Chemical Properties of Volcanic Soil After 10 Years of the Eruption of Mt. Sinabung (North Sumatera, Indonesia)

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Abstract. Mount Sinabung was active again in 2010 after 400 years of dormancy and it is still erupting to date. The eruptions produced volcanic ash which blanket the soil surface. The distribution of volcanic materials was monitored by using Landsat Satellite which covers an area of 30,320 Ha in 2018, then in 2019, it changed to 1,371 Ha. After eruptions for 10 years, we believed soil characteristics are changed. The objective of this study was to characterize soil properties in the vicinity of Mt. Sinabung. There were 34 soil samples taken at a depth of 0-20 cm with a total research area of 4,517.25 Ha. The samples were analyzed for chemical properties included pH (H₂O), total N, organic carbon, exchangeable base cations, and cation exchange capacity (CEC). The results showed that the pH (H₂O) ranged from very acidic to neutral (4.14-6.52). The total N low to high category (0.13-0.60%). Organic carbon low to very high (1.73-13.05%). The exchangeable base cations have a high concentration with values of K (1.60-2.98 cmol kg⁻¹), Na (3.72-7.45 cmol kg⁻¹) and Mg (5.79-12.15 cmol kg⁻¹) respectively. Cation exchange capacity (CEC) showed high to very high category values (11.78-97.71 cmol kg⁻¹). Volcanic ash provides many benefits to soil properties. This indicates that volcanic ash enrich soils by providing nutrients to the soils aftermath of volcanic eruptions.

Keywords: Volcanic Ash Benefits; Pyroclastic Materials; Soil Enrichment; Soil Rejuvenation

1. Introduction

Mount Sinabung is a strato-type volcano with an altitude of 2,460 meters above sea level [1], located in North Sumatra Province 40 km Northwest of Lake Toba. This mountain has been dormant for 400 years and reactivated in August 2010 [2], this eruption is of a phreatic type and emits black smoke reaching 2,000 meters above the Sinabung crater and spewing solid material in the form of volcanic ash and rock [3].

After 3 years of activity stopped, the eruption occurred again. This second eruption was fluctuating and the eruption was of the phreatomagmatic type and caused pyroclastic flows to the south starting from December 2013 to January 10, 2014 [4]. The most intense eruptions with dozens of eruptions per day occurred in mid-January to late February 2014 which also led to an increase in lava extrusion that contributed SO₂ [5]. The direction of the pyroclastic solids to the south after the second crater collapsed which lasted from mid-September 2014 to July 2015 [4].

After several eruptions, pyroclastic materials flow to the southeast and east from 2015 until the present after the collapse of the lava crater. Besides caused disadvantages for the surrounding...
community, volcanic eruptions provide long-term benefits to the soil. The periodic addition of volcanic ash has the potential to rejuvenation soil nutrients and increase soil productivity [6][7].

Volcanic soils are known as the most productive lands in the world because of the influence of volcanic material from eruptions [7]. Volcanic ash is a high nutrient reserve and contributes to macro and micronutrients that are needed by plants such as Ca, Na, K, Mg, Zn, Fe, Cu, and Mn after weathering [8]. Another research [9], reported that soil affected by volcanic material from the activities of Mount Sinabung for 2 years had a cation exchange capacity (24.88 cmol kg⁻¹), N-total (0.20%), and Ca (3.81 cmol kg⁻¹) higher than the soil that is not affected by volcanic ash with the exchange capacity of cation, total N, and Ca, 3.65 cmol kg⁻¹, 0.16%, and 1.54 cmol kg⁻¹, respectively. Furthermore, Anda [10] reported that the soil affected by the eruption of Mount Sinabung for 4 years had a cation exchange capacity of 21.34 cmol kg⁻¹, while the soil not affected by the eruption was around 17.27 cmol kg⁻¹. This indicates that volcanic ash has the potential to enrich nutrients in the soil. This study aims to assess the chemical properties of the soil in the vicinity of Mt. Sinabung after being affected by an eruption for 10 years (2010-2020).

2. Materials and Methods

2.1. Material

Soil samples were taken from the eruption area of Mt. Sinabung, located in Karo Regency, North Sumatera Province, Indonesia. Mount Sinabung has a peak height of 2,460 meters above sea level (a.s.l), and is at coordinates 3 ° 10 ′ 12 ″ N, 98 ° 23 ′ 31.2 ″ E. Soil samples were 34 samples taken on an area of 4,517.25 Ha which was affected by the eruption in 2010 to March 2020. The research area is based on the distribution direction of the pyroclastic material, especially the East, Northeast, Southeast, and South at a radius of 3-7 km (disaster-prone area) from the center of the eruption (Figure 1). Total of samples in each region were 13 (East), 6 (Northeast), 5 (South), and 10 (Southeast), respectively. At the sample point where there is still ash on it, first cleaned the topsoil and soil samples are taken at a depth of 0-20 cm. Each sample point that has been determined is taken at several points which are then composited. Based on field conditions, several land uses were obtained, agricultural land, forests, and open land. The soil sample was dried first and then sieved using a sieve measuring 2 mm and 0.5 mm. The availability of N is determined by the thickness of the ash covering the soil surface. The thicker the volcanic ash deposition in the soil, the plants can not utilize nitrogen in the soil [7].
2.2. Method

Soil chemical analysis was carried out at the Soil Chemistry Laboratory, Soil Science Department, Faculty of Agriculture, Andalas University. The samples analyzed were samples taken in the field in March 2020. Samples were sieved dry then analyzed to obtain data on pH (H$_2$O), total N, base cations, cation exchange capacity (CEC), and organic C.

Analyzed soil pH (H$_2$O) was calculated using soil with a ratio of 1: 2.5 soil/solution using a pH meter. The level of N-Total were measured by the Kjeldahl method. The exchangeable base cations were measured by the NH$_4$Oac leaching method pH 7. The cation exchange capacity was measured using NH$_4$Oac (1 M) with buffer 7. The Walkey and Black method was used in measuring organic carbon (Balittanah Bogor, 2012). The sampling points are shown in Figure 1.

After the results of the analyzed, then the statistical data processing of the chemical properties of the soil is carried out using the software, namely JMP-Pro and kriging data processing digital for mapping of soil chemical properties of Mt. Sinabung using ArcGIS software. The presentation of data is grouped based on the cardinal directions of the sampling points, namely East, Northeast, South and Southeast.
3. Results and Discussion

After 10 years of being affected by the eruption, the highest pH (H₂O) was found in the Southeast (6.52) and the lowest in the Eastern region (4.14). The pH of the research soil has an average, namely in the Southeast (5.66), South (5.63), Northeast (5.24), and East (5.14). Areas with the highest pH are generally in a radius of 7 Km which is an agricultural area and the lowest is at a radius of 3 and 5 Km where there is still volcanic ash. Volcanic ash is in the early stages of the weathering process (Figure 2). The result showed that volcanic ash has a significant effect on soil acidity. Another factor that affects soil acidity in volcanic soils is the accumulation of S from volcanic material [11]. An eruption of Mt. Sinabung contributed to SO₂ in 2010, 2013, and 2014 at an average of ~ 550 ± 180 t/d, ~ 430 ± 310 t/d, and 1680 ± 1070 t/d [5].

In this study, it was seen that there was an increase in soil pH compared to research [10] in the same area. Sampling was carried out in the southern part of the Payung sub-district at a depth of 0-20 cm. Based on research data [10], at a depth of 2-23 cm above which there is still volcanic ash, the pH (H₂O) of the soil is 5.4, while in this study the pH (H₂O) obtained ranged from 5.11 to 6.18. The increase in pH is caused by a weathering process in the volcanic material covering the soil surface. the weathering process of volcanic material has the potential to neutralize soil acidity due to eruptions [12]. Another study [13], reported a decrease in total sulfur in volcanic ash after 2 years of 1.35%. Soil acidity is also influenced by organic matter.
Figure 3. Soil chemical properties affected by volcanic ash for 10 years

The levels of organic C in this study were classified as low to very high (1.73-13.05%) (Figure 3b). The highest organic C is in the northeast area wherein this area several sampling points are still covering with volcanic ash. C Organic soil research has an average, namely in the Northeast (6.915%), East (6.489%), Southeast (6.174%), and South (5.744%). The high level of organic C in volcanic soil is influenced by the presence of volcanic ash. Volcanic soil could high ability store carbon that was covered repeatedly by volcanic materials [14].

The stability of organic C in volcanic soil was influence by the bonding of organic matter with aluminum and iron, which is relatively resistant to weathering by microbes [15]. Organic C in soil tends to increase with soil age from 1,000 to 10,000 years with an increased rate of 4.3 kg m$^{-2}$ per 1,000 years [16].

Another factor that affected organic C is vegetation. Vegetation contributes to organic matter, which is rich in cellulose and lignin [7] and organic matter in volcanic soil can accumulate more organic C due to the presence of the Al humus complex [17]. Moreover may to store a supply of organic C, volcanic soil can also maintain the supply of N in the soil. Volcanic soils can suppress the process of N mineralization in the soil so that the supply of N in the soil remains high [7].

The highest total N are in the Southeast area (0.60%) and the lowest is in the East part (0.13%)(Figure 3d). Levels of Total N is included in the low to high category. The total N in soil research has an average in the Northeast (0.393%), Southeast (0.376%), East (0.307%), and South (0.252%). As one of the macronutrients that plants need throughout their growth, the availability of N becomes an obstacle in volcanic soils [14][18]. The availability of N is determined by the thickness of the ash covering the soil surface. The availability of N is determined by the thickness of the ash covering the soil surface. The thicker the volcanic ash deposition in the soil, the plants can not utilize nitrogen in the soil [7]. Fertilization can increase the total N-content in soils. Intensive application of N fertilizer has the potential to increase nitrate concentration [14].
Figure 4. Base cations in soil that affected of eruption during 10 years

Based on the results of the analyzed, it is known that the highest CEC is in the Northeast, i.e. 97.71 cmol kg\(^{-1}\), and the lowest in the South, namely 11.78 cmol kg\(^{-1}\) (Figure 3c). The average cation exchange capacity in soil research is in the Northeast (67.155 cmol kg\(^{-1}\)), Southeast (60.497 cmol kg\(^{-1}\)), East (56.723 cmol kg\(^{-1}\)) and South (42.048 cmol kg\(^{-1}\)). The cation exchange capacity is influenced by the minerals that make up volcanic soil. The mineral content of volcanic soils is dominated by non-crystalline minerals with high surface area and variable charge that can increase the cation exchange capacity [12]. Non-crystalline minerals and organic matter influence the load on volcanic soils [17].

The primary minerals that make up the volcanic ash of Mount Sinabung are Plagioclase (34%), Hypersthene (4-9%), Amphibole (3-5%), Magnetite (1-2%), Volcanic glass (0-1%), and 0-2% Quartz [19]. These minerals are easily weathered minerals that can increase base cations in the soil [7]. The exchangeable base cations have a high concentration with values of K (1.60-2.98 cmol kg\(^{-1}\)), Na (3.72-7.45 cmol kg\(^{-1}\)), Ca (0.04-0.16 cmol kg\(^{-1}\)) and Mg (5.79-12.15 cmol kg\(^{-1}\)) respectively. The highest average base concentration is in the Eastern to Southeastern areas (Figure 4 and 6).

Based on this study, the highest average cation exchange capacity was in the Northeast (67.155 cmol kg\(^{-1}\)) and organic C (6.915%). The high organic matter content has the potential to increase the cation exchange capacity in the soil [20]. Organic C contributes 4 moles of a negative charge, assuming that per 10 moles of carboxylate is equal to 1 mole of carboxyl groups [17]. Another factor that affects the cation exchange capacity is the rate of mineral weathering. The level of weathering affects the value of the cation exchange capacity which increases with the weathering process [13]. The weathering process also affects the concentration of cations in the soil.
Figure 5. Maps of the distribution of several soil chemical properties in Mt. Sinabung
Figure 6. Maps of the distribution base cations concentration in Mt. Sinabung
4. Conclusion
Mount Sinabung eruptions that contribute volcanic ash have the potential to increase nutrients in the soil. Soils affected by the eruption of Mt. Sinabung for 10 years were proven to increase pH (H₂O), base cations, cation exchange capacity, and soil organic C. So, volcanic ash very give many benefits for soil and can using for rejuvenation and enrich soils.

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References
[1] Syarifuddin M Oishi S Hapsari R I Shiokawa J Mawandha H G and Iguchi M, 2019 Estimating the Volcanic Ash Fall Rate from the Mount Sinabung Eruption on February 19, 2018 Using Weather Radar J. Disaster Res. 14, 1 p. 135–150.
[2] Iguchi M et al., 2012 Methods for eruption prediction and hazard evaluation at Indonesian volcanoes J. Disaster Res. 7, 1 p. 26–36.
[3] Sutawidjaja I S Prambada O and Siregar D A, 2013 The August 2010 Phreatic Eruption of Mount Sinabung, North Sumatra Indones. J. Geosci. 8, 1 p. 55–61.
[4] Pallister J et al., 2019 Monitoring, forecasting collapse events, and mapping pyroclastic deposits at Sinabung volcano with satellite imagery J. Volcanol. Geotherm. Res. 382 p. 149–163.
[5] Primulyana S et al., 2019 Gas and ash emissions associated with the 2010–present activity of Sinabung Volcano, Indonesia J. Volcanol. Geotherm. Res. 382 p. 184–196.
[6] Neall V E, 2009 Volcanic soils L. use, L. Cover soil Sci. 7 p. 23–45.
[7] Shoji S and Takahashi T, 2002, Environmental and agricultural significance of volcanic ash soils, Global Environmental Research-English Edition-, 6, 2. p. 113–135.
[8] Anda M and Sarwani M, 2012 Mineralogy, chemical composition, and dissolution of fresh ash eruption: new potential source of nutrients Soil Sci. Soc. Am. J. 76, 2 p. 733–747.
[9] Simanjuntak C M Elfati D and Delvian D, 2015 Dampak Erupsi Gunung Sinabung Terhadap Sifat Kimia Tanah Di Kabupaten Karo Peronema For. Sci. J. 4, 4 p. 53–58.
[10] Anda M, 2016 Characteristics of pristine volcanic materials: Beneficial and harmful effects and their management for restoration of agroecosystem Sci. Total Environ. 543 p. 480–492.
[11] Delmelle P, 2003 Environmental impacts of tropospheric volcanic gas plumes Geol. Soc. London, Spec. Publ. 213, 1 p. 381–399.
[12] Ugolini F C and Dahlgren R A, 2002 Soil development in volcanic ash Glob. Environ. Res. Ed. 6, 2 p. 69–82.
[13] Fiantis D Nelson M Shamshuddin J Goh T B and Van Ranst E, 2011 Changes in the chemical and mineralogical properties of Mt. Talang volcanic ash in West Sumatra during the initial weathering phase Commun. Soil Sci. Plant Anal. 42, 5 p. 569–585.
[14] Delmelle P Opfergelt S Cornelis J-T and Ping C-L, 2015, Volcanic soils, in The Encyclopedia of Volcanoes, (Elsevier), p. 1253–1264.
[15] Fiantis D Ginting F I Nelson M and Minasny B, 2019 Volcanic Ash, Insecurity for the People but Securing Fertile Soil for the Future Sustainability 11, 11 p. 3072.
[16] Peña-Ramírez V M Vázquez-Selem L and Siebe C, 2009 Soil organic carbon stocks and forest productivity in volcanic ash soils of different age (1835–30,500 years BP) in Mexico Geoderma 149, 3–4 p. 224–234.
[17] Nanzyo M Shoji S and Dahlgren R, 1993, Physical characteristics of volcanic ash soils, in Developments in Soil Science, 21, (Elsevier), p. 189–207.
[18] Dahlgren R A, Saigusa M and Ugolini F C, 2004 The nature, properties and management of volcanic soils *Adv. Agron.* 82, 03 p. 113–182.

[19] Rambe R D H and Setiawan I, 2018, Study of Mineralogy Composition, Total, and Exchangable Content of K, Ca, and Mg of Volcanic Ash from Sinabung Mountain Eruption in North Sumatera, Indonesia, in *Proceedings of MICoMS 2017*, (Emerald Publishing Limited).

[20] Ross D S and Ketterings Q, 1995 Recommended methods for determining soil cation exchange capacity *Recomm. soil Test. Proced. Northeast. United States* 493 p. 62–69.