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Spatial Analisys of Soil Physico-chemical Properties of Land Impacted by Marapi Eruption In Lasi, Agam Regency

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Abstract

The physicochemical properties of soil play a crucial role in determining plant growth, development, and productivity. However, these properties are highly dynamic and can change due to management practices as well as natural phenomena such as volcanic eruptions. This study was aimed to analyze the physicochemical properties of soils under several land-use types (forest, coffee, chili, and rice fields) in Nagari Lasi following Marapi eruption on Dec 03, 2023. Undisturbed and disturbed soil samples were collected at depths of 0–30 cm and 30–60 cm. The results showed that, in general, there were no significant differences in either the physical or the chemical properties of soils across land-use types and soil depths. The soil texture in all land uses and depths was classified as sandy–silt loam, with a very low clay content (5–22%). The bulk density (BD) was <0.80 Mg m^{-3}, total soil porosity (TSP) was moderate, and the hydraulic conductivity (HC) rate was high (20–31 cm h^{-1}), except in rice fields (5.34 cm h^{-1}). The plasticity index (PI) was low in both soil layers (2.21–5.31% at 0–30 cm and 5.63–7.21% at 30–60 cm). Soil chemical properties were also not significantly different among the land uses, particularly pH (5.12–5.86) and total N (0.13–0.41%) for both depths. However, the C/N ratio in the 0–30 cm layer tended to be lower than that in the 30–60 cm layer.

Keywords : *soil depth, land use, soil physical properties, soil chemical properties, soil organic matter*

INTRODUCTION

Plant growth and production are largely determined by the physicochemical properties of the soil, besides climate. Soil physical properties such as texture, structure, bulk density BD, total soil porosity (TSP), infiltration, hydraulic conductivity (HC), water retention, and transmission affect plant root development, nutrient solubility, availability, and transport. Soil physical properties determine the quality of land and the environment.

Land with good soil physical properties will provide excellent environmental quality. Likewise, land degradation is closely related to poor soil physical conditions (Yulnafatmawita *et al.,* 2007). Furthermore, soil chemical properties, such as pH and essential macronutrients, significantly influence plant growth and production (Fadli *et al.,* 2021).

However, soil physical and chemical properties are highly dynamic, changing over time and space, due to both management practices (Yasin and Yulnafatmawita 2018; Yulnafatmawita *et al.*, 2022) and natural phenomena and human activities (Yulnafatmawita *et al*., 2020a). Land management for annual crops will differ from that for perennial crops. Intensive soil cultivation for annual crops, such as horticulture and cereal management will change the physical properties of the soil more rapidly than that for perennial crops (Yulnafatmawita and Yasin, 2018). This is due to the decrease in soil OM content with each tillage practice, especially if OM is not added regularly to the soil. On the other hand, plants will also influence the physical properties of the soil through their roots, canopies, and the OM contributed to the soil (Yulnafatmawita *et al*., 2020b).

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Organic matter, as a soil solid material, is considered as a soil ameliorant, capable of improving the physical, chemical, and biological properties of the soil. For soil physical properties, OM plays a role in forming and stabilizing soil aggregates (Yulnafatmawita *et al.,* 2013), so the soil is less easily destroyed by tillage or rainfall energy, which can cause erosion in sloping area receiving high rainfall.

Organic matter, as an aggregate forming agent, can balance micro- and macropores, improve aeration and drainage, increase plant-available water capacity, and loosen the soil (low BD) (Afner *et al*., 2021). For soil chemical properties, OM will increase the cation exchange capacity (CEC) and provide nutrients for plants (Fadli *et al.,* 2021) when it is enzymatically decomposed with the help of soil biology. Then, OM also becomes an energy source for microbes and macrobes in the soils.

Mount Marapi eruption in December 2023 had accumulated ash on most agricultural land in Agam Regency. The erupted volcanic ash is generally coarse materials, so its accumulation will cause changes in several physical properties of the soil, such as texture, BD, TSP, HC, and PI. Furthermore, volcanic ash has a high nutrient reserve, making it suitable for agricultural land after it has been weathered (Fiantis et al., 2021). One of the agricultural areas affected by the Marapi eruption in December 2023 was Nagari Lasi.

Nagari Lasi is located in Canduang District, Agam Regency, West Sumatra Province, with an area of 17.92 km^2. It is located at the northern slopes of Mount Marapi, the altitude is 1,000-2,700 m above sea level, approximately 13.15 km south of Bukittinggi City and 6.14 km from the summit of the Mount Marapi (BPS, 2024). In addition to its geographic location, Nagari Lasi's has hilly topography with slopes varying from gentle to steep. It is mostly used for agriculture and plantations such as rice, coffee, and vegetable cultivation.

Marapi eruption has happened several times since last two centuries. One of the significant eruption was happened in December 2023. Many agricultural lands around the Marapi were affected by the eruption material. Farmers suffered losses the harvest due to the erupted materials.

In general, land use changes from forest to agricultural land negatively affect the physicochemical properties of the soil. Within the same land use, differences in slope position indicate differences in the physicochemical properties of the soil (Yulnafatmawita and Yasin, 2018). Differences in land management due to land use also influence the physicochemical properties of the soil (Yulnafatmawita *et al.,* 2022). No research has yet been conducted to determine the impact of volcanic eruptions, which add volcanic ash to the soil surface, on physicochemical properties of the soil in Nagari Lasi. Based on the above description, this study was aimed to analyze the physicochemical properties of the soil under different types of land use and soil depth in Nagari Lasi affected by the Marapi eruption.

MATERIAL AND METHOD

This study used a survey method. Soil samples were collected using purposive sampling based on land use (rice fields, chili cultivation, coffee cultivation, and forests) at two depths (0-30 and 30-60 cm) to assess soil physicochemical properties. Three replicates were taken for each land use and depth. There were two types of soil samples: undisturbed (using a ring sampler) and disturbed (using a Belgian bore). The sampling points are shown in Figure 1.

Soil samples were collected within a radius of approximately 6.5 and 9 km from the summit of Mount Marapi on the same slope conditions (0-8%) and within the same soil order. The soil in the study area belongs to Andisol. The study area is an intensive research area for the cultivation of horticulture and plantation commodities such as coffee, in addition to rice fields. The sampling location is at an altitude of 600-1200 m above sea level.

Disturbed soil samples were processed (air-dried, ground, sieved, and water content correction measured) in the laboratory prior to analysis, while undisturbed soil samples were analyzed directly in the laboratory. The

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parameters analyzed were the texture using the Sieve and Pipette method (Gee & Bauder, 1986), BD (Blake & Hartge, 1986), and TSP (Danielson & Sutherland, 1986) using the gravimetric method; HC using the Constant Head Permeameter method (Klute & Dirksen, 1986); OC using wet oxidation method (Nelson & Sommers, 1982); total nitrogen using the Kjehdahl method; pH using the electrometric method; and soil organic matter content was calculated from the soil organic carbon. Data resulted from the laboratory analyses were statistically analyzed using JMP. The calculation of organic matter is shown in Equation 1 (Nelson & Sommers, 1986).

Soil Organic Matter = 1.724 x % C-organic ..(1)

RESULTS AND DISCUSSION

Nagari Lasi is located in Canduang District, Agam Regency, West Sumatra Province, with an area of 17.92 km^2. It is situated on the northern slopes of the Mount Marapi, at an elevation of 1,000-2,700 m above sea level, and has cool air with the temperatures is 15-20°C. Nagari Lasi is approximately 13.15 km south of Bukittinggi City and 6.14 km from the summit of Mount Marapi (BPS, 2024).

Nagari Lasi plays a significant role for agriculture, including rice cultivation, horticulture such chilli, tomatoes, shallot, and perennial crops especially coffee. Based on the area, the largest land use (952 hectares) is forest, followed by rice field (445 hectares), dry fields for crops such as corn, chilies, tomatoes, leeks, coffee, and others (291 hectares), shrubs (34 hectares), and settlements (70 hectares) (BIG, 2023).

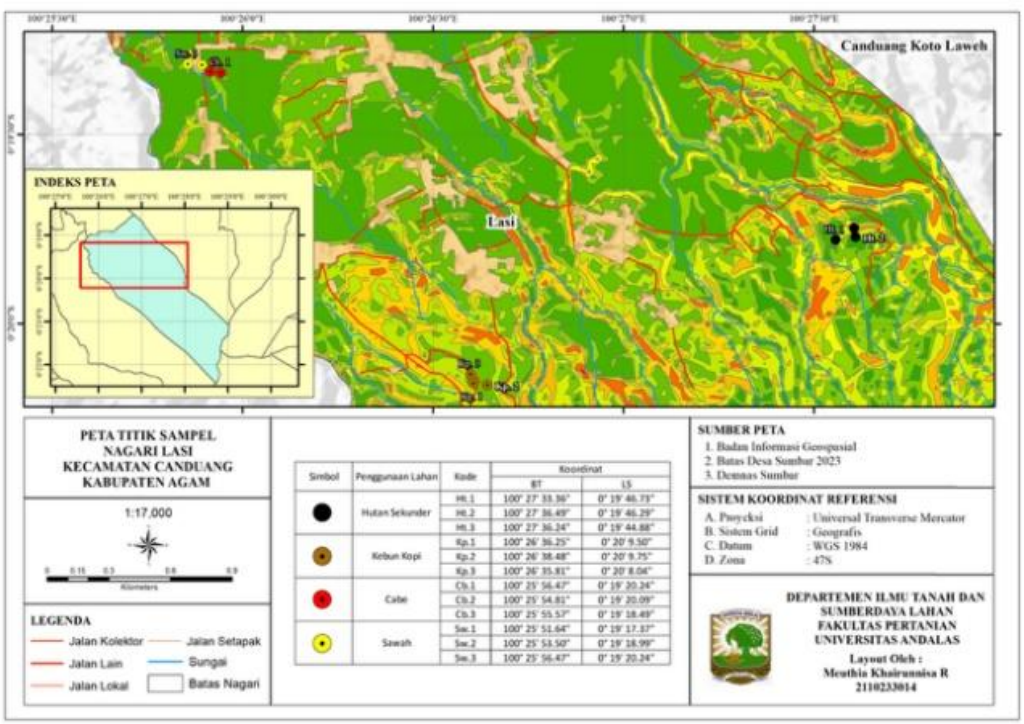

Fig. 1. Map of soil sampling points in Nagari Lasi

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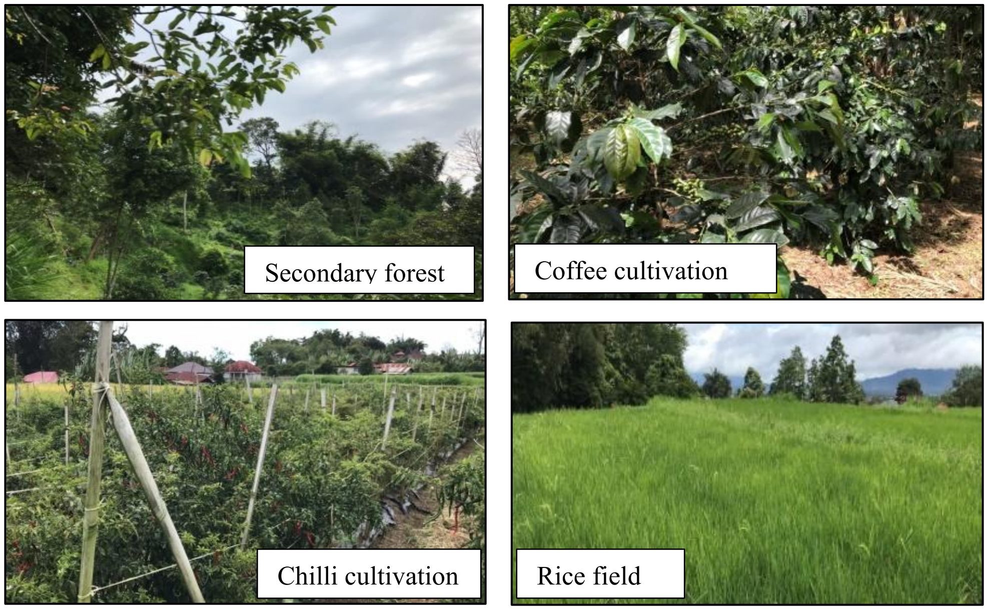

Fig. 2. Four Land use in Nagari Lasi

This diversity influences the physical and chemical properties of the soil, including structure, bulk density, water content, and porosity, aggregate stability, organic matter content, and several chemical properties such as pH, CEC, and plant nutrients. This diversity not only affects the soil capacity to support plant growth but also the environmental quality and overall ecosystem balance.

Nagari Lasi is one of the villages in Candung District, Agam Regency, affected by volcanic ash during the December-2023 Marapi eruption, the largest eruption in the last decade. All areas surrounding the Mount Marapi received volcanic ashfall. Volcanic ash was even reached Lubuk Basung City, located 63 km from Bukittinggi City in the west coast.

The eruption of Mt. Marapi is a natural event that affects the surrounding environment, particularly the physical properties of the soil in the area. The Marapi is an active volcano located on the border between Tanah Datar and Agam Regency in West Sumatra. The eruption occurred on December, 2023 is considered as the largest during the last 3 decades (BIG, 2023).

Water Balance Graph

Fig. 3 shows that the average monthly rainfall is >100 mm. According to Schmidt & Fergusson (1951), months with rainfall >100 mm are considered as wet months. Nagari Lasi has water surplus (Rainfall > ET) throughout the year, except for July, which has water deficit. Therefore, rainfall in Nagari Lasi strongly supports agricultural activities.

The rainfall pattern has two peaks (bimodal): March-April and November-December. Nagari Lasi also has relatively high evapotranspiration, ranging from 3-4 mm per day (90-120 mm per month). This indicates the high intensity of sunlight in this area. High intensity, coupled with sufficient water, promotes good plant growth. Then, the average lower temperature (15-20^{o}C) than the general tropical region results in high net photosynthesis.

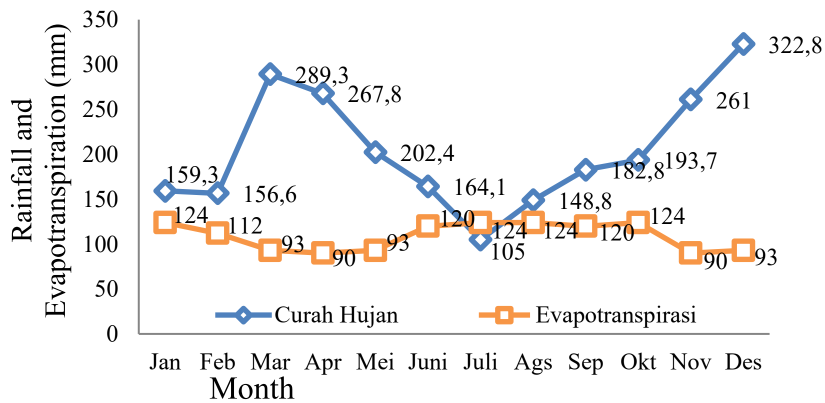

Fig. 3. Water balance in Candung Sub District, Agam Regency

Soil Physical Properties

Soil physical properties presented are particle size distribution (Fig. 4), soil texture class (Tabel 1) and other soil physical properties (Tabel 2).

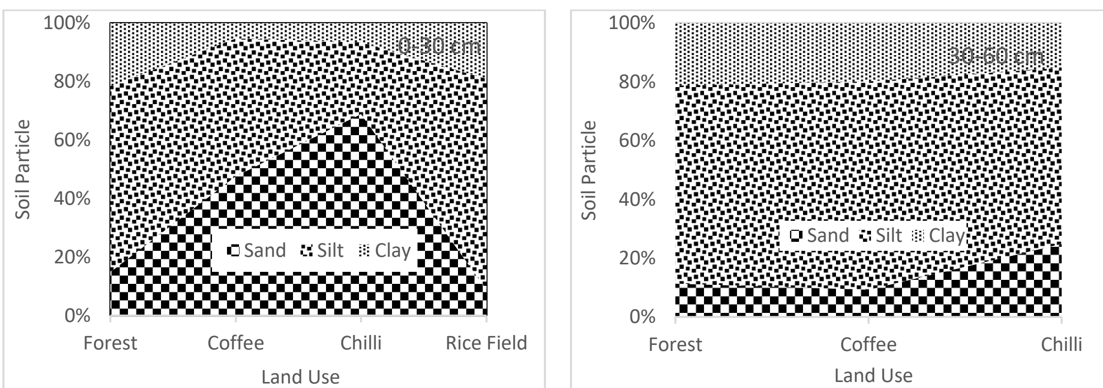

Fig. 4. Soil particle size analyses at several types of land use in Nagari Lasi pasca mount Marapi eruption

Fig.4 shows that, in general, soil at each type of land use being analyzed was dominated by coarse particles (sand and silt). Sand percentage was higher on the top 0-30 cm than on the lower 30-60 cm soil layer. This is due to the effect of material erupted by mount Marapi which is used to silt and sand particles.

At the deeper layer, soil particles were dominated by silt particles. However, less clay particles were found at both soil depths. It is indicated that the soil in the research site is always renewed by the volcanic ash every time the Mt. Marapi erupted. Based on Selviany (2023), it is stated that the Mt. Marapi has erupted since the last 2 centuries (1807). Then, the intense eruption was started in 1985-1990, then 2011 until 2023. This is the reason why the soil particles in Lasi was dominated by sand and silt materials.

Coarse texture soils, sandy to silt loam (Table 1), and less clay cause the soil has less water retention (Anwar *et al.,* 2024), and high vertical water movement downward of the soil. However, since the area receives enough rainfall each month (>100 ml) causes the water enough for crop growth. Therefore, the area was known as one of agriculture production center in Agam Regency.

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Tabel 1. Soil texture class at several types of land use in Nagari Lasi pasca mt. Marapi eruption

Land Use	Soil Texture Class*)	
	0-30 cm	30-60 cm
Forest	Silt Loam	Silt Loam
Coffee	Sandy Loam	Silt Loam
Chilli	Sandy Loam	Silt Loam
Rice Field	Silt Loam	-

Note: *) Soil texture triangle by USDA (BBSDLP, 2006).

Fig. 4 shows that the sand content in the 0-30 cm layer varies from <20% to >70%. The sand content of chili land use was the highest (69%), with no significant difference compared to the coffee cultivation, then decreased drastically (36% compared to topsoil) at the depth of 30-60 cm. Rice fields had the lowest sand particle content among the four types of land use. Measured by horizontal distance, forest and coffee plantations are closer to Mount Marapi (6.8 km), while chili plantations and rice fields are farther (9 km). This indicates that there was a random direction of mt. Marapi eruption.

Silt content in each land use was high at both depths (0-30 and 30-60 cm). This indicates that multiple eruptions have accumulated ash in the soil layer. Rice fields had the highest silt particle content, but this difference was not significant compared to the secondary forest. The percentage of silt at a depth of 30-60 cm tended to be higher than at a depth of 0-30 cm for each land use. This indicates that the material most frequently erupted by Mt. Marapi was silt-sized particles.

Of the three particle sizes that compose the soils, clay particles had the lowest percentage (5-22%), both in the top (0-30 cm) and the bottom (30-60 cm) soil layer. Therefore, the soil texture classified into the loamy class (silty and sandy loam). The low clay percentage results in low water retention capacity.

Table 2. Soil physical properties on four types of land use in Nagari Lasi pasca Mt. Marapi eruption

Land Use	SOM (%)	BD (Mg m^{-3})	TSP (%)	Plasticity Index (%)	Hydraulic Cond. (cm h^{-1})
		0-30 cm			
Secondary Forest	$6,45^{b}$	$0,68^{a}$	$73,02^{a}$	2.21^{b}	$20,36^{a}$
Coffee	$9,42^{a}$	$0,70^{a}$	$71,47^{a}$	2.89^{b}	$31,24^{a}$
Chilli	$5,53^{bc}$	$0,70^{a}$	$73,69^{a}$	2.13^{b}	$27,88^{a}$
Rice Field	$4,00^{c}$	$0,75^{a}$	$71,45^{a}$	5.31^{a}	$5,37^{b}$
		30-60 cm			
Secondary Forest	$5,10^{a}$	$0,73^{a}$	$71,45^{a}$	7.21^{a}	
Coffee	$5,58^{a}$	$0,75^{a}$	$70,26^{a}$	6.99^{a}	
Chilli	$3,86^{a}$	$0,79^{a}$	$69,50^{a}$	5.63^{b}	

Note: Numbers followed by the same small letter in the same column is not significantly different based on t-test (p>0.05)

Table 2 shows that the soil organic matter content in the top layer was higher than in the lower layers. This was due to the higher concentration of OM from the aboveground sources, such as litter and plant residue, compared to sources belowground (root exudates and dead roots, and soil fauna carcasses). Therefore, the soil OM content in the top layer (0-30 cm) is higher than in the lower layer (30-60 cm). The soil OM content at a depth of 30-60 cm decreased by 21% in secondary forest, 30% in chili, and 41% in coffee land use. However, the difference of soil OM content on the lower layer was not significant.

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Soil OM content will affect the soil BD, TSP, HC, and plasticity index. In general, the soil BD level is quite low (<0.8 Mg m^{-3}), and not significantly different among the four types of land use as well as either on the top 30 cm or on the lower soil layer (based on JMP analysis). This was due high silt content derived from volcanic material. According to Fiantis (11), soil BD <0.85 Mg m^{-3} is one characteristic of Andisols, which is soil that develops from volcanic ash. Furthermore, a high organic matter content also significantly reduces the soil BD value.

Soil BD is inversely proportional to TSP (Yulnafatmawita & Adrinal, 2014; Yulnafatmawita *et al*., 2022). Therefore, increasing soil BD decreased the TSP. However, based on the JMP analysis, neither BD nor TSP values significantly differed across four types of the land use.

Soil organic matter content and texture determine the level of soil plasticity. Low clay content reduces soil plasticity. Soils with high sand and silt particles are less likely to deform as easily as clay. Furthermore, a relatively high OM content resulted in a very low the soil plasticity index. Compared to the layer 0-30 cm, the soil plasticity index on the 30-60 cm layer tended to be higher. This is due to the lower organic matter content and the relatively higher clay particle content on the lower layer (Table 1).

Among the four land use types, plasticity index under rice field was the highest on the top 30 cm soil layer. This was due to rice field had high clay and the lowest soil OM content. Clay increases but OM decreases the soil plasticity index.

Soil Chemical Properties

Soil Chemical analyses is presented in Table 3.

Table 3 shows that soil pH values significantly differed between perennial crops (coffee and forest) and annual crops (chili and rice) on the top 30 cm soil layer. This may be due to the high OC source in the coffee and forest land use. Soil OM containing OC can chelate aluminum causing soil acidity. However, the soil pH on the underlying (30-60 cm) was not significantly different, due to less source of OM under soil surface. After 10 years Sinabung eruption, it was found that the soil pH value of the soil impacted was 4.14-6.52 (Lubis *et al*., 2021)

Since the OC is proportional (58%) of OM, the tendency in each land use and soil depths was the same as soil OM content. Soil OC was higher on the top 0-30 cm than on the 30-60 cm soil layer.

Tabel 3. Soil chemical properties of four land uses in Nagari Lasi pasca mt. Marapi eruption

Land Use	pH	Org-C (%)	Total-N (%)	C/N Ratio
		0-30 cm		
Secondary Forest	5.86^{a}	3.75^{b}	0.29^{ab}	12.93 ^{b}
Coffee	5.49^{ab}	5.48^{a}	0.41^{a}	13.37 ^{b}
Chilli	5.43^{b}	3.22^{bc}	0.16^{b}	20.13 ^{a}
Rice Field	5.12^{b}	2.32^{c}	0.16^{b}	14.50 ^{b}
		30-60 cm		
Secondary Forest	5.74^{a}	2.96^{a}	0.20^{b}	14.77 ^{a}
Coffee	5.42^{a}	3.41^{a}	0.35^{a}	9.74 ^{a}
Chilli	5.60^{a}	2.25^{a}	0.13^{b}	17.31 ^{a}

Note : Numbers followed by the same small letter in the same column is not significantly different based on t-test (p>0.05)

Total soil nitrogen was higher in secondary forest and rice field, and significantly higher than that in coffee and chili land use. Higher total N in forest was naturally happened,

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but on rice field was due to management given to the land, especially fertilization practice for rice growth. However, the total N on the lower depth followed the tendency of soil pH and OC content which was not significantly different among the land use types. Total N content of Sinabug was reported very low to high (0.13-0.60%) (Lubis *et al.,* 2021). Soil C/N ratio on the soil layer was fluctuated from 9.74 – 20.13. The value of C/N ratio under chili cultivation was the highest on the top 30 cm soil layer, and also tended to be the highest on the lower layer, even though was not significant. High C/N ratio was due to the fact that the OM under chili cultivation contained less nitrogen, either on the top or on the lower soil layer. Low soil N content under chili means that the OM is quite hard to degrade.

Correlation between soil OM content and other soil properties

Correlation between soil OM and soil physical and chemical properties was presented Fig. 5.

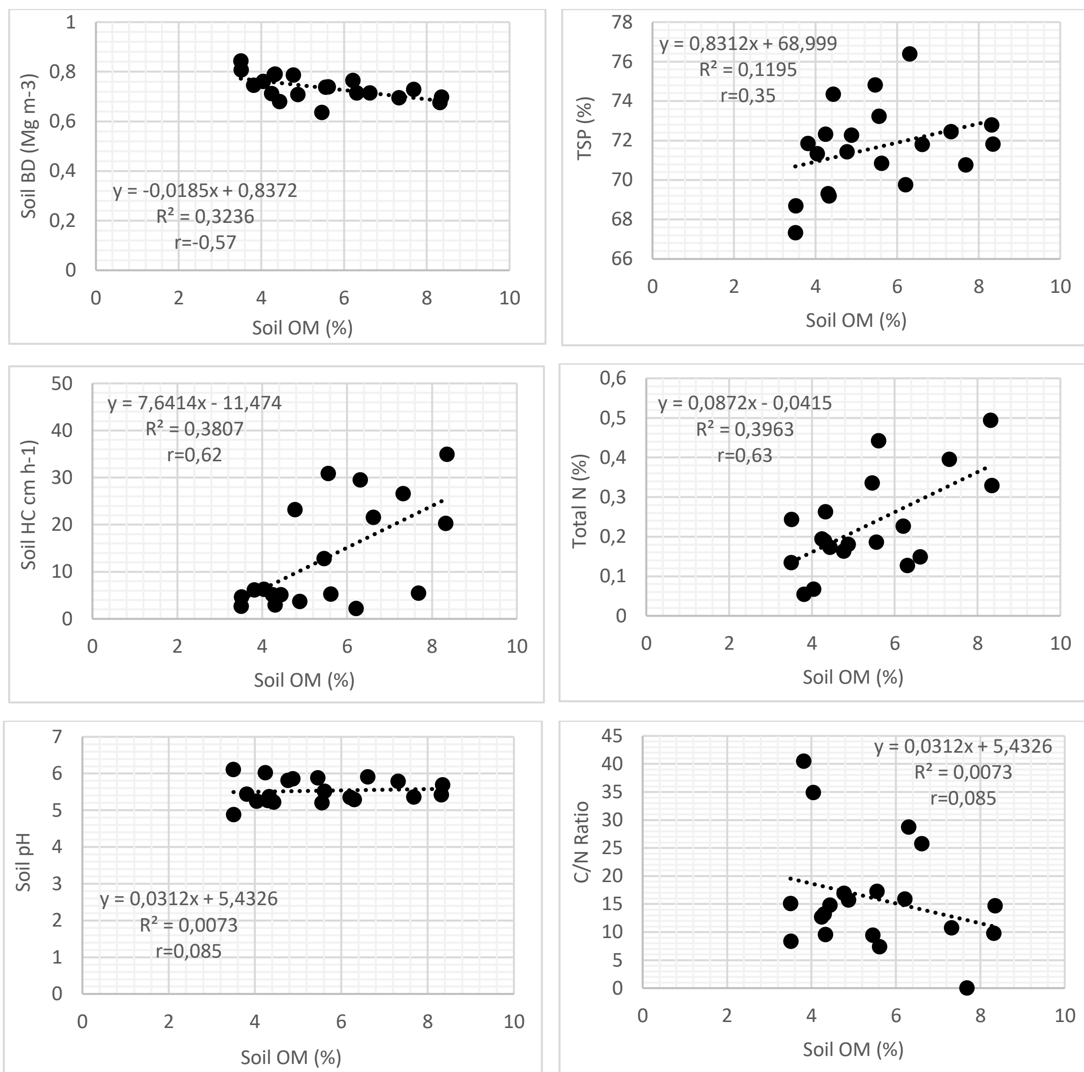

Fig. 5. Correlation between soil OM and some soil physicochemical properties

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Based on Fig. 5, soil OM highly correlated to soil BD (r=-0.57), HC (r=0.62), and total N (r=0.63), but not for TSP, pH, and C/N ratio. Soil OM decreased soil BD, because OM is able to create aggregates which increased the soil porosity. Higher soil porosity will decrease the mass of the soil per unit volume, or the soil BD. Furthermore, low mass of OM per unit volume decreases the soil BD. Besides soil OM, soil texture also determines the soil BD.

Furthermore, high soil OM affecting BD determined soil HC. Soil aggregates bonded by OM produced highly stabile soil aggregates. Because OM is able to stabilize the soil aggregates against sudden water addition. Then, soil OM positively correlated to soil total N. Since OM consisted not only OC but also N. Therefore, increasing soil OM also increased the soil OM.

Furthermore, high soil OM affecting BD determined soil HC. Soil aggregates bonded by OM produced highly stabile soil aggregates. Because OM is able to stabilize the soil aggregates against sudden water addition. Then, soil OM positively correlated to soil total N. Since OM consisted not only OC but also N. Therefore, increasing soil OM also increased the soil OM.

CONCLUSION

Based on the data resulted, it can be concluded that, in general, the soil texture was coarse, 78-94% for sand + silt particles. The clay content in each land uses and depths was <22%. The soil texture was sandy-silt loam.

The soil OC content is relatively high. It was higher on the surface layer (4.00-9.45%) than on the lower layer (3.86-5.58%). The soil BD value (<0.80-Mg m^{-3}) and TRP (>70%) were moderate. The soil permeability rate was quite high (20.36-31.24 cm h^{-1}) except in rice fields (5.37 cm h^{-1}). Soil chemical properties fluctuated, including pH (±5.12-5.86), total N (0.13-0.41%), and C/N ratio (9.74-20.13) at both depths for each land use.

Soil OM highly correlated to soil BD (r=-0.57), HC (r=0.62), and total N (r=0.63).

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