Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2022.v27i2.79-87

Effect of Land Use Change on Soil Physico-chemical Characteristics in Sungai Batang, east part of Maninjau Caldera

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Received 05 January 2022, Revised 02 February 2022; Accepted 12 April 2022

ABSTRACT

Land-use change from the forest to others will affect the soil's physicochemical properties. The research was conducted to identify soil physicochemical properties affected by land-use change in Sungai Batang, the east-south part of Maninjau caldera. The research used a survey method from which soil was sampled at four different types of land use (forest, bushland, mixed garden, and paddy soil) at 0-30 cm depth with three replicates. The results show that the soil in Sungai Batang was still developing. It was indicated by coarse soil texture (clay loam to sandy clay loam). Land-use change from the forest to other uses has altered some soil physicochemical properties. It increased soil bulk density and decreased total soil porosity, permeability rate, SOM content, and total-N. However, there was an increase in soil characteristics, especially soil P-availability, CEC, Ca- and Na-exchangeable . While the soil pH (H_2O), K- and Mg-exchangeable stayed the same. In general, land use changed from forest to other use, mostly farming land degraded physicochemical characteristics of the soil derived from volcanic materials in Sungai Batang. That was mainly due to the decrease in SOM content.

Keywords: Caldera maninjau, land-use change, Physico-chemical characteristics, Sungai Batang, volcanic material

INTRODUCTION

Soil's physical and chemical properties, especially content and type of clay, soil organic carbon (SOC), and season determined soil functions (Valle et al. 2018). Physico-chemical characteristics of soil will determine the fertility degree of the soil as the primary medium for plant growth. Physical soil properties mainly affect the soil's ability against degradation, whether due to natural or anthropogenic degradation. Mismanagement by human action will accelerate soil degradation, mainly when the soil is not cultivated based on conservation rules. This condition will be more affected in the sloping area.

The sloping area is susceptible to soil degradation, especially in the region receiving high rainfall. Nagari Sungai Batang, which is the crater of Mount Tinjau, has a steep slope. According to the Meteorology, Climatology and Geophysics Agency (BMKG) Sicincin, the Sungai Batang area receives 2730 mm rainfall per year (classified as wet climate). Steep slopes will facilitate the flow of water on the soil surface, accelerating the process of land degradation. Besides being influenced by slope and rainfall, soil development in the Sungai Batang is also determined by the type of land use. Mount Tinjau, which relatively recently erupted around 52 thousand years ago (Alloway *et al.* 2004), is indicated by its coarse soil texture. Soil with a coarse texture under high rainfall will quickly absorb the nutrients.

Land-use change from forest to farming land will differ in soil characteristics and physical, chemical, or biological properties. It could improve or worsen soil behavior. Land-use change from forest to corn cultivation reduced SOM stock by 128% under Inceptisols and 14% under Oxisols in Lima Puluh Kota, the tropical area (Yulnafatmawita *et al*. 2020). However, Yulnafatmawita *et al.* (2020) reported land-use conversion from the forest into tea plantation in volcanic soil in Batang Barus dan Gunung Talang, Solok Regency, increased SOM stock and improved soil physical properties. Land-use change from forest to others in recently developed soil in the east part of Maninjau caldera was studied to determine the effect on soil physicochemical properties. Yulnafatmawita and Yasin (2018) found that land use covered by grass contained more SOM content than under intensive seasonal crops' cultivation. Soil having high SOM content would have stable soil aggregates (Yulnafatmawita *et al.* 2013). Decreasing soil carbon content was an indicator of rice field degradation in China (Jin *et al*. 2021).

MATERIALS AND METHODS

This study was conducted in Nagari Sungai Batang, Maninjau District, Agam Regency. The area is located within Mt. Tinjau crater, which erupted approximately 52 (Alloway *et al*. 2004) to 60 thousand years ago (Setyahadi *et al.* 2012). It has a lake terrace and cliff wall with a gentle steep slope. Most people cultivate crops on the lake terrace, such as rice which was rotated with seasonal crop farming, especially corn, peanut, and onion (±357.07 ha), then land planted with perennial crops such as cacao, nutmeg, clove, cinnamon, durian, avocado (±173.53 ha). Some abandoned cultivated lands were grown by bush (±69.81 ha). Then, the secondary or primary forest was on a very steep slope (±1181.42 ha) and then housing (±22.91 ha). Therefore, there were four main types of land use in Sungai Batang: forest, mixed garden, paddy soil, and bushland. The soil in the research location developed from parent material derived from volcanic materials of Mt Tinjau. The area's climate was hot and wet, with annual rainfall >2500 mm. The soil order in this location was classified into Inceptisol based on soil map data of West Sumatra Province (Figure 1).

This research was conducted using a survey method. Soil samples were taken from each land use type (paddy soil, mixed garden, bushland, and secondary forest). Soil samples were taken from the top (0-30 cm) of the soil profile in the land use with three replicates. The replicates of soil samples were randomly collected at the same slope level (15-25%) in each type of land use. For soil samples taken to the soil laboratory, undisturbed (for soil bulk density, total porosity, and permeability analyses) and disturbed (soil texture, organic carbon, pH, cations, CEC, and base saturation) were taken to the soil laboratory Andalas University for analyses. Soil bulk density and total soil porosity were analyzed using a gravimetric method. Soil permeability using permeameter based on Darcy's law, soil texture using sieve and pipette method, pH using pH-meter, organic carbon using wet oxidation based on Walkley

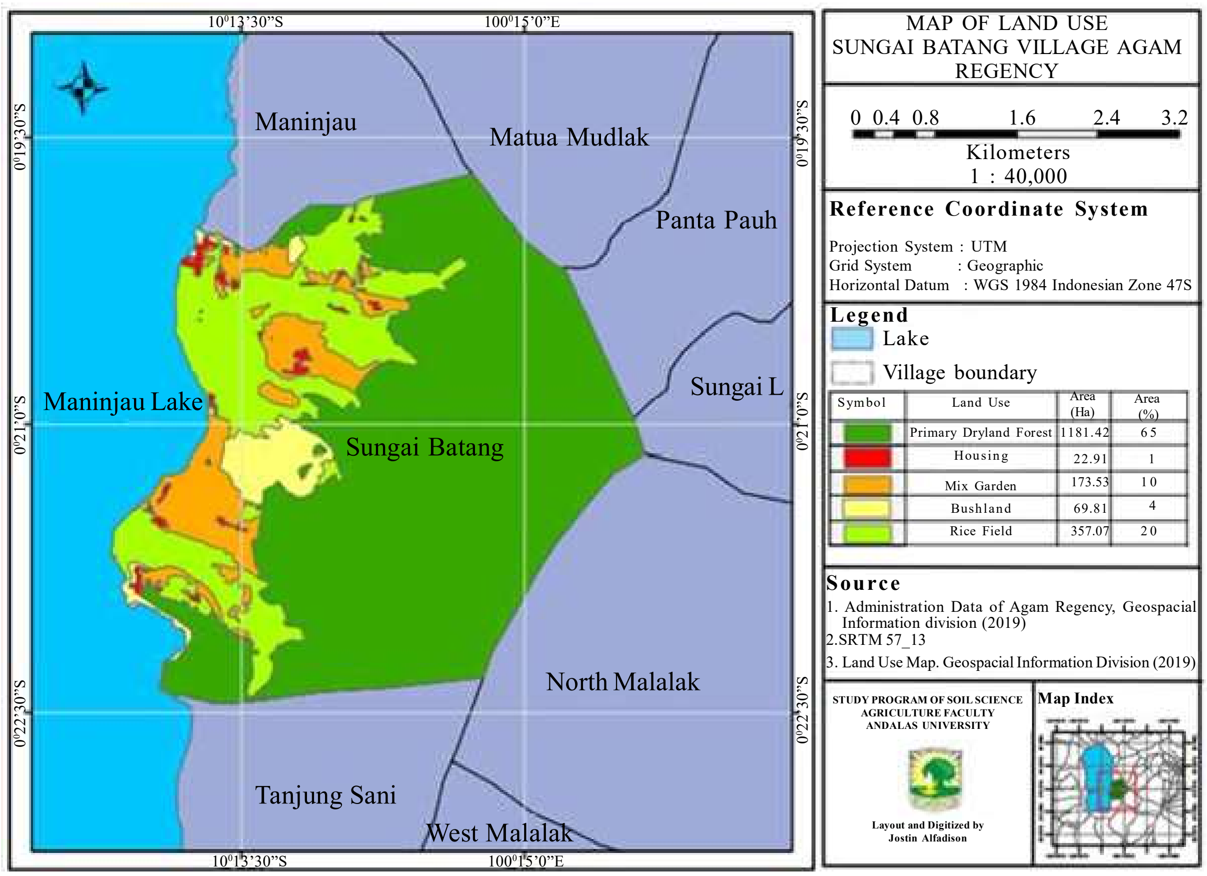

Figure 1. Research location, Nagari Sungai Batang.

Figure 2. Particle size distribution at four different types of land use in Nagari Sungai Batang, Maninjau Region, West Sumatra Indonesia. ▣ : sand %, ▣ : silt, ▣: clay.

and Black, basic cations, CEC, base saturation using leaching method with NH_4-Ac. Then, each element (especially Ca, Mg, K, Na) was run using AAS. Data resulting from laboratory analyses were statistically analyzed using the JMP program, with the mean values being compared using a t-test (0.05), except for texture data.

RESULTS AND DISCUSSION

Soil Physical Properties

Soil's physical properties were presented in figures and tables. Based on Figure 2, it is shown that the soil in Sungai Batang, either under forest, mixed garden, bushland, or paddy soil, was dominated by coarse particles. Approximately 70% of the soil particles consisted of sand and silt (coarse particles) and only about 30% clay particles. Among the three sizes of soil particles arranging soil texture, sand particles showed the dominant (34-55%).

It means that the soil was not wholly weathered because the region was relatively newly developed after the eruption of mount Tinjau. Based on Alloway *et al.* (2004), the mount Tinjau erupted approximately 52k years ago. Therefore, the parent material, volcanic material, was still being weathered.

As stated in Table 1, the class textured of the soil for types of land use was sandy clay loam to clay loam. Soil with high sand particles or coarse texture class is used to have low aggregate stability but a high permeability rate. Therefore the soil is suitable for dryland crops. However, high silt content under paddy soil has caused the single particles to be degraded, and then they will fill and clog the soil pores. Therefore, the soil can be used for rice cultivation under flooding. In general, the region of Sungai Batang and Maninjau was known as a center for rice production for Agam Regency.

Soil Bulk Density (BD), Total Soil Porosity (TSP), and Permeability Rate

Soil bulk density was significantly different among the types of land use. A significant difference was also found for total soil porosity and permeability rate. The highest soil BD was found under bushland. At the same time, the lowest soil BD, the highest TSP, and permeability rate were found under forest land use. This was in line with the result found by

Table 1. Soil texture class at four different types of land use in Nagari Sungai Batang, Maninjau Region, West Sumatra Indonesia.

Land Use	Sand	Silt	Clay	Texture Class
		%		
Forest	46.97	22.43	30.60	Sandy Clay Loam
Mix Garden	48.84	15.01	36.15	Sandy Clay
Bushland	54.69	15.57	29.74	Sandy Clay Loam
Paddy Soil	34.30	36.44	29.26	Clay Loam

Table 2. Mean values of bulk density, total porosity, and permeability rate of soil at four different types of land use in Sungai Batang.

Land Use	Soil Bulk Density ($Mg\ m^{-3}$)	Total Soil Porosity (%)	Permeability Rate ($Cm\ h^{-1}$)
Forest	0.97 c	63.37 a	40.95 a
Bushland	1.53 a	42.12 c	4.08 b
Mix Garden	1.38 ab	47.76 bc	2.42 b
Paddy Soil	1.14 bc	56.86 ab	2.07 b

Note: Data followed by the same small letter in a column are not significantly different based on Student's-t (0.05)

Toohey *et al*. (2018) that the BD of Forest land use of volcanic soil in Costa Rica was the lowest value (0.7 g cm^{-3}) and the highest hydraulic conductivity (>32 mm h^{-1}) among the land use types, sugar cane and pasture. High BD and low TSP in most of the land use in Sungai Batang were due to the development of the soil, which was relatively new, proved by high sand and low clay particles. Sandy textured soils (Tabel 1) having a high percentage of macropores are easy to pass water. Yulnafatmawita *et al.* (2020) reported that soil under tea plantations with high SOM content had low soil BD and high TSP and permeability rate. Land-use change increases soil BD (Campos *et al.* 2007).

The bulk density of paddy soil was still considered high (based on soil physical characteristic criteria). This was due to high coarse particles and low SOM (Table 2, Figure 3). However, it had a low soil permeability rate, needed for rice cultivation. This happened because the soil contained low OM, and the soil's intensive cultivation before rice transplantation degraded the soil aggregates. Silt particles will get into the pores and clog them. Therefore, soil can be flooded on the topsoil for rice growth. Forest conversion into cleared areas decreased the soil's physical quality, significantly increasing the soil BD by 57% (Zaher *et al.* 2020). High soil BD in the four land-use types indicated that the soil was not classified as Andisol.

Soil Chemical Properties

Soil pH H_2O (1:1)

Based on laboratory analyses, the soil's pH H_2O (1:2) value under different land-use types in Sungai Batang was not significantly different since the soil in the research location was still relatively new (Table 3, Figure 4). It was developed from volcano material erupted by mount Tinjau approximately 52k years ago (Alloway *et al*. 2004). Therefore, the soil particles were not yet wholly weathered, and the coarse particles have more minor elements causing low pH.

Among the land use types, soil pH under paddy soil tended to be the highest (6.59). It was 12.5% higher than that under bushland (5.86). Soils being abandoned and undisturbed showed the highest level of acidity (Campos *et al*. 2007). The high soil pH

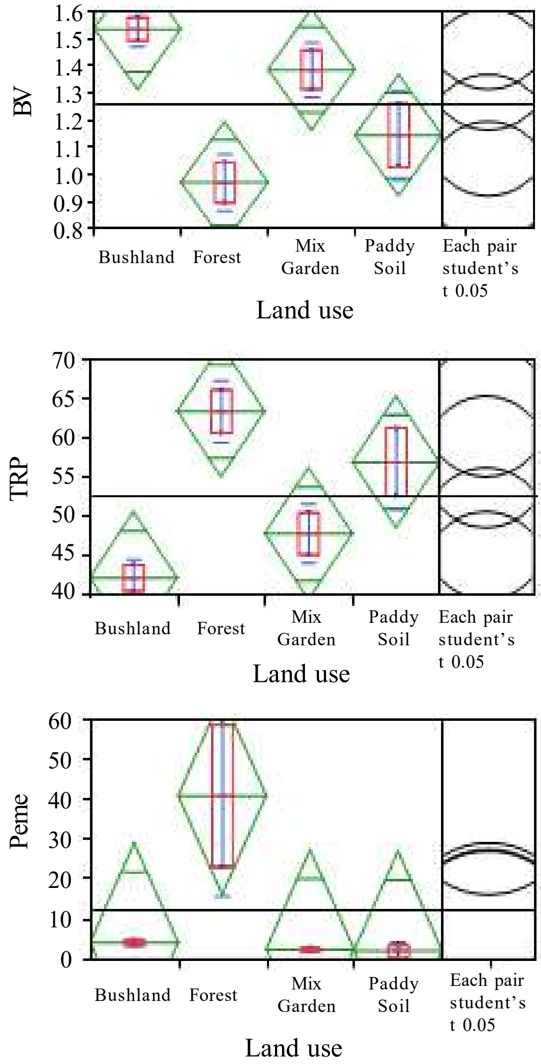

Figure 3. Variability of bulk density, total porosity, and permeability of soil at four different types of land use in Sungai Batang.

Table 3. Values of soil pH and P-availability under four types of land use in Sungai Batang.

Land Use	pH H_2O (1:1)	pH KCl (1:2)	P-Available (mg kg^{-1})
Forest	6.53 a	5.21 b	0.52 b
Bushland	5.86 a	5.46 ab	0.92 a
Mix Garden	6.42 a	6.00 a	0.36 b
Paddy Soil	6.59 a	5.62 ab	0.66 ab

Note: Data followed by the same small letter in a column are not significantly different based on Student's-t (0.05)

value under rice fields could be due to the ameliorant such as fertilizer added at each cropping season to the rice field. Some fertilizers added during rice cultivation contain a carrier, such as Ca (for phosphorus-containing fertilizer), which can cause high soil pH.

Compared to the soil chemical criteria for plant growth, the soil pH in the research area was slightly acid, except for forest land use which was classified as an acid. It means that almost all types of food crops can grow well because most plant nutrients are available at the soil pH values (close to neutral). The soil pH, which was classified as slightly acid, was due to the condition climate being wet (> 2500 mm/year). The soil texture was dominated by coarse size particles that had a low ability to absorb cations. Therefore, the cations were leached by rainwater as plants did not yet take them. Therefore, the probability of cation leaching from the soils was high.

In general, soil pH extracted with KCl (1:2) showed a significant difference among land-use types. Mix garden land use had the highest soil pH (6.0), higher by 0.79 points (±13%) than under secondary forests due to the land use's highest clay content. High clay means that the soils have more colloids or negative charges, and, of course, they will have more cations adsorbed on them. More basic cations will cause a higher pH value in the soil. Hendra (2021) also found that soil pH ranged between 5.5-6.5 (pH H_2O) and between 4.1-6.0 (pH KCl) in the east-south part of Maninjau caldera. Compared to soil pH extracted with H_2O, the pH values extracted with KCl were lower, showing that negative charges dominated the adsorption site (soil colloid).

Available P was significantly different among types of land use. The highest P-available was found under paddy soil type of land use, and it was significantly higher than that under bushland and mixed garden. It was 139%-256% higher than the others. Higher P-available under paddy soil mainly correlated to the fertilizer application to the soil at each cropping season. Jiang *et al*. (2021) reported that phosphorous addition to soil would strongly affect soil P-availability. Higher P availability in paddy soil and forest was also affected by higher soil pH values (Figure 2) under land use. The availability of P in

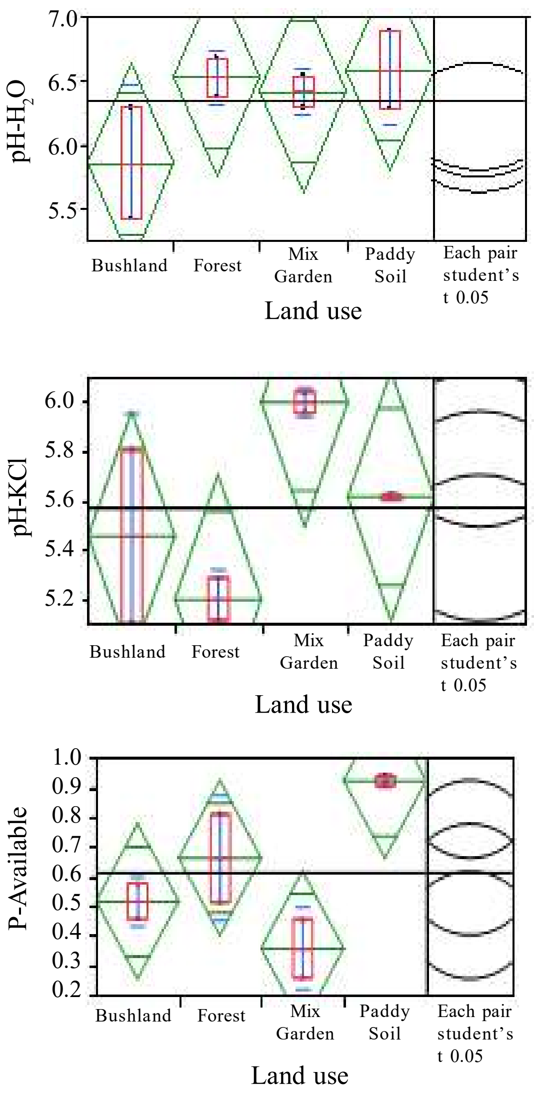

Figure 4. Variability of soil pH (H_2O and KCl) and P-available values at different types of land use in Sungai Batang

Table 4. Mean values of SOM, Total-N, C/N ratio, and P-availability under four types of land use in Sungai Batang.

Land Use	SOM g kg^{-1}	Tot-N g kg^{-1}	C/N ratio	P-Available1 Mg kg^{-1}
Forest	54.7 a	4.0 a	8.09 ab	0.66 ab
Bushland	52.6 a	3.2 ab	11.13 a	0.52 b
Mix Garden	49.8 a	3.8 ab	7.56 b	0.36 b
Paddy Soil	18.4 b	2.7 b	3.96 c	0.92 a

Note: Data followed by the same small letter in a column are not significantly different based on Student's-t (0.05)

soil is minimal because it will be bound by Al and Feat acid condition (lower pH) and by Ca and Mg at basic condition (higher pH).

SOM Content

Soil organic matter content was significantly different among the land use types (Table 4, Figure 5). Soil OM content in paddy soil was the lowest among the four land-use types, caused by the soil's management effect. Since rice farmers did not use OM on the land (rice field) and the biomass was not returned, the SOM content of the paddy soil became lower over time because of the effect of coarse soil structure, causing OM decomposition and mineralization intensively. Course texture soils have a high percentage of macro-pores, and good aeration, causing decomposing microorganisms to become intensively worked.

However, there was a tendency for the highest SOM content under forest land use among the types of land use due to high OM source and no management given to or disturbance of the land. Therefore, the OM was accumulated over time. It reached 297% of that under paddy soil. Besides high SOC storage, volcanic materials also increase N immobilization and N content in the soil (Yokobe *et al*. 2020)

On the other hand, land use conversion into farming land (especially bushland, mixed garden, and paddy soil) decreased the SOM content to 96%, 91%, and 37% under forest land use. Zaher *et al*. (2020) reported that carbon storage in the forest was much higher than in cleared areas. Land-use change from forest to farming land declined C-stock in Northwest Africa approximately by 70% (Assefa *et al.* 2017). Paddy soil tended to have the lowest SOM content among the land use types. It was classified as shallow SOM content. Low SOM content under paddy soil could be due to management (incredibly intensive cultivation) given to the soil. Farmers used to apply synthetic fertilizer and almost none to return OM to the land. Then, rice biomass was generally burnt instead of degraded and applied back to the soil. Sierra and Causeret (2018) reported that intensive tillage after land-use change in low altitude volcanic soil caused the SOC easy to degrade.

Low SOM content in coarse texture soil will cause low soil aggregate stability, and the soil was easy to degrade and even dispersed as it is cultivated or impacted by rainfall kinetic energy. As the soil is

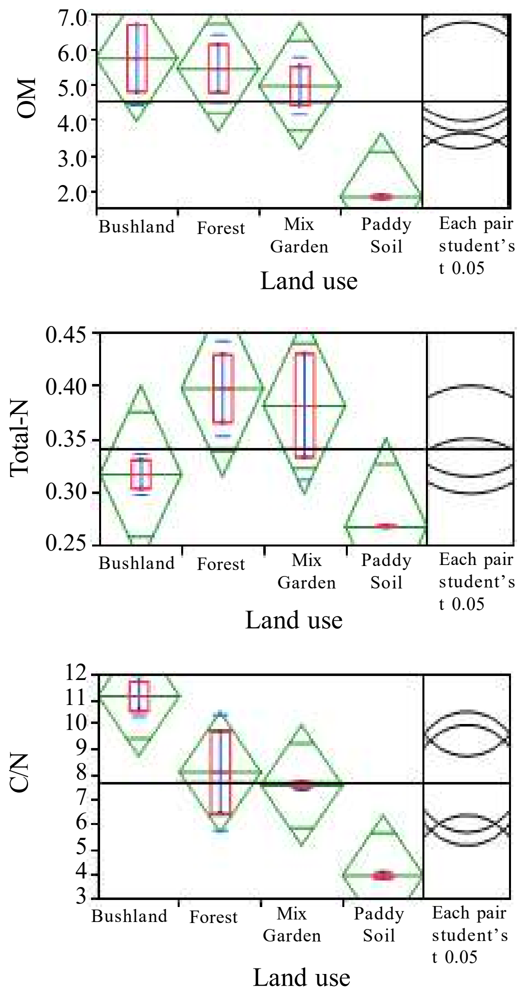

Figure 5. Variability of soil organic matter (SOM) and total nitrogen (Total-N) content and C/N ratio at four different types of land use in Sungai Batang.

intensively cultivated in a sloping area, opened at a certain period each year, such as seasonal crop farming, it will be susceptible to degradation. Soil OC stock decreased by 34% (approximately 1.3 tons/ ha/y) over 32 years due to land conversion in Southwest Cameroon (Nguemezi *et al.* 2021).

As presented in Table 4, the total nitrogen of the soil was significantly different among the types of land use. The total N of the forest was the highest, and it was 148% of the total N under paddy soil. The values followed the values of SOM content. It was found to be true since nitrogen is one of the SOM elements. High total-N under forest land use was due to the high amount of SOM accumulated in the soil. Low SOM content under paddy soil was probably caused by the residue of the crops being generally burnt with no OM addition to the land. Then, N synthetic fertilizer will not accumulate N in the paddy soil. Application of NO_3^- type N-fertilizer will cause leaching or volatilizing if converted to N_2. as reported by Hendra (2021), the total-N content in the east-south part of caldera Maninjau soil was approximately 0.44%.

The carbon to nitrogen ratio was also significantly different among the land use types. The highest C/N ratio was under bushland (11.13), 281% under paddy soil. In general, the value C/N ratio of the soils was relatively low, which means that the SOM was readily decomposed since the soil had a coarse texture providing enough oxygen (good aeration) for microorganisms in decomposing organic material.

Assefa *et al.* (2017) reported that carbon and nitrogen accumulation in soil was mainly affected by climate and soil texture. The SOM and N content of the soil in Sungai Batang under four types of land use was categorized as low to medium. Soil OM ranged from low to medium, and N content was medium due to the high percentage of sand particles arranging the soil texture. Low clay particles under low to medium SOM content will produce less aggregated soils. Therefore, the SOM cannot be physically protected within aggregates, meaning the SOM was easily reached and decomposed by microorganisms.

Soil Exchangeable Cation (K-, Na-, Ca-, and Mg)

Based on Table 5, there was no significant difference in K availability in soil among the four types of land use in Sungai Batang due to the leaching process in the soil. Since the soil was classified as coarse texture soil having a high percentage of macropores, it is easy to leach potassium (K). Potassium is a basic cation having one positive charge, so the adsorption on the colloid is not as tight as the a-two charged cation. Among the four types of land use, forest land use tended to have the lowest K-availability. This is probably due to the pore size of the soil. As the soil texture was classified as coarse-textured soil, dominated by sand particles, it will have high macropores. Since the forest was not cultivated, so the macropores were well-maintained. During rain, the cations, especially K^+, will be easily leached with percolation water. Rainfall in Sungai Batang was high (>2500 mm/year). It means that enough water comes to leach soil cations in the area.

Unlike K, Na availability was significantly different among the types of land use. The highest Na availability was found under paddy soil. It reached 4.1 times higher than that under the mixed garden. Higher Na availability in paddy soil could probably be due to synthetic fertilizer applied to the land at each cropping season, or approximately 2-3 times a year. The carrier of fertilizer could increase the Na concentration in soil.

Calcium exchangeable in four types of land use in Sungai Batang was significantly different. The Ca-exchangeable was found to be significantly lowest under forest land use. It was only 64% of that under paddy soil. The Ca-exchangeable under paddy soil tended to be the highest value even though it was not significantly different from bushland and mixed garden. High Ca-exch in paddy soil was probably due to synthetic fertilizer, such as TSP, with

Table 5. Cations exchangeable of soil under four types of land use in Sungai Batang.

Land Use	K-Exch	Na-Exch	Ca-Exch	Mg-Exch.
	cmol(+) kg^{-1}			
Forest	2.00 a	0.27 b	9.40 b	2.53 a
Bushland	2.76 a	0.19 b	13.80 a	2.41 a
Mix Garden	2.56 a	0.14 b	13.63 a	2.49 a
Paddy Soil	2.49 a	0.58 a	14.79 a	1.86 a

Note: Data followed by the same small letter in a column are not significantly different based on Student's t (0.05)

Table 6. Mean values of cations exchangeable of soil under four types of land use in Sungai Batang.

Land Use	CEC cmol(+) kg^{-1}		Base Sat %	
Forest	23.48	b	61.44	a
Bushland	31.31	ab	61.33	a
Mix Garden	31.64	a	59.51	a
Paddy Soil	25.33	ab	77.78	a

Note: Data followed by the same small letter in a column are not significantly different based on Student's-t (0.05).

Ca as the carrier, and it also affected the pH value of the soil in this land-use type. Compared to soil chemical criteria, the Ca content in the four land-use types was categorized as medium to high. High Ca content within the soil in Sungai Batang was probably due to the soil developed from volcanic materials reaching in calcium.

Unlike Ca-exchangeable, Mg-exchangeable did not show a significant difference among the four types of land use. It was probably due to high rainfall, which could leach the Mg. Besides, there was no Mg addition to the soil. However, there was a tendency for the lowest Mg-exchangeable under paddy soil. Only 73.5% of the Mg was contained in forest land use due to intensive cultivation of paddy soil for rice cultivation compared to the other land-use types. Since there was no Mg addition to the soil, intensive rice cultivation had absorbed more Mg from the soil.

Compared to the soil chemical properties criteria, the soil's Mg content belonged to medium to high. As Ca concentration is high, Ca and Mg within the soil in Sungai Batang are likely to correlate to the soil's parent material, which was material from the Mt. Tinjau eruption.

Cation Exchange Capacity and Base Saturation

Based on JMP analyses, there was a significant difference in CEC among the four types of land use in Sungai Batang (Table 6). Mix garden showed the highest, about 135% of that under forest land use as affected by the clay content of the soil. The soil cation exchanged capacity depends on the clay colloid, the amount and the type, as well as the OM content of the soil. As the mixed garden had the highest clay content (Figure 1). In contrast, the clay content of the other land-use types was about 6% lower than that under the mixed garden. The SOM content did not show the effect on CEC. Forest had the highest SOM content, but it had the lowest CEC value. The CEC values were within the range (18-81 with the average = 45.37 cmol kg^{-1}) of the CEC found by Hendra (2021) in the east-south part of Maninjau caldera.

Based on statistical analyses using the JMP program, there was no significant difference in base saturation among the four types of land use. It was classified between high and very high values of base saturation. High base saturation was affected by high Ca-exchangeable, which was categorized as medium to high based on soil chemical criteria. There was no significant difference among the land use types due to high variation data, especially under forest land use. However, the base saturation tended to be the highest under paddy soil. It showed 131% higher than that under mix garden. High base saturation

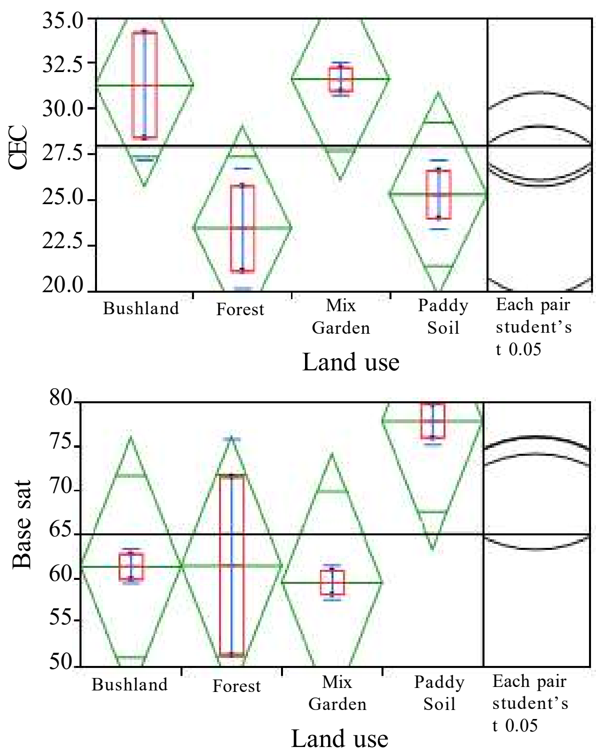

Figure 6. Variability of soil CEC and base saturation at four different types of land use in Sungai Batang.

under paddy soil was supported by high soil pH and Ca- and Na-exchangeable soil.

CONCLUSIONS

Land-use change from the forest to other uses degraded the soil physicochemical properties in Sungai Batang. It was indicated by increasing soil BD (from 0.97 to 1.53 g cm^{-3}), then decreasing TSP (from 63.37 to 42.12-56.86 %), permeability (from 40.95 to 2.07cm h^{-1}), SOM content (from 5.47 to 1.84%), total-N (from 0.40 to 0.27%), C/N ratio (from 8.09 to 3.96%), and P-available (from 0.66-0.36 ppm). However, the increasing of soil CEC (from 23.48 to 31.64 cmol kg^{-1}), Ca-exchangeable (from 9.40 to 14.79 cmol kg^{-1}), and Na-exchangeable (from 0.27 to 0.58 cmol kg^{-1}). While the soil pH (H_2O), K- and Mg-exchangeable stayed the same. In general, land-use change from forest to farming land and bushland of soil derived from relatively recently developed volcanic materials decreased the physical-chemicals properties.

ACKNOWLEDGMENT

Authors would like to thank LPPM Universitas Andalas for the funding under contract number: T/50/UN.16.17/PM.PKM-MUB/2021, as well as Agung Perdana, SP. and Muhammad Farhan Aturullah for soil sampling collection and Dahlia for laboratory analyses.

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