mizota and Chapelle (1988) who found that high amounts of halloysite accumulated in the lower parts of volcanic ash soils in Rwanda. Silicon with its intermediate solubility can partly be leached out and precipitate in the lower subsoils (Van Ranst, 1995).

Interstratified 1:1-2:1 phyllosilicates are observed in the fine and medium clay fraction of the surface horizons (Figure 1c). The presence of shoulder at the low angle side of 0.715 nm after heating at 350°C and 550°C and the shift of this peak towards the low angle side after glycolation indicates the presence of interstratified 1:1-2:1 layers and swelling properties. Dehydroxylation of the interstratified 1:1 layers gives a broad diffraction band between 0.99-1.4 nm (Herbillon et al., 1981). This result is in agreement with the study of Wada et al. (1987) and Delvaux et al. (1990). Wada et al. (1987) named this mineral as ‘embryonic halloysite’, but Parfitt et al. (1988) disagreed and call it as ‘a mixed layer of kaolinite/smectite’ instead.

CONCLUSION

The soils under study are rich in organic carbon, have high P-retention, low in BD and have low to medium CEC values, which may influence their management practices. Soils are characterized by high amounts of amorphous materials. Allophane content is lower in the topsoil than in the subsoil. Soils of Mt. Talamau are more weathered than those of Mt. Marapi.

The clay fraction of all the soils is composed mainly of halloysite, cristobalite and feldspars. Gibbsite is only present in the clay of the soils at Mt. Talamau, while opaline silica is only present in the clay of Mt. Marapi soils. Interstratified 1/1-2/1 phyllosilicates are identified in the chemically treated clay fraction.

Acknowledgement

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REFERENCES


Keywords : andisols, allophane, P fixation, mineralogy
Mots clés : andisols, allophane, fixation au phosphore, minéralogie
Table 2. Dissolution analyses and allophane content of the soils studied

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Acid Oxalate</th>
<th>Pyrophosphate</th>
<th>DCB</th>
<th>Feₐ - Feₚ, Feₚ - Feₐ</th>
<th>Feₚ / Feₙ, Alₘ / Alₚ (Alₘ - Alₚ) / Si₀</th>
<th>Allophane*</th>
<th>Allophane**</th>
<th>Alₘ + 1/2 Feₚ</th>
</tr>
</thead>
<tbody>
<tr>
<td>P I Mt. Marapi</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>3.60</td>
<td>1.54</td>
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<td>0.46</td>
<td>0.28</td>
<td>1.41</td>
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<td>1.04</td>
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<td>1.60</td>
<td>1.34</td>
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<td>0.14</td>
<td>1.41</td>
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<tr>
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<td>1.39</td>
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<td>0.20</td>
<td>2.26</td>
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<tr>
<td>B</td>
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<td>2.43</td>
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* Allophane = (100 /y) * % Si₀;  
** Allophane = % Si₀ * 7.1  (Parfitt and Henmi, 1982)