Variability of soil mineralogical composition in Sentra Bareh Solok paddy field as affected by eruption material from Mt. Talang

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Abstract. Mt. Talang is one of the active volcanoes in West Sumatra with the last eruption occurred in 2017. The Sentra Bareh Solok paddy field distributed from volcanic middle slope to Singkarak Lacustrine Plain. The composition of sand mineral fraction of nine representative of soil profiles has been analysed using polarization microscope with line counting method. Results show that mineralogical composition are the same, but the amount are different. At the volcanic middle slope, opaque is dominant. It is probably due to thermal formation associated with the melting of existing iron oxides attributed by lava flow. Labradorite and hypersthene are dominant in Alluvial Plain and it could indicate rather slow weathering processes. While, the soils at Lacustrine Plain were dominated by volcanic glass and labradorite and it could be due to silica saturation; more cations and higher pH of soil solution hindering dissolution of minerals. The K-bearing minerals were absent in all soils, indicating K would be the problem as revealed by low K content and its trend decreased from middle slope to the lacustrine. The implication is soils in the Lacustrine Plain and Alluvial Plain would need more K fertilizers than soils in the middle slope.

1. Introduction

Minerals are the main constituent element of soil and play an important role in determining soil properties, including indicators of nutrient reserves, soil load, and the environment in which they are formed [1]. Mt. Talang is one of the active volcanoes in West Sumatra. Kriswati et al. [2] reported that the volcanic activity of Mt. Talang has a relatively long eruption period with the shortest interval of 2 years and the longest to 40 years. Mt. Talang has an altitude of 2,597 m above sea level which is located in the Solok Regency area. Historical records reported a large magmatic eruption has occurred since 1833, and was last reported in 2007. In the eruption of 12 April 2005, Fiantis et al. [3] reported that the mineral composition of the erupted ash was dominated by labradorite (35 to 42%) and volcanic glass (25 to 29%) with SiO₂ content reached 57.61%.

From the middle slope of Mt. Talang to the lacustrine plains of Lake Singkarak distributed the rice fields producing Bareh Solok known as Sentra Bareh Solok (figure 1). This rice field is the major rice production to provide food for the people in West Sumatra, even for people outside West Sumatra, such as Riau and Jambi. Based on the geological map [4], paddy soils on volcanic slopes develops from weathering products of volcanic andesite, while paddy soils in alluvial plains and lacustrine plains develop from clay, sand, and gravel deposits.
The results of spatial identification showed Sentra Bareh Solok’s rice fields mostly occurred on volcanic areas 14,751 ha (79.49%) followed by alluvial plains around 2,770 ha (4.93%) and lacustrine plains about 1,035 ha (5.58%) [5]. The average rice mill production increased from 3.37 t ha⁻¹ in the lacustrine plain to 4.36 t ha⁻¹ alluvial plain and to 4.49 t ha⁻¹ in volcanic slope [5]. According to Allen and Hajek [1] the differences in rice production could be attributed to the differences in the mineral constituents of soil parent materials. The weathering of primary minerals released the plant nutrients and resulted clay minerals that governed the soil colloidal surface charge, where wetland soil which is dominated by clay minerals bearing more negative charge is more reactive than paddy soils dominated by positive charges [6]. This study aims to identify the mineralogical composition of paddy soils of Sentra Bareh Solok occurring on the middle volcanic slopes, alluvial plains and lacustrine plains, and their implications on soil nutrient management in increasing productivity of paddy fields.

2. Materials and methods

Nine representative soil profiles were made, consisting of three profiles on the middle volcanic slope (PV1, PV2, and PV3), three profiles on the alluvial plain (PA1, PA2 and PA3) and three profiles on the lacustrine plain (PL1, PL2, and PL3). The PV1, PV2 and PV3 profiles represented soils in the upper, middle and lower volcanic slopes, respectively. Three soil profiles on the alluvial plain were made sequentially along the Batang Sumani River, while the three soil profiles on the lacustrine were made in the sequence to Singkarak Lake (see figure 1).

![Figure 1. Location of the study area and sampled profiles on the middle slope, alluvial and lacustrine landforms.](image)

A total of 38 soil samples from the nine representative profiles were analyzed for the mineralogical compositions of the sand fraction at the Mineralogical Laboratory of Indonesian Center for Agricultural Land Resource Research and Development using a Polarization Microscope with the line counting method. Mineralogical composition of soil clay fraction was determined using X-Ray Diffractometer (XRD). The samples were treated with MgCl₂, MgCl₂ and Glycerol, KCl, and KCl plus heating at 550°C. Type of each clay mineral within the samples was determined from the XRD peaks of clay diffraction.
3. Results and discussion

3.1. Mineralogical composition of the sand fraction

The rice fields of Sentra Bareh Solok developed from different parent materials, but type of their mineral composition of the sand fraction was the same, consisting of volcanic glass, plagioclase feldspar (labradorite), amphibole (hornblende) ferromagnesian and pyroxene (augite and hypersthene), opaque and a little quartz. However, the number of each type of minerals was different (table 1). The mineral composition indicated that the paddy soil developed from andesitic volcanic materials.

| Location                      | Depth (cm) | Average mineral composition (%) |
|-------------------------------|------------|---------------------------------|
| Volcanic middle slope (PV1)   | 0-21       | Op 32 Qu 7 Mw 10 Vg 17 La 4 Sa 1 Ho 1 Au 5 Hy 17 |
|                               | 21-35      | Op 41 Qu 7 Mw 14 Vg 10 La 3 Sa 1 Ho 4 Au 14 |
|                               | 35-39      | Op 31 Qu 8 Mw 14 Vg 14 La 1 Sa 7 Ho 2 Au 13 |
|                               | 39-43      | Op 45 Qu 7 Mw 11 Vg 10 La 1 Sa 1 Ho 5 Au 12 |
|                               | 43-74      | Op 43 Qu 6 Mw 14 Vg 15 Sa 1 Ho 3 Sp 4 |
|                               | 74-100     | Op 53 Qu 8 Mw 9 Vg Sp 14 Sa 1 Ho 4 Au 1 Sp 3 |
| Alluvial Plain (PA3):         | 0-15       | Op 12 Qu 1 Mw 5 Vg 28 Sp 42 |
|                               | 15-35      | Op 15 Qu 1 Mw 4 Vg 33 Sp 37 |
|                               | 35-50      | Op 20 Qu 1 Mw 27 Vg 42 - - 2 14 |
|                               | 50-72      | Op 10 Qu Sp 28 Vg 9 Sa 30 Sp 1 13 |
|                               | 72-90      | Op 11 Qu Sp 26 Vg 9 Ho 23 Sp 5 16 |
| Lacustrine Plain (PD3):       | 0-15       | Op 6 Qu 10 Mw 6 Vg 23 Sa 25 Ho 1 Sp 2 12 |
|                               | 15-40      | Op 6 Qu 8 Mw 13 Vg 30 Sa 21 Sp 2 1 11 |
|                               | 40-70      | Op 5 Qu 6 Mw 36 Vg 20 Sa 14 Sp 2 Sp 4 |
|                               | 70-100     | Op 3 Qu Sp 47 Vg 16 Sa 14 Sp 2 4 |
|                               | 100-120    | Op 2 Qu 1 Mw 41 Vg 19 Sa 21 Sp 2 1 2 |

Note: Op = Opaque, Qu = Quartz, Mw = weathered mineral, Vg = Volcanic glass, La = Labradorite, Sa = Sanidine, Ho = Hornblende, Au = Augite, Hy = Hypersthene, sp = < 1%.

At the volcanic middle slope, the opaque is dominant and its content continues to decrease with increasing distance to the alluvial and lacustrine plains (figure 2A). Labradorite and hypersthene are dominant in the Alluvial Plain (figure 2B). Labradorite content ranged from 23 to 33%, and hypersthene from 13 to 42%. While the soils at Lacustrine Plain were dominated by the volcanic glass (16 to 30%) and labradorite (14 to 25%). The K-bearing minerals were few in all soils of any landform.

Figure 2. Distribution of minerals in sand fraction of paddy field in Bareh Solok: (A) opaque and hypersthene, and (B) volcanic glass and labradorite.
3.2. Mineralogical composition of clay fraction

X-Ray Diffractogram of paddy soils on the middle volcanic slopes (PV1 and PV2) indicates the presence of halloysite hydrate and metahalloysite minerals (figure 3). The top layer of the PV1 profile (PV1-1) contained halloysite hydrate (moderate proportion) minerals as indicated by XRD peaks at 10.07Å and 4.46Å with Mg treatment. Metahalloysite (moderate proportion) was shown by XRD peaks at 7.46Å and 3.62Å with the Mg treatment. Gibbsite in minor proportion was shown by a peak at 4.86Å and the presence of cristobalite was shown by a peak at 4.06Å.

The top layer of the PV2 profile (PV2-1) showed similar mineralogical composition to PV1. The clay mineral composition consisted of halloysite hydrate (10.14Å and 4.44Å). Metahalloysite (moderate) is shown by XRD peaks at 7.36Å and 3.56Å. XRD peak of gibbsite (a small proportion) occurred at 4.83Å, while cristobalite (a small proportion) at 4.03Å, and goethite (a very small proportion) at 4.18Å.

![Figure 3](image-url)

**Figure 3.** The clay mineral composition of the top layer of paddy soils on the middle volcanic slopes: (A) PV1 profile, and (B) profile PV2.

The mineralogical composition of clay fraction in paddy soils on alluvial plains is shown in Figure 4. It appeared that halloysite dominated PA1 profile, followed by cristobalite in small amounts. In contrast, the PA2 profile was dominated by smectite followed by metahalloysite and halloysite hydrates, respectively in a small amount each. The PA3 profile showed moderate amounts of smectite and metahalloysite, and small amounts of halloysite hydrates. In all soils, a small amount of feldspar (labradorite) is found in the clay fraction.

Profiles in the alluvial plain have different clay mineral compositions, although the composition and amount of minerals in sand fraction are relatively the same (table 1). This difference is thought to be due to differences in profile positions on the alluvial plains. The PA1 and PA3 profiles are in a slightly convex shape slope, where the PA1 profile is closer to the river (figure 1). The PA2 profile is between the PA1 and PA3 profile in more concave slope of the landform.

![Figure 4](image-url)

**Figure 4.** The clay mineral composition of the topsoil in the alluvial plain: (A) PA1 profile, (B) PA2 profile, and (C) PA3 profile.
The top layer of PA1 profile (PA1-1) was dominated by metahalloysite as shown by diffraction peaks at 7.16 Å, 4.45 Å, and 3.58 Å (figure 4A). Feldspar (slight proportion) was shown by peaks at 4.04 Å and 3.20 Å. The top layer of profile PA2 (PA2-1) was dominated by smectites as shown by the diffraction peaks at 15.50 Å in the Mg treatment, 18.03 Å in the Mg + glycerol treatment, 12.71 Å in the K treatment, and 10.07 Å in the K + 550 treatment (Fig 4B). Metahalloysite (moderate proportion) was shown by peaks at 7.26 Å, 4.42 Å, and 3.55 Å in the Mg treatment. Feldspar (4.04 Å and 3.20 Å) occurred in small amounts. The top layer of PA3 profile (PA3-1) consisted of smectite and metahalloysite with feldspar in small amount (figure 4C).

The profiles in the lacustrine plain (Figure 5) have similar clay mineral composition. Smectite is dominant followed by kaolinite. In the clay fraction, there is a small amount of feldspar (labradorite) mineral.

![Figure 5. The clay mineral composition of the top soils in the lacustrine plain: (A) profile PL1, and (B) PL2 profile.](image)

Sentra Bareh Solok developed from parent materials consisting of clay, sand, and gravel deposits for alluvial plains and lacustrine plains, and volcanic weathered andesite for volcanic slopes [4]. Although the soils derived from different parent materials, the mineral type composition of sand is the same, namely volcanic glass, plagioclase feldspar (labradorite), amphibole (hornblende) and pyroxene (augite and hypersthene), opaque and a small quartz. This mineral composition indicates that the paddy soil developed from basaltic andesite volcanic materials. However, the number or proportion of mineral type is different between landforms (table 1). The eruption of Mt. Talang on April 12, 2005, reported by Fiantis et al. [3] showed the primary mineral composition in the eruption was dominated by labradorite (35 to 42%) and volcanic glass (25 to 29%), while total SiO₂ content reached 57.61%.

Based on their position in the landscape (figure 1), the alluvial plain is the first depositional area, while the lacustrine plain is the next (last) deposition area. The deposition of volcanic material on the alluvial plains is influenced by the activity of the Sumani river with the upper stream started from Mt. Talang and the lower stream in Singkarak lake. The volcanic materials transported by Sumani river were deposited in the alluvial plain and Singkarak lake. Later, some parts of the lake were exposed and become the lacustrine when the water level of the lake decreased. The large exposed plain formation was called the lacustrine plain [7]. Due to the soil parent materials in different landforms derived from the similar eruption (materials spewing by Mt. Talang), the primary mineral types (sand fraction) of paddy soils in the alluvial and lacustrine plains may have the same sand mineral composition as the paddy soils on the middle slopes of Mt. Talang. However, it is well shown that the number of weatherable minerals was different between landforms.

At the volcanic middle slope, opaque is dominant and its content decreases with increasing distance to the depositional area (figure 2A). It is probably due to thermal formation associated with the melting of existing iron oxides attributed by lava flow. On the middle slope, the clay mineral formation are
mainly halloysite (halloysite hydrate and metahalloysite). This indicated the weathering of volcanic glass and feldspar minerals under high rainfall and paddy field conditions resulted the halloysite mineral as the weathering products.

Clay minerals are the result of chemical weathering of primary minerals or the result of new formation (neoformation) in the soil [1]. Eswaran [8], Delvaux et al. [9] and Wada [10] suggest that weathering of volcanic materials in the tropics produces allophane, halloysite, smectite, kaolinite, goethite, and gibbsite. Among the clay minerals, allophane and halloysite are the dominant clay fractions. Furthermore, halloysite is formed from the weathering of allophane.

The clay mineral halloysite found on the middle volcanic slopes is thought to have been formed from the weathering of allophane. This estimate is based on the results of semi-detailed soil mapping at a scale of 1: 50,000 [11] which mostly found Andosols on the upper slopes of Mt. Talang formed as a result of a relatively recent eruption. Furthermore, halloysite would weather to form kaolinite, as stated by McIntosh [12], Singleton [13], and van Wambeke [14] that halloysite is the initial form of weathering system with high activity silica solution before finally being transformed into a more stable form.

Labradorite and hypersthene are dominant in the Alluvial Plain (figure 2B). Labradorite content ranged from 23 to 33%, and hypersthene from 13 to 42%. These high levels of easily weathered minerals indicate that the soils developed from young volcanic materials. The soils at Lacustrine Plain were dominated by the volcanic glass (16 to 30%) and labradorite (14 to 25%) which is associated with slow weathering processes of volcanic glass and labradorite minerals. This is explained by environmental conditions associated to silica saturation, high cations and higher pH of soil solution hindering the dissolution of minerals. The clay minerals found in alluvial plains are smectite, halloysite, and kaolinite. These minerals are found in varying amounts between profiles, whereas in the lacustrine plains, similar amounts of smectite and kaolinite are found between profiles.

The comparison of soil profiles in alluvial plains and lacustrine plains showed smectites are mostly found in the lacustrine plains. According to Borchardt [6], the presence of smectite in the soil occurs in three ways. First, formation from solution; second, through mica transformation; third, through material smectite deposition. The formation of smectite from soil solution is the main source of smectite in the soils. In the present study, the presence of smectites in soils of the alluvial and lacustrine plains is considered to be mainly formed from solutions. The high soil pH and cations like Ca and Mg were the suitable conditions for neoformation of smectite in this study.

Weathering of minerals on volcanic slopes in well-drained environments releases alkaline cations into the soil solution which are then leached and accumulated in the alluvial plain with poor drainage conditions. The accumulation of alkaline cations, especially Ca$^{2+}$ and Mg$^{2+}$, at high pH and Si-rich environments forms smectites [6]. At these high pH conditions, according to Dixon [15], kaolinite and halloysite formation are unlikely, because kaolinite and halloysite are the results of weathering in an acidic environment [16]. This indicates that the presence of kaolinite and halloysite in alluvial and lacustrine plains is the result of translocation from volcanic slopes. Another alternative of smectite formation on the lacustrine plane was probably formed by the depotassication process of mica. This is unlikely occur in this study since there is no biotite and muscovite minerals as the precursor of illite in the sand fraction of all soils.

In Table 1, it can be seen that the K-bearing minerals were absent in all soils, and its trend decreased from the middle slope to the lacustrine. This condition shows that the availability of K is a major problem in the lowland soils of Sentra Bareh Solok. In the lacustrine and alluvial plains, the problem of K availability is further exacerbated by the presence of high Ca$^{2+}$ and Mg$^{2+}$ accumulating in these areas. The Ca/K and Mg/K ratios in the lacustrine plains are greater than the alluvial plains and the middle volcanic slopes, as a result, the need for K fertilizer for lowland soils in the lacustrine plains is greater than the alluvial plains and the middle volcanic slopes.

4. Conclusions
The rice fields of Sentra Bareh Solok developed from the basaltic andesite volcanic material of Mt. Talang. The mineral composition of soil sand fraction in different landforms is the same mineral types
but they are different in proportion between landforms. The mineral compositions are volcanic glass, plagioclase feldspar (labradorite), amphibole (hornblende) and pyroxene (augite and hypersthene), opaque and a little quartz. The mineral composition of clay fraction is mainly halloysite for soils in middle volcanic slope; halloysite, kaolinite and smectites for soils in the Alluvial plain; and smectite and kaolinite for soils in the lacustrine. Based on the mineral composition, the soils formed are still relatively young, however, K-rich mineral content is detected very little or almost none. This is a problem for the availability of K, especially in plain areas. The problem is exacerbated by the presence of high Ca$^{2+}$ and Mg$^{2+}$ accumulation in the area. The Ca/K and Mg/K ratios are greater in the lacustrine plains than in the alluvial plains and the middle volcanic slopes, as a result, the need for K fertilizer for lowland soils in the lacustrine plains is higher than the alluvial plains and the middle volcanic slopes.

Acknowledgments
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