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INFLUENCE OF VOLCANO ERUPTION TO WEATHERABLE MINERALS AND CHEMICAL PROPERTIES OF RED SOILS IN SOUTH SUMATRA, INDONESIA

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ABSTRACT: The red soils spread over South Sumatra are generally derived from the materials of the late Tertiary Period, are more than 1 million years old, and have fully developed and ultimately weathered. Thus, these soils commonly have weatherable minerals and chemical properties with low values. The eruption of Mount Krakatau, more than a hundred years ago, brought about the spreading of fresh volcanic materials particularly to the surface horizons of the soils. Therefore, it is expected that the weatherable minerals and chemical properties of the soils in South Sumatra will increase. The aim of this research is to study the weatherable minerals and some chemical properties of the red soils distributed in the southern part of Sumatra Island due to their exposure to the Krakatau eruption of 1883. The results show that all the soils have colors of 10YR to 10R; and thus, they can be classified as red soils. The eruption of Mount Krakatau has significantly increased the percentage of weatherable minerals and the CEC of the clay in the surface horizons of the soils in the southern part of Sumatra Island.

Keywords: Krakatau eruption, red soil, weatherable mineral, volcanic eruption, CEC of clay

1. INTRODUCTION

Red soils occupy the greater part of Indonesia [1]. The term ‘red soil’ in Indonesia is used to describe soils that have hues of 10YR to 5YR, with values and chroma ranging from 2 to 8 [2]. These soils are distributed from lowlands to highlands, from undulating to mountainous topography, from humid to semi-arid climates, and from felsic to mafic rocks [1]. The red color of the soils is a reflection of the results of the Fe/Al oxidation process. The more intensive the Fe/Al oxidation, the redder the soil color will be. This process is usually followed by a decline in the other chemical properties of the soils, because the soils have developed and ultimately weathered [3]. Therefore, the red color of a soil could be associated with both its physical and chemical properties.

The color of a soil is generally related to the type or the origin of the rock materials, particularly the composition of the primary minerals and the stage of the soil development. Among the soil color dimensions, the hue is the dominant spectrum that can show soil weathering, the soil chemical properties, and the drainage rate. The specific mineralogical properties and nutrient contents in primary minerals actually have an important role in soil management, but fertilizers are uniformly applied to almost all soils in practical farming [4]. High air temperature and heavy rainfall throughout the year promote weathering and pedogenesis at a high rate. The physical breakdown and chemical weathering of minerals are always intense under tropical climates regardless of the nature of the parent materials [5]. As a result, soils in humid tropical regions develop and weather more quickly; this is indicated by the rapid decline in the amounts of minerals that can be weathered. With the same age of parent materials, soils in humid tropical regions are more weathered and degrade more rapidly than soils in other regions. Anda et al. [4] reported that easily weathered minerals rapidly release their elemental constituents into the soil during the weathering processes, and that intermediary volcanic materials have a higher Cation Exchangeable Capacity (CEC) of soil and sum of exchangeable bases than acid volcanic materials. The CEC of a soil is one of the most important parameters determining the soil fertility [6]. According to Wilding et al. [7], the CEC value of clay from weathered soil, such as Oxisol, is usually low (<16 cmol kg^{-1}) so that the CEC of the soil is very dependent on the organic matter as a source of the negative charge.

Generally, the red soils in South Sumatra are derived from materials with an age of more than one million years (Late Tersiary Period); therefore, the soils usually have developed and ultimately weathered. As a result, the soils commonly have weatherable minerals with low values or natural fertility and chemical properties with low values.

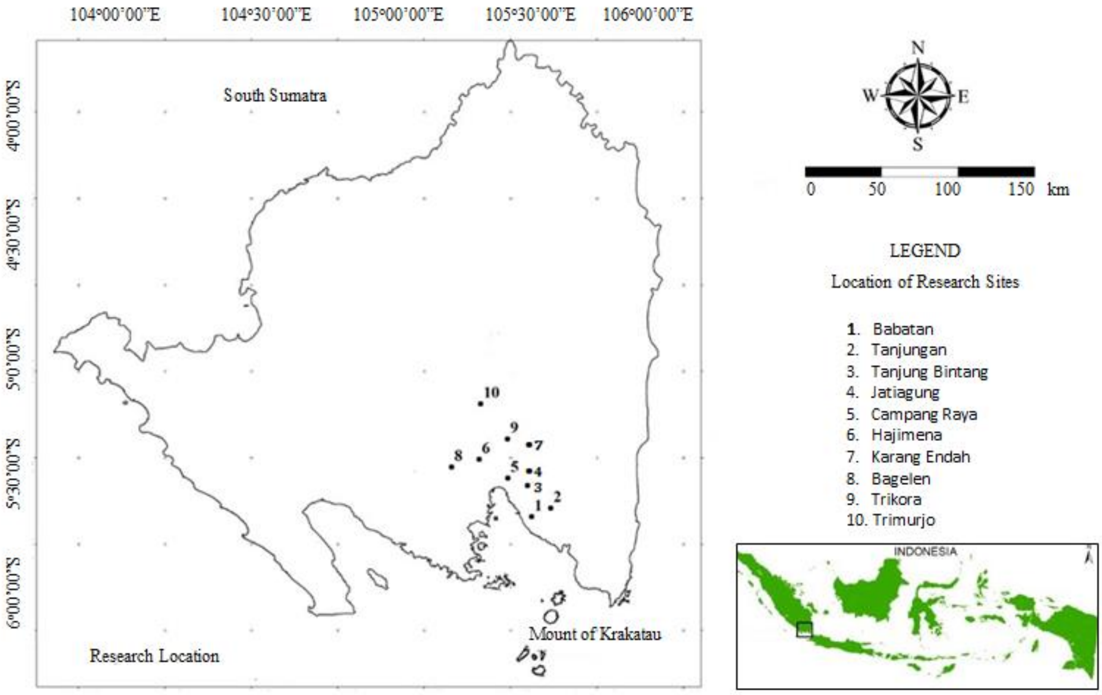

Fig.1 Locations of research sites

Table 1 Geographical characteristics of the research locations

Research location	Abbreviation	Distance from Krakatau (km)	Elevation asl (m)	Parent rocks*	Age*
Babatan	BB	63.6	179	Granite	Cretaceous
Tanjungan	TJ	66.2	107	Granite	Cretaceous
Tanjung Bintang	TB	78.5	47	Quartzite, Schist	Permian
Jatiagung	JA	81.8	72	Acid tuffs	Pleistocene
Campang Raya	CR	85.6	142	Acid tuffs	Pleistocene
Hajimena	HM	87.4	112	Andesite	Holocene
Karang Endah	KE	89.7	105	Acid tuffs	Pleistocene
Bagelen	BG	91.5	150	Andesite	Holocene
Trikora	TK	95.2	62	Acid tuffs	Pleistocene
Trimurjo	TM	107.0	67	Acid tuffs	Pleistocene

*Mangga et al. [8]

The volcanic ash dispersed from the Krakatau eruption was distributed to the west of the Krakatau volcano [9] to Sumatra Island. The eruption of Krakatau (or Krakatoa) in 1883 spread fresh volcanic material above the soil surface; therefore, the weatherable minerals and chemical properties of the soils in South Sumatra are expected to be greater.

The spectacular eruption of the Krakatau volcano in August 1883 had profound global effects [10].

According to van Bemmelen [11], the eruption of Mount Krakatau in 1883 was enormous. It caused the death of 36,417 people and the ejection of about 18 - 21 km^3 of pumice and volcanic ash. The ejected material spread over vast areas [9,11]. Massive and poorly stratified units were formed predominantly from the pyroclastic flows and surged out over the sea for a distance of up to 80 km. The area affected by the flows was at least $4×10^3$ km^2 and the area of dispersal was estimated at $8 × 10^3$ km^2 [12].

Table 2 Composition of weatherable minerals in the research areas

Research location	The amount of Weatherable minerals (%)															
	Soil horizon	Volcanic glass	Albite	Oligoclase	Andesine	Labradorite	Bitownite	Orthoclase	Sanidine	Muscovite	Green Hornblende	Brown Hornblende	Augite	Hypersthene	Enstatite	Weatherable mineral
BB	A	3	1	sp	0	3	sp	sp	14	sp	0	0	1	2	sp	24
	B	0	sp	0	0	0	0	1	4	sp	0	0	0	0	0	5
TJ	A	1	0	0	4	0	0	0	0	0	0	0	0	1	0	6
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TB	A	0	0	0	0	0	0	sp	0	0	0	0	0	2	0	2
	B	0	0	0	0	0	0	sp	0	0	0	0	0	0	0	sp
JA	A	sp	0	0	0	sp	0	0	sp	0	0	0	sp	sp	0	sp
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR	A	sp	sp	sp	sp	0	0	sp	0	0	0	0	sp	sp	0	sp
	B	sp	sp	sp	sp	0	0	sp	0	0	sp	0	0	sp	0	sp
HM	A	6	0	4	0	0	0	0	0	0	0	0	sp	3	0	13
	B	0	0	4	0	0	0	sp	0	0	0	0	0	sp	0	4
KE	A	5	0	0	sp	5	sp	0	2	0	0	0	1	1	0	14
	B	0	0	sp	0	0	0	0	3	0	0	0	0	0	0	3
BG	A	2	0	sp	sp	4	0	0	1	0	2	2	sp	sp	0	11
	B	sp	0	sp	0	1	0	0	2	0	2	1	0	sp	0	6
TK	A	1	0	0	0	3	0	0	sp	0	0	0	sp	sp	0	4
	B	sp	0	0	0	0	0	0	1	sp	0	0	0	0	sp	1
TM	A	1	0	0	0	2	0	0	sp	0	0	0	1	1	0	5
	B	0	0	0	0	0	0	0	0	0	0	0	0	sp	0	sp

sp=sporadic, amount of minerals is less than 1% (minerals could not be counted by the line counting method)

Although the Krakatau eruption of 1883 was very spectacular, most of the previous studies related to this eruption have been limited to only the islands near this mountain, such as Sertung Island, Rakata Island, and Anak Rakata Island [13-15]. To the author's best knowledge, no research has ever been done on the impact of the eruption of Krakatau on the weatherable minerals and their impact on the chemical properties of the soils in the southern region of Sumatra to a radius of a hundred km from the center of the eruption. Therefore, this study was conducted.

The aim of this research was to study the influences of the Krakatau eruption on the weatherable minerals and some chemical properties of the red soils in South Sumatra.

2. MATERIALS AND METHODS

2.1 Research Sites

This study was conducted in the southern part of Sumatra Island. The research locations were selected by purposeful sampling based on the various parent rocks and distances from Mount Krakatau (Fig. 1 and Table 1). All of the research locations were being used by farmers as mixed gardens (mixed trees at small scale plantation) or had been left as natural vegetation where several kinds of trees were growing without tillage management. One exception was Bagelen whose soil had been used in highland rice fields, not in low areas or swamps. The topography of all the soils was almost the same and gently sloped with a gradient of 0 to 3%.

2.2 Soil Sampling and Method

A pit was dug at each sampling site to obtain a soil profile. Soil samples were taken from the surface horizon (A-horizon) and the subsurface horizon (B-horizon). The soils were sampled in the center of each horizon and described according to the requirements of Soil Taxonomy [16].

2.3 Soil Analysis

The chemical properties of the soils were determined according to Soil Survey Staff [17]. The CEC and exchangeable bases (Ca^+, Mg^+, K^+, and Na^+) were extracted using 1N Ammonium Acetate (buffered at pH 7.0) and then measured by Atomic Absorption Spectrophotometry. The mineralogical compositions of the sand fractions,

Table 3 Composition of non-opaque heavy minerals in the research areas

Research location	The amount of non-opaque heavy minerals (%)														
	Soil horizon	Zircon	Monazite	Fe concretion	Limonite	Green Hornblende	Brown Hornblende	Augite	Hypersthene	Staurolite	Andalusite	Epidote	Kyanite	Rutile & Anatase	Turmaline
BB	A	1	2	1	48	0	0	12	0	0	sp	2	0	1	0
	B	2	5	3	64	1	0	sp	0	0	sp	3	0	sp	0
TJ	A	21	0	0	0	0	0	30	45	0	0	4	0	0	0
	B	95	0	0	0	0	0	1	2	0	0	2	0	0	0
TB	A	12	0	0	0	0	0	20	52	0	sp	0	0	0	6
	B	3	0	0	0	0	0	0	0	0	0	0	0	0	0
JA	A	25	12	0	1	0	0	23	32	0	1	0	sp	4	3
	B	64	19	0	1	0	0	0	sp	1	5	0	sp	6	5
CR	A	0	0	0	0	1	0	19	51	0	0	0	0	0	0
	B	sp	0	0	0	0	0	0	0	0	0	0	0	0	0
HM	A	1	0	0	0	0	0	26	58	0	0	0	0	0	0
	B	4	0	0	0	sp	0	sp	2	0	0	0	0	0	0
KE	A	24	2	0	0	0	0	0	0	0	1	0	sp	0	1
	B	87	6	0	1	0	0	0	0	sp	1	0	0	0	1
BG	A	19	0	sp	0	30	27	11	13	0	0	0	0	0	0
	B	28	0	sp	0	33	37	0	2	0	0	0	0	0	0
TK	A	30	8	sp	0	sp	0	28	31	0	2	0	sp	1	sp
	B	75	14	sp	2	0	0	0	sp	0	5	0	1	1	2
TM	A	18	1	0	0	sp	0	30	50	0	sp	0	0	sp	1
	B	85	6	0	0	0	0	1	sp	0	2	0	0	0	6

sp=sporadic, amount of minerals is less than 1% (minerals could not be counted by the line counting method)

Table 4 Differences in the soil properties between A and B horizons

Soil property	Mean		Standard deviation		P-value	Difference
	A	B	A	B		
Weatherable mineral in the sand fraction	7.9	1.9	7.59	2.38	0.028	s
Weatherable mineral in the heavy fraction	58.9	6.9	29.50	19.40	0.000	s
Zircon in the heavy fraction	15.1	44.3	11.00	40.50	0.041	s

A and B are soil horizons, s: significant (P-value<0.05), ns: not significant (P-value>0.05)

from 50 to 250 μm, were determined using a polarizing microscope and the line counting method.

3. RESULTS AND DISCUSSION

3.1 Weatherable and Heavy Minerals

The results of the mineralogical analysis are shown in Table 2 (weatherable minerals) and Table 3 (heavy minerals). It is clear from Table 2 that almost all of the soils in the research areas still have volcanic glass in their A-horizons, while the soils in the B-horizons have mostly weathered. Volcanic glass is the amorphous mineral (uncrystallized mineral) produced by very rapidly cooling magma; thus, it is also very easily weathered. Therefore, volcanic glass is usually found in young soils at high altitudes, forming from volcanic ash, such as Andisol. Keller [18] and Birkeland [3] stated that volcanic glass was highly susceptible to weathering due to its low energy bonding. Intrusive or plutonic rocks, metamorphic rocks, and old sedimentary rocks basically do not contain volcanic glass. Therefore, the presence of volcanic glass in the upper layers of the soils formed from these rocks can be ascertained as having originated from volcanic eruptions. For soils that were derived from rock materials at any given time, the weathering processes of the minerals will start from the top layer and then proceed to the layers beneath it. Thus, the presence of volcanic glass in the soil surface horizon, but not in the layers below it, shows that the soils have acquired the addition of new volcanic materials. As shown in Table 2, almost all of the samples have weatherable minerals in the surface horizon (A-horizon) that are higher than those in the subsurface horizon (B-horizon). The average of the weatherable minerals in the A-horizon is 7.9%, while that in the B-horizon is 1.9%. A statistical analysis using the T-Test shows that the percentage of weatherable minerals in the A-horizon is significantly larger than that in the B-horizon (Table 4). The higher content of weatherable minerals in the soil surface horizon indicates that new or fresh volcanic materials have been added from a recent eruption near the research areas. Fresh volcanic material must have been added from the eruption of Mount Krakatau in 1883, because the addition of volcanic material to the study site from any eruption other than that of Mount Krakatau in 1883 is impossible. The addition of fresh volcanic material from the eruption of Mount Krakatau in 1883 as pyroclastic material and volcanic ash reached the Ketimbang area [19], now called Katibung, near Babatan and Tanjungan, Lampung Province, the southern part of Sumatra Island.

The composition of non-opaque heavy minerals in the surface horizon of the soils in the research areas, dominated by Hypersthene and Augite (Table 3), indicates that the materials came from intermediary volcanic materials. Escher [20] and Hardjowigeno [15] also reported finding the same materials around the areas where the Krakatau volcano had erupted. The domination of the zircon mineral in the subsurface horizons of the five research areas (Tanjungan, Jatiagung, Trikora, Karang Endah, and Trimurjo) shows that the soils are derived from felsic materials (granite and acid tuffs), the original rock of this area. According to Mange and Wright [21], zircon is found in granitic rocks and acid volcanic rocks.

In the surface horizons, the domination of zircon, hypersthene, and augite in the non-opaque heavy fractions indicates that there has been a mixing of the intermediary volcanic ash from the Krakatau eruption and the soil in the area which had been previously formed from acid materials. Zircon is a mineral that is resistant to weathering; therefore, its position will tend to remain in each layer of the soil. The difference in the average number of zircons between the A and B horizons that are significant (Table 4) shows that the two horizons have different types of parent materials. The lesser amount of zircon and the greater number of weathered minerals in the surface horizon shows that horizon A is not entirely derived from additional new material, because intermediate volcanic rocks have almost no zircon minerals. Zircon minerals can be ascertained from acid rock that formed soils in the study area.

3.2 Soil Color

Soil morphology is the result of soil formation processes and soil development; therefore, the soil morphology can reflect or indicate how far or to what level the soils have developed. The soil color shows the soil morphology; it is strongly associated with the types of parent materials, certain pedogenesis processes, and how advanced the level of development is. For soils with the same soil-forming factors, except age, the older the parent material, the redder the soil color and the more developed the soil is [3].

Soil colors in the research areas have hue values from 10 YR to 10 R and chroma values from 2 to 8, except for the surface horizon of the Bagelen soil which has a chroma value of 1 after being used as rice paddy soil for 40 years. Thus, all the soils in the research areas could be classified as red soils (Table 5). Based on the development of the soil color, particularly in the B-horizon (subsurface horizon), the soil in the Trimurjo area could be determined as the youngest soil because it has a hue color of 10 YR, while the soil in the Trikora area has a hue color of 10 R, and therefore, could be determined as the oldest

Table 5 Soil color in the research areas

Profile location	Soil color			
	A-horizon		B-horizon	
BB	7.5 YR 4/2	brown to dark brown	5 YR 5/6	yellowish red
TJ	7.5 YR 3/4	dark brown	2.5 YR 5/8	red
TB	5 YR 3/2	dark reddish brown	2.5 YR 3/6	dark red
JA	10 YR 3/2	very dark grayish brown	7.5 YR 4/6	strong brown
CR	5 YR 3/3	dark reddish brown	2.5 YR 4/6	red
HM	7.5 YR 3/2	dark brown	5 YR 4/4	reddish brown
KE	7.5 YR 3/2	dark brown	5 YR 4/6	yellowish red
BG	5 YR 4/1	dark gray	7.5 YR 3/4	dark brown
TK	7.5 YR 3/4	dark brown	10 R 4/6	red
TM	10 YR 4/2	dark grayish brown	10 YR 5/4	yellowish brown

Table 6 Chemical properties of the soils in the research areas

Profile location	Sum of Ech. bases (cmol kg^{-1})		Clay CEC (cmol kg^{-1})		Soil CEC (cmol kg^{-1})		Base saturation (%)	
	A	B	A	B	A	B	A	B
BB	9.3	5.1	37.1	30.9	11.7	8.5	79.5	59.8
TJ	9.8	3.8	92.9	41.5	14.8	14.5	66.5	26.5
TB	3.9	1.7	59.2	13.4	5.6	4.5	69.5	37.7
JA	4.6	3.6	54.4	24.6	8.7	6.4	53.2	55.8
CR	6.1	4.7	86.2	31.5	14.5	14.1	41.7	33.2
HM	8.4	8.0	23.9	13.0	13.9	10.5	60.1	76.3
KE	6.3	7.5	35.0	15.2	9.7	9.2	65.1	81.4
BG	12.1	8.6	47.7	27.0	18.4	17.0	66.1	50.8
TK	3.4	2.7	38.0	9.5	9.9	5.1	34.6	51.9
TM	2.0	1.4	12.3	6.8	8.1	5.5	24.2	24.6

A and B are soil horizons

Table 7 Differences in the soil chemical properties between A and B horizon

Soil property	Mean		Standard deviation		P-value	Difference
	A	B	A	B		
CEC of clay	48.70	21.30	25.60	11.40	0.006	s
CEC of soil	11.50	9.50	3.80	4.40	0.297	ns
Exchangeable bases	6.59	4.71	3.24	2.60	0.169	ns
Base saturation	56.00	49.80	17.40	19.60	0.460	ns

A and B are soil horizons, s: significant (P-value<0.05), ns: not significant (P-value>0.05)

soil.

The soil color, particularly of the soil in the subsurface horizon, indicates the degree of soil weathering because it is not mixed with the new volcanic materials from Mount Krakatau. The subsurface horizons of the soils in Tanjung Bintang, Campang Raya, and Tanjungan all have a soil color with the same hue, whereas the three areas have different types of parent materials and different ages (Table 1). Although the soil in Campang Raya is the youngest, when compared with the other two soils, the amount of sesquioxides (Fe_2O_3 and Al_2O_3), as a result of the oxidation processes, could be almost the same, because the parent materials have a higher amount of iron than the parent materials of the other two soils. The soil in Campang Raya is derived from Tertiary volcanic materials and contains minerals ranging from intermediary to basaltic rocks (Tables 2 and 3).

Another issue that has also arisen is the difference in hue color among the subsoils in the Jatiagung, Trikora, Karang Endah, and Trimurjo areas, even though the parent materials of the soils in these four areas come from the same Geological Formation. Differences in landform, topography, and rock diversity can lead to differences in the rates of the oxidation processes of iron and aluminum. The reddest soil color was found in the soil profile of the Trikora area, reaching a hue value of 10 R, followed by that of the Karang Endah area, reaching a hue value of 5 YR, then that of the Jatiagung area, reaching a hue value of 7.5 YR, and finally that of the Trimurjo area, reaching a hue value of 10 YR.

3.3 Natural Fertility of Soils in the Research Areas

Soil fertility, according to FAO [22], refers to the ability of a soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth. Generally, the ability of a soil to supply plant nutrients refers to the ability of the clay minerals in the soil to release cations (nutrients). Natural fertility is the term used to discuss the amount of primary minerals that could be easily weathered and refers to the ability of a soil to provide plant growth thoroughly. Weatherable minerals are the primary minerals (sand fractions) that could be weathered. The percentage of weatherable minerals indicates the real natural fertility of soils; therefore, the value is used in the Soil Taxonomy (USDA) system to characterize the oxic horizon, that is, the most weathered subsoil horizon [16].

The composition of the primary minerals (sand fractions) plays a key role in controlling the reserved nutrients in soils, while that of the secondary minerals (clay fractions) determines the capability of the soil to retain various cations and anions released from the weathering primary minerals. However, the primary and secondary minerals of soils normally receive very little attention, while the chemical and physical properties receive a great deal.

This could be due to the problems of expensive analyses and the availability of instruments, which are beyond the reach of many laboratories. Consequently, the interpretation of soil properties has not been supported by the amount of data required to predict the potential availability of various reserved elements that affect soil fertility [23]. Understanding the effect of the mineralogical composition of a soil on its chemical properties is crucial to soil management practices. From a pedological viewpoint, it is well known that parent materials containing various easily weathered minerals with high amounts of reserved potential nutrients produce more fertile soils [23].

All the soils in the research areas have weatherable minerals in the B-horizon of less than 10% (Table 2). Therefore, those soils have the oxic property according to Soil Taxonomy [16]. The presence of the oxic property in the B-horizon shows the development of soil that has reached the final stage or very old soil resulting from intensive weathering processes from the past and continuing until the amount of weatherable minerals is close to zero (<10%). Among these soils, the amount of weatherable minerals in the B-horizons of the soils in Tanjungan, Tanjung Bintang, Campang Raya, Jatiagung, and Trimurjo is less than the others. Therefore, the soils in those areas are seen to be more developed than the soils in Babatan, Trikora, Karang Endah, Hajimena, and Bagelen.

3.4 Soil Chemical Properties

Table 6 shows the soil chemical properties of each layer at the research sites. Based on the formation processes of soils, the type of parent materials or the percentage of weatherable minerals must be closely related to the chemical properties of the soils, especially to the CEC of clay. Mafic or basaltic parent materials usually form clay minerals with a higher negative charge, such as monmorillonite or chlorite, while felsic parent materials usually form minerals with a lower negative charge, such as Halloysite or Kaolinite. In fact, there is only a slight relationship between weatherable minerals and the CEC, exchangeable bases, or base saturation (Table 7). However, the addition of fresh volcanic materials from the eruption of Mount Krakatau has a tendency to increase the soil CEC, exchangeable bases, and base saturation of the soils in the southern part of Sumatra Island.

There is a relationship between the weatherable minerals and the CEC of clay. If the percentage of the weatherable minerals of a soil is low (less than 10%), the soil will usually also have a low CEC of clay of less than 16 $cmol.kg^{-1}$ [7]. The results of a statistical analysis using the T-Test (Minitab 16) showed that the CEC of clay at the A-horizon differed significantly from that at the B-horizon, while no significant difference was observed for the other chemical properties of the soil (Table 7). Thus, increasing the percentage of weatherable minerals at the A-horizon is seen to significantly affect the value of the CEC of the clay in the soils found in the southern part of Sumatra Island. These two properties (weatherable minerals and the CEC of clay) are the important requirements of an oxic horizon [16]. In this research, although all of the soils have weatherable minerals of less than 10%, most of the data on the CEC of clay are still higher than 16 $cmol.kg^{-1}$, except for the CEC of the clay in the subhorizon of the soils from Tanjung Bintang, Trikora, Karang Endah, Hajimena, and Trimurjo (Table 6). In the soil surface horizons, all of the soils have a CEC of clay of more than 16 $cmol.kg^{-1}$, except in the Trimurjo area.

4. CONCLUSION

The soils in the research areas of this study had matrix colors in the range of hues from 10 YR to 10R and chroma values from 2 to 8. Therefore, all the soils could be classified as red soils. The eruption of Mount Krakatau in 1883 is seen to have significantly increased the amount of weatherable minerals and CEC of the clay in the soil surface horizon, and to have brought about the tendency for increases in the CEC, the exchangeable bases, and the base saturation of the soils in the southern part of Sumatra Island.

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