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Plant nutritional potency of recent volcanic materials from the southern flank of mt. Merapi, Indonesia

Lis Noer Aini[1*], Bambang Hendro Soenarminto[2], Eko Hanudin[2], Junun Sartohadi[2]

[1]*Muhammadiyah University of Yogakarta, Faculty of Agriculture, Department of Agrotechnology, Yogyakarta 55183, Indonesia*
[2]*Gadjah Mada University, Department of Soil Sciences, Faculty of Agriculture, Yogyakarta 55281, Indonesia*
[*]*Corresponding author:* nenny@umy.ac.id

Abstract

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The explanation of the vegetation growth rate on land buried by volcanic eruption material has not been done from the point of view of nutrient supply. The main objective of the research was to find out the distribution of pyroclastic material bearing weatherable minerals potentially as nutrient resources for plant growth. The field survey method was applied for landscape characterizations and soil sampling. The map and imageries interpretation was done to determine the slope units at the southern flank of Merapi into: cone, upper slope, middle slope, lower slope, and foot slope. The samples distribution were not covering the cone area. Samples of surface materials and the developed soils underneath were collected and measured the minerals, macronutrients and micronutrients content. The results revealed that the recent volcanic material contained primary minerals such as volcanic glass, plagioclase, hornblende, quartz and opaque with proportion of 50, 30, 10, 6 and 4%, respectively. While in the soil observed was plagioclase, pyroxene, and hornblende with proportion at range of 90.7-95.2, 2.5-4.1, and 1.04-3.88%, respectively. The highest total nutrient content was Fe, and followed by Ca > Mg > P > K > Na > Zn. The three primary minerals were categorized as weatherable minerals. The geomorphological unit had a very important role in nutrient distribution where the nutrient content for each unit was in sequence as upper slope > foot slope > lower slope > middle slope. Weatherable mineral in volcanic material was quite potential as nutrient resources for plant growth.

Keywords: nutritional potency; plagioclase; hornblende; pyroxene; macro-micronutrients

Introduction

Merapi is the most active volcano in Indonesia, therefore it attracts many scientists from various countries to conduct a research related to the volcanoes aspects. Previous researches that have been done include: Enryd (1998) examined the land capability classification, Gitteser (2012) studied geological evolution, Budi-Santoso et al. (2013), Jousset et al. (2013) analyzed a seismic activity, Hadisantono et al. (2012) studied volcanic hazards, Santoso and Sutikno (2006) did zoning the Merapi area for land use planning. However, the research that study the positive impact of Merapi eruption is still very limited, especially regarding the nutritional potency of pyroclastic material. This is confirmed by Ugolini and Dahlgren (2002), who asserted that fresh pyroclastic material as a result of eruption not only provides a new substrate for enslaving soil processes and conserving productivity, but also counteracts eroded or degraded soil. Likewise, Shoji and Takahashi (2002) added that pyroclastic deposit is a suitable medium for plant growth, providing physical support, essential plant nutrients and plant available water.

The primary mineral composition in volcanic material erupted in 2006 consisted of glass Vulcan (60%) and Labradorite (34%) (Fiantis et al., 2009). While Sudaryo and Sutjipto (2009) using the technique of Rapid Neutron Activation Analysis, obtained the composition of volcanic materials as follows: Al (1.8 – 5.9%), Mg (1 – 2.4%), Si (2.6 – 28%) and Fe (1.4 – 9.3%). On the other hand, in the oxide form according to Kusumastuti (2012), the composition includes: SiO_2 (45.7%), Fe_2O_3 (18.2%), CaO (16.1%), Al_2O_3 (14%) and K_2O (3.86%).

The quantity of the weatherable mineral supply was affected by the frequency and magnitude of the Mt. Merapi eruption. The large supply of pyroclastic materials in an area was strongly related to the material distribution mechanism. There were three scatter mechanisms of the pyroclastic material to the area around the volcano, namely: a) Wind motion transports fine material of dust size, b) In sloping terrain, the material slides as it affected the earth's gravitation force, c) The material was swept away by the movement of surface water flow. Therefore, the main objective of this research was to find out the distribution and composition of pyroclastic material bearing weatherable minerals in which possess a nutritional potency for plant growth.

Materials and Methods

General description of studied area

The research was conducted at the southern flank of Mount Merapi which is situated between 7°32′5″-7°40′25″ south latitude and 110°26′5″ -110°28′9″ east longitude with altitudes ranging from 447 to 1197 m (Figure 1). Topographically, the research area covers relatively flat areas (slope 0-8%) to mountainous (slope > 45%). The research site is passed by several rivers including: Woro, Gendol, Opak, Boyong, Bedok, Yellow, Bedog and some small tributaries. Volcanic ash from Mount Merapi is categorized as intermediate andesitic rock because it contains SiO_2 in the range 55.2 – 60.3% (Wulaningsih et al., 2013).

Soil types observed in the studied area were three orders of Entisols, Inceptisols and Andisols. Vegetations grow at the upland area was dominated by forest plants such as Acacia decurens, Albasia, Bamboo, and Mahogany. Fruit crops such as Coffee, Jackfruit, *Gnetum Genemon*, Rambutan, Mangosteen, and Coconut were found at the lower terrains. While groups of grasses such as Para Grass and Cogongrass grew evenly from the upper slope to the lower slope terrain.

Field Work

The field survey method was applied for landscape characterizations and soil sampling. The map and imageries interpretation was conducted to determine the slope units at the southern flank of Merapi into: cone, upper slope, middle slope, lower slope, and foot slope. The samples distribution did not cover the cone. Observation of thickness and distribution of volcanic material were done by making 100 minipits from upper to foot slope area. Then from the 100 minipits were selected 20 profiles as representative pedons. Soil sampling was conducted for each horizon/layer until the deepest root tip. Each soil sample was put into a plastic bag and taken to the laboratory for preparation prior to analyzing its physical, chemical, and mineralogical properties.

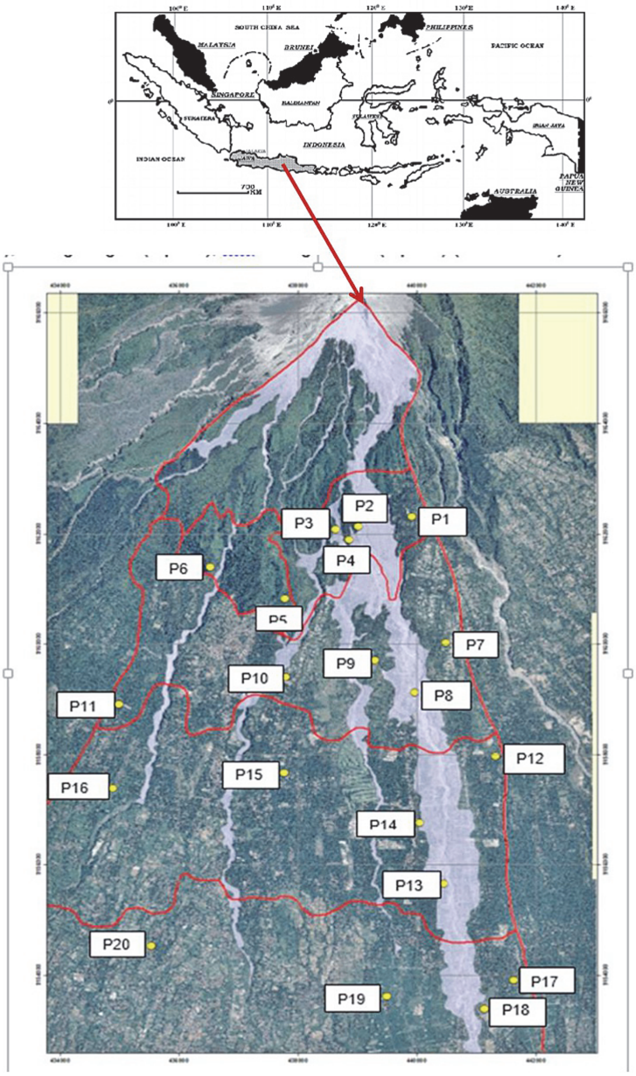

Fig. 1. Description of studied area

Laboratory Analysis

Nutrient analysis carried out including macro nutrients (P, K, Ca and Mg), micro nutrients (Fe, Cu, Mn and Zn), and beneficial nutrient (Na) in the total form as an estimator of nutritional potency. Total nutrient analysis used the modified wet destruction method with the extracting ratio of HNO_3: $HClO_4$ 3: 1 (Eviati & Sulaeman, 2012). Total P was measured by Spectrophotometer with wave number 665 nm (phospho-molibdate complex) (Tadesse et al., 1991). Total Ca, Mg, Fe, Cu, Mn and Zn were measured by atomic absorption spectrophotometer (AAS), while for K and Na by flame photometer (Tadesse et al, 1991). The type of primary mineral composing fresh volcanic material was analyzed by Polarized Microscope (Raith et al., 2011) and X-ray Diffractometer (Ulery & Drees, 2008). Bulk density (BD) was determined by core sampling (gravimetry) method (USDA, 1996) and computed based on the formula as follow:

$$Db = \frac{ODW - RF - CW}{CV - \left(\frac{RF}{PD}\right)},$$

where: Db = bulk density of < 2 mm fabric at sampled (g cm^{-3}), ODW = oven dry weight, RF = weight of rock fragments, CW = empty core, CV = core volume, and PD = density of rock fragments.

Calculation of Nutritional Potency

The nutritional potency values of the surface materials and the soil presented in the study area could be calculated by following the formula:

$$P = L \times k \times BD \times h \text{ (ton/ha)},$$

where: P = nutritional potency value of volcanic material for each nutrient (ton/ha), L = area (Ha), k = the thickness of the surface material and soil (m), BD = bulk density of the surface material and soil (g/cm^3), and h = nutrient concentration in the surface material and soil (%).

Results and Discussion

Mineral Composition in the Volcanic Material and Soil

Results of pyroclastic material and soil analysis with polarized microscope were presented in Fig. 2. Based on the figure, it shows the mineral units microscopically, consisted of white yellowish, clastic texture, clay-fine sand in particle size. The primary mineral composition is volcanic glass, plagioclase, hornblende, quartz, and opaque mineral. It appears that most of the volcanic glasses have undergone a transformation into clay mineral. The mineral that has the largest proportion was the 50% volcanic glass. The characteristics of the mineral were colorless, dark colored crossword, gypsy chip, and violet.

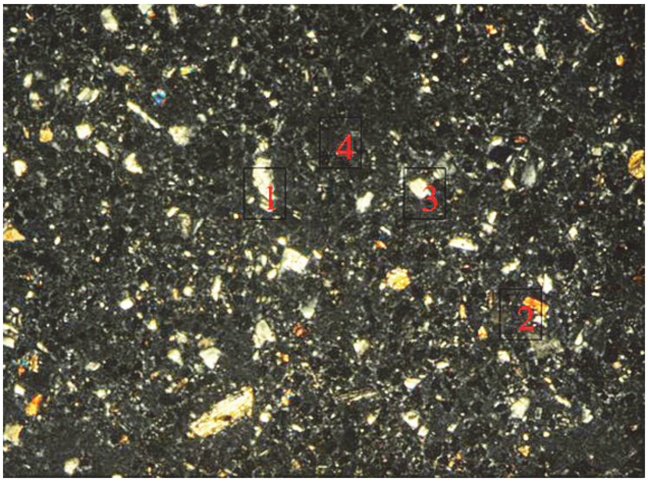

Fig. 2. Composition in the volcanic material and soil

The second mineral observed was plagioclase with percentage of 30%. Its mineralogical characteristics were color features ranging from colorless to gray, 0.08-0.3 mm in size, anhedral-subhedral shape, low relief, categorized as andesine type (An_{44}). The andesine contained 44% anorthite, the remaining minerals was 54% albit. Thus, their chemical structure was (Na54%, Ca44%) $Al_{1-2}Si_{3-2}O_8$. The third mineral was hornblende (10%) with the characteristics of brownish yellow color, 0.06-0.2 mm in size, anhedral – subhedral shape, high relief, and strong pleokroime. The fourth mineral was quartz (6%) with colorless features, low relief, refractive index n > nkb, 0.05-0.1 mm in size, wavy outages, and angular shape. The fifth mineral was opaque (4%) with black, untranslucent, 0.06-0.1 mm in size, and uneven distribution.

The result of soil analysis using X-ray diffractometer was presented in Fig. 3. Based on the difractographs, mineral composition of the samples from the upper to the foot slope was relatively similar. The predominant primary minerals was plagioclase with content ranging of 90.7-94.6%, 91.5-95.9%, 90.6-95.2%, and 92.3-94.7% for each sample from the upper slopes, the central slopes, the lower slopes, and the foot slope. The second primary mineral found was Hornblende with proportion ranging of 1.43 to 3.88%, 1.33-2.13%, 1.30-3.35, and 1.04-2.49% for each of the four units of the slope. The third primary mineral observed was Pyroxene with levels ranging of 2.54-3.91%, 2.29-5.78%, 2.67-

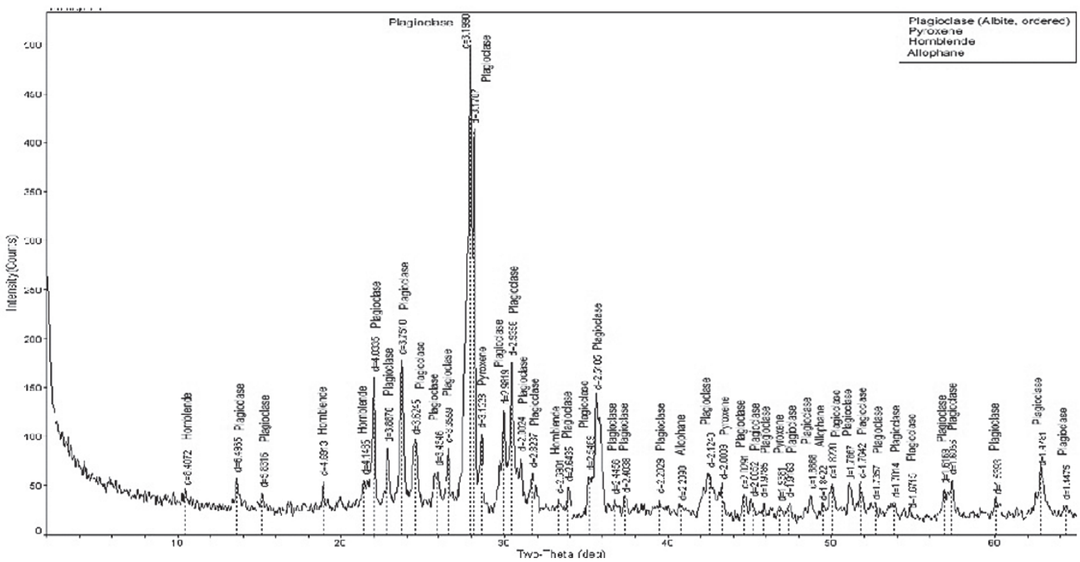

Fig. 3. Soil analysis using X-ray diffractometer

4.47%, and 3.17-4.11%. The X-RD results also indicated that the secondary minerals such as allofan (d = 2.2 Å) presented in the soil samples. This fact was in line with the results of microscopic observations that show the occurrence of the transformation process of volcanic glass into clay minerals.

_Plagioclase is the name of the feldspar mineral groups composed of albit ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) (Schlesinger, 1997). The labelling of the mineral group members were based on the proportion of albite and anorthite. If the percentage of albit was at ranges of 50-70% and anorthite 30-50%, it was categorized as andesine. The plagioclase presented in the soil samples contained 54% albite and 44% anorthite, therefore, it was categorized as andesine. The existence of alkaline and alkaline earth elements (Na and Ca) resulted the mineral was relatively easy to decay. Therefore, the mineral was categorized as a weatherable mineral.

Hornblende is a primary mineral belonging to the ferromagnesian group which is often referred to as Calcium Magnesium Iron Aluminum Silicate Hydroxide with chemical formula $Ca_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$ (Schlesinger, 1997). Based on the chemical structure, it is indicated that the mineral could be used as nutrient resource for plant growth, especially Ca, Mg, and Fe. Monovalent cations such K and Na was absent in the mineral, therefore, the solubility of hornblende is lower than plagioclase.

Pyroxene is also an important group of minerals commonly found in igneous and metamorphic rocks. Normally, the mineral occurred as inosilicate form with the chemical formula $(Ca,Mg,Fe)Si_4O_{12}$ (Schlesinger, 1997). Elements of the pyroxene constituent besides silicon-aluminum oxide also contain Ca, Na, Fe, Mg, Zn, Mn and Li. Some of these cations also substitute Si and Al elements. The general formula of pyroxene is often written $XY(Si, Al)_2O_6$ (where, X = Ca, Na, Fe^{2+}, Mg, sometimes also Zn, Mn and Li; Y = smaller ions such as Al, Fe^{3+}, Mg, Co, Mn, Sc, Ti, V and also sometimes Fe^{2+}). The pyroxene is also categorised as ferromagnesian and easily to weather, therefore, the mineral was potential to be nutrient source of Ca, Mg, Fe, Zn and Mn.

According to Mitchell and Soga (2005), plagioclase, hornblende, and pyroxene are categorized as weatherable minerals. The existence of the primary minerals as a constituent of volcanic material was very important because it contributes to accelerating the agroecosystem recovery process that was damaged by exposure to hot pyroclastic materials. The three primary minerals were very potential as nutrient sources for plant growth in the active volcano areas. In terms of the soil fertility recovery, volcanic eruption was a process of rejuvenating or regenerating land that has been degraded by landslides, erosion, and leaching.

Plant Nutritional Potency of Recent Volcanic Materials

The calculation of the nutritional potency of the volcanic soil taken from 20 pedons representing each geomorphology unit was summarized in Table 1. The table revealed that soil samples taken from the upper slope possess the different nutrient potential values. There was a tendency of samples taken from locations near the Gendol river (P2 and P4) con-

Table 1. Nutritional potency (ton/Ha) of volcanic material and soil from studied areas

GU	Location/	Nutrient Potency (ton/Ha)						
	Pedon	P	K	Ca	Mg	Fe	Zn	Na
US	Kalitengah Lor (P1)	135.3	16.5	360.2	67.3	622.1	2.3	15.0
US	Kaliadem (P2)	1578.3	370.1	27796.9	854.9	23007.3	50.2	283.5
US	Kinahrejo (P3)	44.4	13.6	190.1	42.5	652.1	2.0	10.1
US	Kinahrejo2 (P4)	79.9	22.8	484.7	101.4	1092.9	3.8	21.6
US	Plawangan (P5)	41.4	9.6	196.6	49.2	897.1	1.8	10.0
US	Turgo (P6)	86.0	8.2	134.8	31.7	688.9	1.5	6.6
MS	Srunen (P7)	83.6	14.2	292.2	61.1	1184.6	2.2	12.3
MS	Jambu (P8)	125.7	20.8	523.1	78.3	1497.7	2.9	17.9
MS	Petung (P9)	56.3	15.3	296.3	78.8	998.8	2.6	11.7
MS	Sidorejo (P10)	64.5	14.6	475.6	105.4	1101.7	2.6	15.9
MS	Tritis (P11)	115.8	23.9	993.7	152.9	2012.7	3.8	31.8
LS	Gading (P12)	60.4	11.0	335.9	48.8	897.6	1.5	10.9
LS	Ngepringan (P13)	97.4	29.8	640.9	66.7	1189.2	4.2	24.8
LS	Pagerjurang (P14)	124.8	15.4	687.7	71.5	1164.2	3.1	24.0
LS	Balong (P15)	103.0	27.9	811.4	131.8	1827.2	3.6	27.8
LS	Kemiri Cilik (P16)	85.5	18.1	483.1	95.4	1516.5	3.1	18.5
FS	Mudal (P17	57.6	5.8	96.9	14.8	329.4	0.9	3.8
FS	Gadingan (P18)	117.4	18.4	963.5	78.6	1154.1	2.7	27.1
FS	Ngemplak (P19)	109.5	25.1	960.0	204.8	1980.5	4.0	33.7
FS	Trojayan (P20)	144.5	19.2	511.0	113.6	1411.6	3.0	19.1

Note: GU = Geomorphological Unit, US = upper slope, MS = middle slope, LS = lower slope, FS = Foot slope.

tained a higher nutrient. The possibility was related to the large supply of pyroclastic material in the area. The same pattern occurred for all of P, K, Ca, Mg, Fe, Zn and Na.

The samples from Kaliadem (P2) contained the higher nutrients compared to other places because the volcanic material as rock block form has not been relatively weathered. Therefore, at the areas, the higher plants could not grow rapidly, as a result, the weathering process of the rocks has also been run slowly. Only a few pioneer plants such as ferns and perennial flowers are able to live on the lava sediment.

The soil sample from the upper slope area was divided into two parts, namely: the Young Merapi terrain represented by pedon P1-P4, whereas P5-P6 as representative of Old Merapi. The samples from the Young Merapi area possess the nutritional potency was higher than the old one, except for Fe. The possibility was related to the low solubility of Fe remained a lot in the soil.

Based on Table 1, it revealed that the distribution of the seven nutrients possesses a similar pattern that was the highest nutrient content of Fe then followed by Ca, Mg, P, K, Na and Zn. The high nutrient Fe in volcanic materials and soil has an implication on the nutrient management, because Fe was the micro nutrients needed by plants in small quantities. If the area was used as a rice field, the plants could contain the iron toxicity.

Distribution of nutrient potential (P, Fe, Ca and Mg) in the soil at the southern slopes of Mount Merapi was presented in the Fig. 4. Based on the figure, calcium was the highest macro nutrient, followed by Fe, P and Mg. The high nutrient Ca was probably derived from plagioclase, hornblende and pyroxene since they possess Ca. The last two minerals belong to the ferromagnesian group that is why they become the main sources of Fe and Mg in the soil. Iron, although it is included in the micro nutrient group, yet, it provides the highest quantity than other macro nutrients such as P, K, and Mg.

The possibility was related to Fe behavior which was immobile or insoluble and it remained a lot in the soil. The high Fe in the soil will give a bad impact on the rice crops if the area was used for rice fields. Inundation of paddy soil will cause Ferri (Fe^{3+}) become Ferro (Fe^{2+}) which is more soluble. The nutrient content of P observed was higher than Mg, especially the soil samples from the upper slopes. Allegedly, volcanic material from Mount Merapi contains mineral apatite. Fiantis et al. (2009) successfully identified the presence of apatite minerals in the volcanic ash even though the presence is in small amounts.

Fig. 4 reflects the relationship of geomorphological units with the nutrient content present in the soil. Upper slope areas closer to the eruption source significantly contain higher

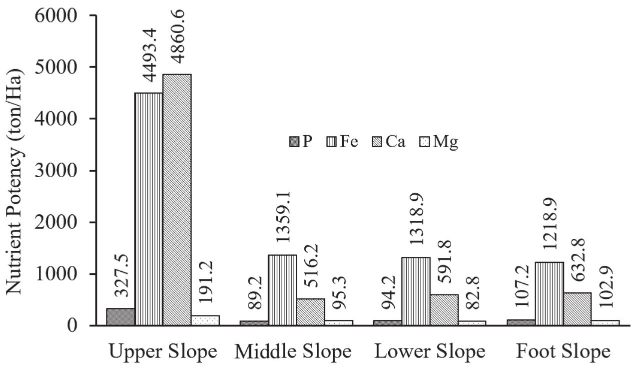

Fig.4. Distribution of nutritional potency of P, Fe, Ca and Mg in the soil at the southen flank of Mt. Merapi

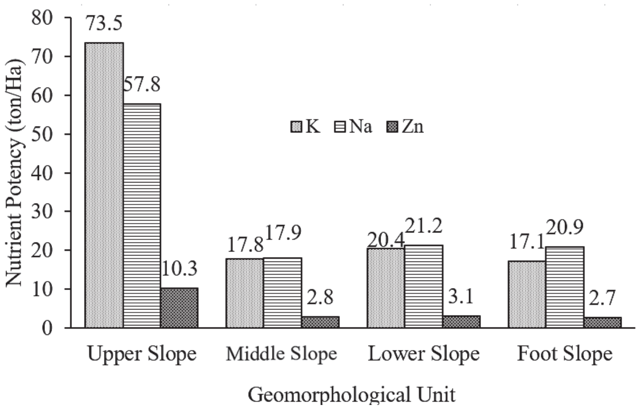

Fig. 5. Distribution of nutritional potency of K, Na and Zn in the soil at the southern flank of Mt. Merapi

levels of P, Ca, Fe and Mg compared to those in the lower ones. The second largest nutrient content found in the foot slope. It is possibly because the area obtained supplies of the materials from the upper region. Geomorphological units that contained the low nutrient potential were in the middle and the bottom slopes. The four nutritional potencies contained therein were relatively similar.

The distribution of nutrient potentials (K, Na and Zn) in the soil was summarized in the Fig. 5. The content of these three nutrients was far below the four prior nutrients (Fe, Ca, P and Mg). The primary source of K and Na nutrients in volcanic materials was plagioclase. While Zn could be derived from ferromagnesian groups such as hornblende and pyroxene. These three nutrients were also widely present in the soil in the upper slope because it was close to the source of magma. While the soil in the middle, lower and foot slopes possess the similar nutrient potential of K, Na and Zn.

The nutritional potency of K in the upper slope areas was higher than Na. This possibility was probably related to Na was more soluble than K. The nutritional potency of K and Na in the soil from the middle and lower slopes was similar, however, at the foot slope, Na was a little bit higher than K. The Zn content in the soil of the upper slope was higher than at the lower areas. At the middle, lower and foot slope area possess the similar Zn nutrient potential. Zinc (Zn) as micro and immobile nutrient was usually only as a complementary element that comes from ferromagnesian group.

Conclusions

The recent volcanic material of Merapi was composed of 50% volcanic glass, 30% plagioclase, 10% hornblende, 6% quartz, and 4% opaque minerals. While primary minerals in the soil were developed from the older volcanic material consisted of 90.7-95.2% plagioclase, 2.5-4.1% pyroxene, and 1.04-3.88% hornblende. The concentration order from the highest to the lowest of total nutrient content was Fe followed by Ca > Mg > P >K > Na > Zn. Those total nutrients mainly came from the weathering of plagioclase and hornblende. The distribution of weatherable minerals as well as the total nutrient on the landscape was following the sequence of slopes as upper slope>foot slope>lower slope>middle slope. The sequence was following the deposition processes of recent volcanic materials.

Acknowledgments

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