Effects of the Mount Marapi Eruption on Plant Diversity and Mineral Status of Soil and Forage in West Sumatra, Indonesia

Khalil Khalil[1*], *Dwi* Anata[2], *Hermon* Hermon[3], and *Hendri* Hendri[4]

[1]Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, Andalas University, Campus II, Payakumbuh, West Sumatra, Indonesia
[2]Department of Animal Production and Technology, State Agricultural Polytechnic of Payakumbuh, West Sumatra, Indonesia
[3]Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, Andalas University, Padang, West Sumatra, Indonesia
[4]Department of Animal Production and Feed Technology, Faculty of Animal Science, Andalas University, Padang, West Sumatra, Indonesia

Abstract. The December 2023 eruption of Mount Marapi in West Sumatra deposited volcanic ash and gravel across agricultural landscapes, disrupting crop production, forage availability, and livestock health. This study evaluated the effects of the eruption on forage diversity, biomass production, and the mineral status of soils and forages. A survey of 55 cattle farmers across five subdistricts (Ampek Angkek, Canduang, Sungai Pua, X Koto, and Batipuah) classified impacts as severe, moderate, or low. In severely affected zones, farmers reported livestock health problems, and forage biomass declined due to ash deposition. In moderately affected zones, cattle remained healthy; however, the forage supply decreased significantly due to ash contamination and scarcity. In low-impact zones, livestock and forage supply were largely unaffected, though farmers experienced economic losses due to reduced crop yields and lower market prices. Across all zones, 70 forage species were identified, dominated by Pennisetum purpureum (19.2%), Axonopus compressus (14.6%), Digitaria sanguinalis (7.4%), and Cynodon dactylon (5.3%). Forage diversity increased post-eruption, while average biomass (8.9-9.2 tons DM/ha) and carrying capacity (2.2-2.3 AU/ha) did not differ significantly among impact zones ($p > 0.05$). Most soil and forage minerals, including phosphorus (0.32–0.36%), magnesium (1,321-1,625 ppm), and sulfur (238-257 ppm), remained above deficiency thresholds. However, copper concentrations in forage were consistently low (4.8-5.3 ppm), which is well below the critical requirement of 8 ppm, posing a long-term risk to grazing cattle. These findings demonstrate the resilience of dominant tropical grasses to volcanic ash deposition, suggesting that while forage productivity and mineral availability were largely sustained, persistent copper deficiency requires targeted supplementation strategies to safeguard livestock health and productivity in volcanic regions.

* Corresponding author: khalil@anci.unand.ac.id

1 Introduction

The fertile land and cool climate of the Mount Marapi slopes make it a key agricultural and livestock hub for the Agam and Tanah Datar districts in West Sumatra. This region supports the cultivation of various vegetables and horticultural crops, including chilli peppers, cabbage, beans, leeks, celery, eggplants, shallots, tomatoes, and carrots [1]. Furthermore, cattle farming is a common side business in volcanic areas, providing organic fertiliser and utilising wild plants and agricultural waste as feed [2]. Beyond its agricultural significance, Mount Marapi is also one of the most popular hiking destinations in West Sumatra.

However, since early December 2023, Mt. Marapi has erupted, releasing hot clouds, volcanic gravel, and ash. This high-intensity eruption persisted for approximately six months, causing widespread crop damage and severe health impacts on livestock and humans [1]. Agricultural fields were buried under volcanic ash, leading to crop failures and plummeting prices. Cattle faced feed shortages as plants perished or became contaminated with ash, resulting in health problems, weight loss, and increased stress due to inadequate nutrition and care [2]. Mountain climbing tourism was also suspended indefinitely due to the hazardous conditions. The eruption had significant economic consequences, particularly in the districts of Canduang, Sungai Pua, and Ampek Angkek (Agam Regency), as well as X Koto and Batipuh (Tanah Datar Regency) [3,4,5,6]. The extent of agricultural damage varied depending on proximity to the eruption centre and the prevailing wind direction at the time of the eruption [3].

The volcanic materials have a significant impact on soil composition, plant diversity, and livestock health in the affected areas [2]. The changes in soil mineral composition can influence plant diversity and biomass production. The deposition of ashes may initially damage existing vegetation. Still, as the soil becomes enriched with nutrients from weathered volcanic materials, conditions may favour the growth of diverse plant species, including forages that are consumed by grazing cattle. Unlike other natural disasters, volcanic eruptions in Indonesia rarely cause direct cattle fatalities. Thus, even after the eruption, farmers retained their livestock as a valuable economic asset [2]. However, ensuring adequate nutrition and feed for cattle after the eruption is critical for their recovery, growth, and reproductive health. Volcanic ash contains various minerals influencing soil and plant composition [7]. During plant regrowth, several months after eruption, the growth may be more vigorous and nutrient-rich. Still, the mineral composition of these plants may not always align with cattle's dietary requirements, potentially leading to mineral imbalances [8].

The mineral intake of grazing cattle is closely tied to the mineral content of soils and forages. Deficiencies or imbalances in essential elements within volcanic soils can lead to health issues in grazing animals. Previous studies on five different volcanoes in Indonesia have indicated that post-eruption feed is often deficient in phosphorus (P) and sodium (Na), but excessively rich in potassium (K), sulfur (S), and copper (Cu), sometimes surpassing cattle tolerance thresholds [9,10]. These imbalances can impair the metabolism, growth, reproduction, and overall health of grazing livestock.

However, most existing post-volcanic eruption studies in Indonesia have concentrated on either soil fertility or crop productivity, with far less attention given to the combined assessment of plant diversity, biomass availability, and mineral composition of both soil and forage in the immediate aftermath of eruptions. Furthermore, few studies have been conducted in West Sumatra, despite its high livestock density and economic dependence on mixed crop–livestock systems. Little is known about recent eruptions' impact on the recovery trajectory of forage resources and their mineral adequacy for grazing cattle in this region.

The present study addresses these gaps by assessing (i) changes in forage species diversity and biomass production, and (ii) the mineral status of soils and forages following the Mount Marapi eruption. This study is the first to integrate post-eruption assessments of forage species diversity, biomass yield, and mineral status of both soils and forages in West Sumatra. Linking ecological recovery with livestock nutritional adequacy addresses a critical gap in post-volcanic eruption research, which has largely overlooked the combined impacts on forage availability and mineral balance essential for cattle health.

2 Materials and Methods

2.1 Description of the study sites

Mount (Mt) Marapi is located administratively within the Agam and Tanah Datar Regencies in West Sumatra, Indonesia. Geographically, this conical stratovolcano reaches an elevation of 2,891 meters above sea level (m asl) (9,484 feet) and is positioned at coordinates 0°22'47.72" S, 100°28'16.71" E. It is recognized as the most active volcano in West Sumatra, exhibiting both explosive and effusive eruption styles, with an average recurrence interval of approximately four years.

Mt. Marapi is classified as a complex stratovolcano featuring five primary craters: Bancah Caldera (A), Kapundan Tuo (B), Kabun Bungo (C), Kapundan Bongso (D), and Verbeek or Kapundan Tenga Crater (D4). Volcanic activity in Marapi does not always originate from the same crater; eruptions typically follow a linear pattern along an east-southwest alignment between the Tuo and Bongsu craters. Historical records indicate that Marapi has erupted over 50 times since the 18th century, with notable eruptive periods occurring in 1822, 1979, 2004–2005, 2006–2007, 2011, 2012, 2014, 2017, and most recently, 2023–2024.

The surrounding region is primarily characterised by agricultural and livestock-based livelihoods, which benefit from the volcanically enriched soil and the region's cool climate [1]. Mount Marapi also plays a significant cultural and ecological role, attracting residents and tourists for hiking and exploration. However, the recent eruptive episode, from December 2023 to June 2024, which produced ashfall, sandfall, and seismic activity, had severe socio-economic impacts. Approximately 250,000 people within a 10-kilometer radius were affected, and the event led to the deaths of over two dozen climbers, prompting the restriction of tourism.

2.2 Field survey on the impact of the eruption

A field survey was conducted in five sub-districts to assess the impact of the eruption and volcanic materials on cattle farming, forage availability, farmers, and overall farm management: Sungai Pua, Canduang, and Ampek Angkek in Agam Regency, as well as X Koto and Batipuh in Tanah Datar Regency. Within these areas, 55 cattle farms were selected as respondents. A purposive sampling approach was employed to identify respondent farms, following recommendations from the local government and agricultural authorities to ensure the inclusion of those most affected by the eruption.

Table 1 summarizes the background characteristics of the selected respondents. The number of respondent farms per subdistrict ranged from 7 to 16. Flock sizes varied considerably, with Batipuah reporting the highest average (6.6 ± 7.1 cattle/farm), while X Koto had the smallest (1.7 ± 1.1). Various cattle breeds, predominantly Simental and Limousin, were present, with local breeds such as Pesisir cattle also represented. Farmers' average age ranged from 44.3 to 57.3 years, with a male majority in all subdistricts (63.6–100%). Educational attainment varied; elementary school education was most common, particularly in Sungai Pua (70.0%), while some farmers completed junior or senior high school. Household size was relatively consistent, averaging 4 to 5 members. Farming experience differed among many respondents.

Table 1. Background of cattle farms and farm owners as respondents located in Mt. Marapi's eruption-impacted areas.

Parameter	Name of subdistricts:				
	Canduang	**Sungai Pua**	**Ampek Angkek**	**X Koto**	**Batipuah**
Number of farms (farms	16	10	11	11	7
Mean flock size and type of cattle:					
Flock size (cattle/farm)	3.7±1.9	4.2±5.7	2.3±1.6	1.7±1.1	6.6±7.1
Type of cattle	Simental, Limousin, FH, Ongole	Simenta l, Limousin	Simental, Limousin, Pesisir	Simental, Limousin, Brangus	Simental, Limousin, Brahman, Pesisir
Background of farm owners:					
Age (years)	44.6±15.5	53.4±9. 3	57.3±10.5	51.0±14.6	44.3±12.3
Sex (%):					
Male	100.0	80.0	63.6	100.0	85.7
Female	0.0	20.0	36.4	0.0	14.3
Levels of education (%):					
Elementary school	43.7	70.0	36.4	4 (36.4)	2 (28.6)
Junior high school	12.5	0.0	27.3	3 (27.3)	2(28.6)
Senior high school	37.5	30.0	36.4	4(36.4)	2 (28.6)
Number of family members (people)	5.1±1.6	4.7±1.6	4.0±1.5	4.3±1.1	4.6±1.4
Experience in cattle farming:					
≤ 5 years	18.8	10.0)	0.0	18.2	14.3
5-10 years	31.3	0.0	45.5	9.1	42.9
≥ 10 years	50.0	70.0	54.5	72.7	42.9

Data was collected through on-site farm visits and structured interviews with farm owners. During these visits, comprehensive information was gathered on the number and types of cattle raised, herd composition, livestock rearing, and feeding management practices, as well as the eruption's impact on farmers' livelihoods, cattle health, and forage availability. Additionally, challenges in maintaining farm operations during and after the disaster were identified.

2.3 Collection, preparation, and analysis of forage and soil samples

Forage samples were collected from locations where farmers normally harvested fodder or where livestock were regularly grazed or tethered. A stratified random sampling approach was used to capture the full range of plant diversity, ensuring that areas with different topographic conditions and vegetation densities were represented. At each site, five sampling points were selected. At each point, a 0.5 × 0.5 m quadrant frame was randomly placed on vegetated ground, and all plants within the frame were cut 5–10 cm above ground level to simulate the height at which cattle typically graze.

Immediately after cutting, the fresh forage samples were sealed in labelled plastic bags. The samples were weighed and sorted in the laboratory by species to determine botanical composition. Botanical composition was calculated as the proportion of each species' fresh weight relative to the total sample weight, expressed as a percentage. Plant species that made up at least 5% of the total weight were considered predominant.

Forage samples from fields with the same level of eruption impact were combined and mixed thoroughly to form composite samples. This resulted in six composite samples for each impact level, giving 18 samples (three impact levels × six replicates). The mixed samples were chopped into 2–3 cm pieces, and a 150 g subsample was taken from each composite. These subsamples were oven-dried at 60°C for 48 hours to determine dry matter (DM) content, then ground into a fine meal for analysis. Nutrient analyses included crude ash, crude protein, crude fiber, and mineral content (P, S, Mg, Na), following standard AOAC procedures.

Biomass production in tons of DM per hectare per year was calculated as:

$$\text{Biomass production} = (\text{Fresh weight x } 4) \times 10{,}000 \times (365/60 \times \%\ \text{DM}$$

Daily biomass production was obtained by dividing the annual biomass production by 365. Carrying capacity, expressed as animal units per hectare (AU/ha), was calculated by dividing daily biomass production by the daily DM requirement of one animal unit (2.8% of 454 kg body weight).

Soil samples were collected from the exact locations of the forage samples to assess nutrient availability. Before sampling, plant residues and roots on the soil surface were removed. Soil was then collected from a depth of 10–15 cm using a cement spoon, with approximately 1 kg taken from each sampling point. The fresh soil samples were placed in labelled plastic bags and transported to the laboratory for analysis. In the laboratory, soil samples were manually cleaned to remove roots, gravel, and other debris, and then weighed to determine fresh weight. They were air-dried, weighed again to determine air-dry weight, and then ground to a fine texture using a combination of manual grinding and blending. Soil samples from each eruption impact level were thoroughly mixed to form six composite samples per level, resulting in a total of 18 samples. The prepared soil samples were analyzed for nitrogen (N), phosphorus (P), sulfur (S), and magnesium (Mg). Magnesium and sulfur were determined using flame photometry according to the methods of Eviati and Sulaeman. All mineral concentrations were expressed on a dry matter basis.

2.4 Statistical analysis

The survey result data is calculated as an average and a percentage. Data on forage biomass production and mineral content of soils and forage were statistically analysed using a one-way analysis of variance (ANOVA) with SPSS software version 18. The variance analysis was followed by Duncan post hoc multiple comparisons to estimate significant differences between means at $p < 0.05$. The results were expressed as mean ± SD. The mean concentrations of the determined forage minerals were compared with the standard mineral requirements of grazing cattle.

3 Results and Discussion

3.1 Impact of eruption and volcanic materials

The December 2023 eruption of Mt. Marapi caused substantial disruptions to livestock, forage availability, and farmer livelihoods in West Sumatra, with impacts varying by proximity to the eruption center and prevailing wind patterns. The affected areas were categorised as having severe, moderate, or low impact based on the observed effects.

- Severe impact: Livestock exhibited health problems, and forages were destroyed or heavily contaminated with ash.
- Moderate impact: Cattle remained healthy, but forage scarcity occurred due to damage and contamination.
- Low impact: Livestock and forage supplies were unaffected, but farmers faced economic losses due to reduced crop yields and lower market prices.

Table 2. The severity of the eruption impacts Mt. Marapi on grazing cattle, forages, and farmers

	Eruption impacts:			
	Severe	**Moderate**	**Low**	**Total**
Cattle	Livestock experienced various health issues, including sore eyes, fever, digestive problems, cough, bloating, and diarrhoea.	Cattle remained healthy	Livestock and forage supply were unaffected.	
Forages	Forages were either destroyed or heavily contaminated, resulting in feed scarcity.	Forage scarcity was prevalent due to damage and contamination.		
Farmers	Income has decreased drastically due to crop damage	Decreased income due to crop damage, reduced crop yields, and declining market prices	Farmers faced economic losses due to reduced crop yields and declining market prices	
Distribution of selected farms in different eruption impacts of Mt. Marapi (%):				
Canduang subdistrict	2 (12.5)	7 (43.8)	7 (43.8)	**16**
Sungai Puar subdistrict	5 (50.0)	3 (30.0)	2 (20.0)	**10**
Ampek Angkek subdistrict	5 (45.5)	5 (45.5)	1 (9.1)	**11**
X Koto subdistrict	2 (18.2)	2 (18.2)	7 (63.6)	**11**
Batipuah subdistrict	3 (42.9)	1 (14.3)	3 (42.9)	**7**
Total	**17** (30.9)	**18** (32.7)	**20** (36.4)	**55**

Among the 55 farms surveyed, 30.9% experienced severe impacts, 32.7% moderate impacts, and 36.4% low impacts. Severe cases were concentrated in Sungai Puar and Ampek Angkek subdistricts (50.0% and 45.5% of farms, respectively), whereas X Koto had the highest proportion of low-impact farms (63.6%). These patterns suggest that local topography, wind direction, and distance from the eruption center strongly influenced the degree of damage [1,2].

Cattle in severely affected areas developed symptoms such as sore eyes, fever, digestive disorders, coughing, bloating, and diarrhea—likely caused by inhalation of volcanic ash and ingestion of contaminated forage [3]. In moderately impacted areas, livestock remained healthy, though forage availability was reduced. Low-impact zones showed no direct health effects on cattle, but farmers suffered financial losses.

Forage availability followed a similar trend. Pasturelands were destroyed or coated with ash in severely impacted areas, creating acute feed shortages. Moderately impacted areas retained forage, but quality and quantity were diminished. Low-impact areas experienced minimal forage losses but endured indirect economic effects from reduced crop yields and falling market prices. The economic burden was most significant in severely affected areas due to extensive crop damage, followed by moderate zones where market conditions compounded yield losses. Even in low-impact areas, reduced prices eroded farm income [4].

3.2 Impact of eruption on the diversity and biomass production of forages

Table 3 summarises the botanical composition and productivity across the impact zones. Species richness was highest in the severe-impact area (38 species), declined in the moderate zone (31 species), and slightly increased in the low-impact zone (33 species). This trend suggests that volcanic ash influenced species diversity, potentially through differences in species tolerance, recolonization rates, and competitive dynamics.

Grasses dominated all zones, with the highest proportion in the low-impact area (90.8%) compared to severe (79.3%) and moderate (80.4%) zones. Higher grass persistence in low-impact areas likely reflected reduced ash deposition. In contrast, herbaceous and broadleaf plants were more abundant in severe (16.6%) and moderate (18.7%) zones than in low-impact areas (7.7%), possibly reflecting the colonisation of disturbance-adapted species [5]. Shrubs and ferns comprised only minor components of the forage community across all zones.

Table 3. Botanical composition, biomass production, carrying capacity, and dominant species of forage samples collected from different eruption-impacted severities of Mt. Marapi.

Parameter	Eruption impacts:		
	Severe	Moderate	Low
Total number of species (species)	38	31	33
Botanical composition (%)			
Grasses	79.3	80.4	90.8
Herbaceous and broadleaves	16.6	18.7	7.7
Shrubs	3.9	0.6	1.5
Fern	0.2	0.3	0.1
Dominant species (%)			
Pennisetum purpureum	21.1	16.0	20.5
Axonopus compressus	19.0	16.2	8.7
Digitaria sanguinalis	0.3	6.9	14.9
Cynodon dactylon	9.9	5.7	0.2
Biomass production in dry matter and carrying capacity:			
Biomass production, t/y	9.33±0.63	10.58±1.25	9.54±2.10
Biomass production, kg/d	25.55±1.72	28.99±3.44	26.13±5.76
Carrying capacity, AU*/ha	2.16±0.15	2.46±0.29	2.21±0.49

*) AU = animal unit

The dominant species were Pennisetum purpureum and Axonopus compressus, though their abundances varied. Axonopus compressus was less prevalent in low-impact areas

(8.7%) than in severe-impact zones (19.0%). Digitaria sanguinalis was common in low-impact areas (14.9%) but nearly absent in severely impacted zones (0.3%). These patterns indicate species-specific responses to ash deposition and suggest succession processes shaping recovery [5].

Despite shifts in composition, mean biomass production (on a dry matter basis) remained consistent across impact zones, with no statistically significant differences in biomass or carrying capacity. This stability likely reflects the resilience of dominant grasses, which have extensive root systems and rapid regrowth capacity [6,7]. However, the reduced species diversity in the moderate zone suggests that, while overall productivity was maintained, ashfall temporarily suppressed the growth of particular species.

3.3 Mineral status of forages and soils

Soil mineral concentrations varied among zones (Table 4). Total phosphorus (P) ranged from 0.14% in low-impact to 0.20% in moderate-impact areas, remaining above deficiency thresholds. Sulfur (S) levels were stable (238.75–256.80 ppm). Magnesium (Mg) peaked in moderate zones (1624.64 ppm) and was lowest in severe zones (1321.42 ppm). Sodium (Na) varied most sharply, from 416.18 ppm (low-impact) to 759.72 ppm (moderate-impact), although differences were not statistically significant. These variations align with the known effects of volcanic ash on soil chemistry, which are driven by mineral solubility, grain size, and weathering rates [8,9].

Table 4. Mineral means concentration in soil samples (means ± standard deviation) from different eruption-impacted severities of Mt. Marapi.

Minerals in DM	Eruption impact:			Critical levels (ppm *)
	Severe	Moderate	Low	
P total (%)	0.16±0.05	0.20±0.13	0.14±0.06	< 10
S total (ppm)	245.01±28.36	238.75±30.21	256.80±34.69	< 10
Mg total (ppm)	1321.42±410.76	1624.64±840.60	1496.55±838.34	< 30
Na total (ppm)	573.96±270.77	759.72±237.99	416.18±41.50	< 62

*) [30]; [31]

Forage mineral levels generally mirrored soil trends (Table 5). P ranged from 0.32% to 0.36%, remaining within the adequate range. Mg and S were stable, though S rose slightly in low-impact zones. Na was highest in severe zones (346.64 ppm) and much lower in moderate (92.97 ppm) and low (113.17 ppm) zones. Copper (Cu) was consistently low (4.79–5.31 ppm), approaching the critical deficiency threshold of 8 ppm, [12].

Low Cu availability likely reflects high soil concentrations of antagonistic minerals, such as molybdenum (Mo), sulfur (S), and iron (Fe), which form insoluble complexes or compete for absorption [10,11]. Even if total soil Cu is adequate, its plant-available fraction may be limited, particularly in organic-rich volcanic soils where Cu binds to humic matter. Persistent Cu deficiency in volcanic grazing systems can impair immune function, reproduction, and growth, creating a feedback loop of reduced productivity and slower pasture recovery.

The absence of significant differences among zones may stem from uneven ash deposition, wind-driven dispersal, soil binding effects, and species-specific uptake patterns [13, 14]. Localised enrichment or depletion of Na likely reflects microtopographic effects and the distribution of ash particles. While P, Mg, and S remained within safe ranges, Na variability may influence grazing behavior and hydration due to its role in osmotic balance.

Table 5. The mean concentration of dry matter (DM), crude ash, and minerals of forage samples (means ± standard deviation) collected from different eruption-impacted severities of Mt. Marapi

Parameter	Eruption impact:			Critical levels (%)**)	Maximum tolerable level***)
	Severe	Moderate	Low		
DM and crude ash content:					
• DM (% FW*)	25.27±5.34	20.36±5.86	20.63±5.53		
• Crude ash (% DM)	14.68±3.07	15.53±1.97	16.39±2.42		
Minerals in DM:					
• P (%)	0.34±0.10	0.36±0.08	0.32±0.09	< 0.25	
• Mg (%)	0.39±0.11	0.36±0.16	0.38±0.17	< 0.10	0.40
• S (%)	0.34±0.10	0.35±0.12	0.44±0.33	< 0.08	0.50
• Na (ppm)	346.64±335.86	92.97±66.66	113.17±70.41	< 0.06	
• Cu (ppm	4.97±2.16	5.31±1.22	4.79±19.61	< 8	40

*) FW = fresh weight; **) [14] and ***) [15]

From a management standpoint, Cu deficiency poses the most urgent nutritional risk. Recommended measures include targeted mineral supplementation, incorporation of Cu-efficient forage species, and rotational grazing to diversify plant intake. Long-term monitoring is essential, as copper (Cu) availability may shift with ash weathering and changes in vegetation. Developing region-specific supplementation programs, such as mineral-enriched feed blocks or seasonal strategies aligned with forage mineral cycles, could sustain livestock health.

4 Conclusion

The severity of the December 2023 Mt. Marapi eruption varied according to proximity to the eruption site and prevailing wind patterns. While forage species diversity differed among impact zones, overall productivity and carrying capacity remained stable. Notably, species diversity declined in the moderate-impact zone, indicating that ash deposition may have temporarily suppressed the growth of particular plant species. Most forage mineral concentrations remained within normal ranges; however, the persistently low Cu levels present a clear and ongoing nutritional risk for grazing cattle. This deficiency, if unaddressed, can impair growth, immune function, and reproductive performance, ultimately reducing livestock productivity and resilience. The findings emphasize the need for continued monitoring and potential Cu supplementation to prevent long-term nutritional deficits in cattle grazing in eruption-affected areas.

Acknowledgments

This article is part of a project titled "Design of feed formula to improve the mineral and nutritional status of grazing cattle in the eruption-impacted areas of Mt. Marapi, West Sumatra". The research scheme, "Penelitian Unggulan Jalur Kepakaran" (PUJK), was financially supported by Andalas University through the Centre for Research and Community Service (LPPM), Batch I, grant number: 351/UN16.19/PT.01.03/PUJK/2024, for the Fiscal Year 2024.

References

1. Neild J, O'Flaherty P, Hedley P, Underwood R, Johnston D, Christenson B and Brown P 1998 Impact of a Volcanic Eruption on Agriculture and Forestry in New Zealand. MAF Policy Technical Paper 99/2. Ministry of Agriculture and Forestry of New Zealand.
2. Putra D E, Supriatna and F.TH.R. Sitanala F TH R 2016 Risk of eruption of Mount Marapi in Tanah Datar Regency (in Indonesian). J. Geosains Terapan, 2(3):7-13.
3. Rozaki Z, Rahmawati N, Wijaya O, Azizah S N, Pratama A C, Pramudya Y, Novianto F, Hanum F F, Rahmat A, Jumakir and Waluyo 2022 Farmers' food security in the volcanic area: A case in Mount Merapi, Indonesia. De Gruyter, Open Agriculture.7: 554–565. DOI: https://doi.org/10.1515/opag-2022-0122.
4. Del Moral R and Grishin S Y 1999 Volcanic disturbances and ecosystem recovery. Ecosystems, 2(2): 137–141.
5. Walker L R and del Moral R 2003 Primary succession and ecosystem rehabilitation. Cambridge University Press.
6. Antos J A and Zobel D B 1985 Recovery of forest vegetation following the 1980 eruption of Mount St. Helens. Vegetatio, 60(2): 133–145.
7. Lata K, Dwivedi S K and Singh A 2018 Nutritive value and yield potential of Pennisetum purpureum in disturbed ecosystems. Journal of Grassland Science, 64(3): 213–225.
8. Duggan B 2020 The impact of volcanic eruptions on agricultural systems: mechanisms and mitigation strategies. Geosciences, 10(6): 234-249.
9. Cronin S J, Hedley M J, Smith R G, Neall V E, Fukasi Y 2003 Environmental hazards of fluoride in volcanic ash: a case study from Ruapehu volcano, New Zealand. Journal of Volcanology and Geothermal Research, 121(3-4): 271-291.
10. McDowell L R 1985 Nutrition of Grazing Ruminants in Warm Climates. Academic Press New York, pp-443.
11. Rhue R D and Kidder D 1983. Analytical procedures used by the IFAS extension soil laboratory and the interpretation of results. Soil Sci Dept. Univ of Florida, Gainesville. USA. 1983.
12. McDowell L R 2003 Minerals in Animal and Human Nutrition. Elsevier.
13. Delmelle P, Lambert M, Dufrêne Y, Gerin P and Óskarsson N 2007 Deposition rate and environmental impact of volcanic ashfall: a review of recent assessments. Earth-Science Reviews, 81(3-4): 120-144.
14. Suttle N F 2010 Mineral nutrition of livestock. CABI.
15. Witham C S, Oppenheimer C and Horwell C J 2005 Volcanic ash-leachates: a review and recommendations for sampling methods. Journal of Volcanology and Geothermal Research, 141(3-4): 299-326.