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Organic Matter Sequestration Under Coffee Plantation Based on Slope and Crop Age in Sibarasok Maninjau, West Sumatra Indonesia

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Organic Matter Sequestration Under Coffee Plantation Based on Slope and Crop Age in Sibarasok Maninjau, West Sumatra Indonesia

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Abstract. Organic matter is one parameter of soil properties which can be used as an indicator of soil physical quality and environmental sustainability. The objective of this research was to determine the amount of OM being sequestered under coffee plantation based on slope and crop age at the top 30 cm soil. The research took place in Sibarasok Maninjau, Agam Regency, West Sumatra Indonesia, on which the coffee plantation has been started since the Dutch colonial (in 1936). Based on the research conducted, it was found that the SOC content on the top 30 cm soil was quite high, it reached 4.44% to 7.39% while on the top 5 cm was 8.37%-12.58%. After being calculated with the bulk density of the soil, the stock of OM on the top 30 cm soil was 244 to 368 Mg/ha. Slope showed significant difference on the SOM content. The soil was dominated by loam texture with coarse (sand + silt) particles was >76%, therefore, it had high hydraulic conductivity (12.80 cm/h), but low bulk density (0.93 Mg/m^3), medium total soil porosity (64.73%), and high aggregate stability (137.81) in average.
Keywords: crop age, coffee plantation, OC stock, slope, Sibarasok

1. Introduction

Soil organic matter is known as a soil quality indicator, because it will improve soil properties, either physically, chemically, or biologically. However, it is very dynamic, it changes by time and management given to a piece of land. Change in soil OM will affect soil physical properties determining soil erodibility, especially under sloping area in wet tropical region.

Land use change (LUC) from forest to agricultural land is used to decrease soil organic matter content and finally degrade soil physical characteristics, which finally impact the soil, water, and air environment. Soils being intensively cultivated will decrease the SOM, which cause the soil to be very susceptible to erosion, especially in wet tropical area. Additionally, intensive cultivation of land will also cause rapid oxidation of SOM, which will let an increase in CO_2 emission to the atmosphere. Carbon dioxide gas is one of GHG which contribute > 50% to global warming. This gas can be derived from agriculture especially due to forest clearance and land cultivation. Yulnafatmawita [1] reported that CO_2 emission increased by cultivation. Tumwebaze and Byakagaba [2], reported that agroforestry system of coffee crops can be an alternative way to increase OM sequestration in soil, and to reduce CO_2 concentration in the atmosphere causing global warming.

Land use change from forest into agricultural land will change SOM content, which will cause alteration in soil physical properties as well as environment. Forest clearance or deforestation is an activity causing SOM content and stock in soil becomes low. Low OM content of a soil will decrease soil fertility especially physical fertility besides chemical and biological fertility of the soil. Organic matter was reported to be able to create and stabilize soil aggregates [3] which can resist the effect of kinetic energy of rainfall, as well as to balance soil pores between macro (transmitting water) and micro (retaining water) pores [4]. Loss of OM from soil will allow the soil to have high soil BD and low TSP as well as to decrease soil aggregate stability [3].

In term of soil chemical properties, SOM can contribute nutrients, increase CEC, as well as buffer capacity of the soil [4; 5]. While biologically, SOM can become an energy source for the microbes. For environment, OM sequestration is very important to indirectly decrease runoff causing erosion in sloping areas. Boix-Fayos *et al.* [6] and Yasin & Yulnafatmawita [7] found that there was an indication of soil and OM movement from the top to the lower part of the slope in oil palm plantation. Erosion is known as one of the worst soil degradation phenomenon in the world, which cannot only decrease the *in situ* soil productivity but also the *ex situ* environment.

Land use change from annual crops could increase SOM stock. Zhu *et al*. [8] reported that LUC from agricultural land under intensive cultivation to coffee plantation was able to increase OM sequestration after 17 years in China. Organic coffee cultivation could sequester more carbon than conventional one in China [9; 10] and in India [11]. The older the coffee crops was the more they sequester OM in the standing crops.

As a natural resource, soil has main function to keep productive land and sustainable environment. Land use change from forest into pasture had decrease SOM by 20.3% (from 6.9 to 5.4%) on Ferrosol, as well as by 25% and 40% into pasture and annual crops on Grey Clay soil in Queensland Australia [1]. Then, Yulnafatmawita and Yasin [12] explained that different land use gave different SOM content in several locations in Padang city. They found SOM content of grassland (pasture) was higher than that under annual crop, mix garden, and rice field land use. Then Yulnafatmawita *et al*. [13] reported that amount of OM sequestered in soil under tea plantation was affected by crop age. The older the tea plantation was the higher the amount of OC stock the soil.

Coffee is a tropical crop that can grow from 200-2000 m *asl* and between 14-25°C [14]. It can grow for a long time, but it was trimmed periodically to keep the crop height is ideal. The trims of the coffee become one of SOM source of the soil. The quality of the trims will be different based on the age. Wang *et al.* [15] reported that coffee plantation has an important role in sequestering carbon in soil, the rate of sequestration decreases by age of the crops. Furthermore, they found that >50% of the SOM was accumulated within small aggregates (50-250 μm) especially under old (>50 years old) crops.

This research was conducted to determine SOM stock and some soil physical properties under coffee plantation in Sibarasok having coarse texture soil located on the top ridge of Maninjau lake.

2. Materials and Method

2.1. Research site and time

This research was conducted in local society coffee plantation in Sibarasok Maninjau, West Sumatra, Indonesia in 2020. The area is located at 0°18’54” S and 100°08’54” E, with elevation is ± 800 m above sea level. The plantation was initiated by Dutch during colonialism (1936), and then some were revegetated by local society since the last 6 years. Therefore, there are 3 different ages of coffee in the research site, those were 84, 6, and 3 years old. The coffee was planted at 4 different slope levels (0-8%, 15-25 %, 25-45%, and>45%). Then, as a comparison, soil was also sampled from primary forest. The soil was classified as Inceptisols. Based on the data of crop age, slope level, and soil order, there were 5 land units plus 1 unit from primary forest as presented in Table 1.

Table 1. Land unit being sampled in coffee plantation in Sibarasok Maninjau.

Land Unit	Code	Soil Order	Crop Age (Y)	Slope Level (%)
1	A	Inceptisols	84	0-8
2	B	Inceptisols	84	15-25
3	C	Inceptisols	84	>45
4	D	Inceptisols	6	25-45
5	E	Inceptisols	3	15-25
6	Primary Forest	Inceptisols	-	>45%

2.2. Research method
This research was conducted by using survey method. Soil samples were taken by purposive sampling based on the slope and crop age (there were totally 5 land units). Soil samples were randomly taken at each land unit at the depth 0-30 soil depth and plus 0-5 cm for OC content. There were 3 types of soil samples, those were undisturbed soil sample (using metal core having 7 cm in diameter and 4 cm in height) for bulk density (BD), total soil porosity (TSP), hydraulic conductivity analyses. Undisturbed soil aggregates were used to analyze soil aggregate stability, and bulk soil for soil texture as well as total and labile organic carbon analyses.

Soil samples were analyzed at Soil Laboratory Andalas University from July to October 2020. Soil texture was analyzed by using sieve and pipette method, soil BD and TSP by using gravimetric method, soil aggregate stability using dry and wet sieving method, and soil hydraulic conductivity by using constant head permeameter based on Darcy's law. Soil organic carbon was determined by Wet Oxidation (Walkley & Black) method. The data resulted was calculated the mean and the standard error, and then compared to the soil physical criteria. Soil organic matter (SOM) stock was calculated by using formula [12]:

$$SOM\ Stock = SOM * soil\ volume * \rho b$$

SOM = OC * 1.724
Soil Volume (m^3) = area (m^2) x soil depth (m)
'ρb (=BD) = soil bulk density (Mg/m^3)

3. Results and discussion

3.1 Soil organic carbon content

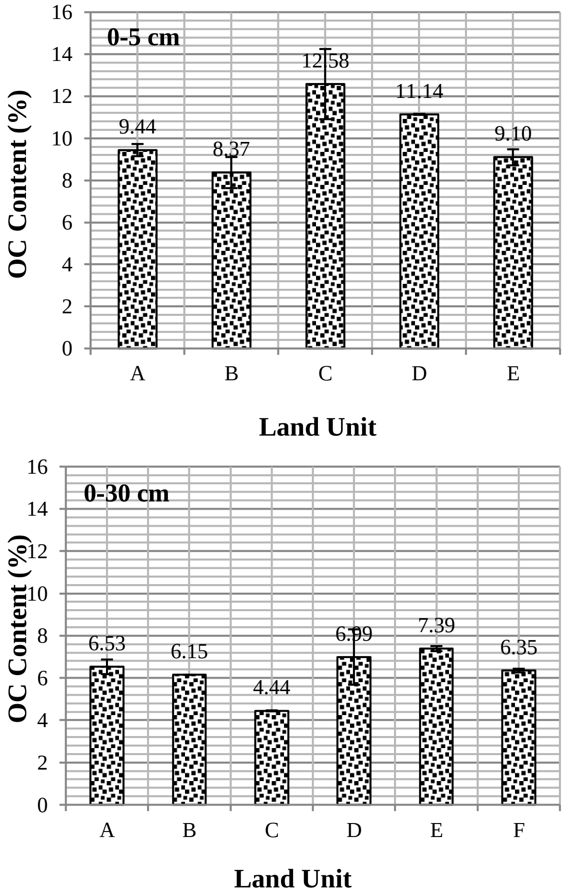

Figure 1. Soil OC content at the top 5 cm and 30 cm soil profile under coffee plantation in Sibarasok Maninjau

As presented at Tabel 1, the percentage of OC content on the top 5 cm soil depth was higher than that on the top 30 cm. It increased from 123 to 283%. The highest percentage of OC (283%) on the top 5 cm was found under coffee having 84 years old and slope >45% (land unit 3 = C). However, it had the lowest OC content (4.44%) on the top 30 cm soil depth. This could be due to the steep slope of the land. Based on survey conducted in the field, the area was highly steep (approximately 100%) slope, therefore, the plant residue was just accumulated on the soil surface. As reported by Yulnafatmawita *et al.* [13] that SOC content decreased by soil depth under tea plantation in wet tropical region.

At Figure 2, it is showed that labile OC content of the soil at 0-5 was lower than that under 0-30 cm soil depth. This could be due to coarse textured soil that coud easily leach the OM from surface into the soil profile through infiltration process. Then, high labile OM frcation at the lower depth could be also due to contribution of the root exudates of the coffee crops.

The OC content consisted of 7-18% labile OC on the top 5 cm and 15-65% on the top 30 cm soil depth. The highest percentage of labile OC percentage (65%) was also found under land unit 3. It means that more than 50% of the SOC on the top 30 cm soil surface was in form of labile fraction. Labile fraction of OC is easy to decompose and provides nutrients for plant growth.

Compared to primary forest in adjacent site, the OC content of the soil ranged between 70-116% on the top 30 cm. It means that the percentage of OC content in the soil under coffee plantation could exceed the percentage of OC under primary forest. However, under very steep slope, the percentage of OC accumulated under coffee plantation after 84 years only 70% of that under primary forest.

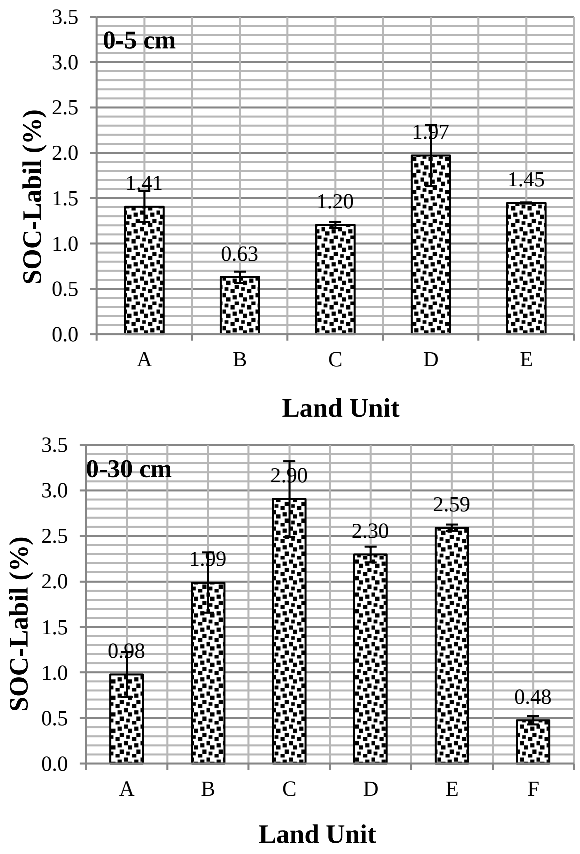

Figure 2. Stock of labile-SOC on the top 5 cm and 30 cm soil profile under coffee plantation in Sibarasok Maninjau

3.2 Soil organic matter stock

Soil OM stock under coffee plantation ranged between 244 to 367.9 Mg/ha. The lowest amount (244 Mg ha^{-1}) was found under coffee plantation having very steep slope (Land Unit 3). This could be due to the effect of slope which cannot retain all of the OM residue on the soil surface. So, the crops residue cannot be all sequestered in the soil to be SOM, even though the crop has already been 84 years old. As detected in the field, the slope of the area was >100%. Compared to primary forest, the amount of OM sequestered in the land unit 3 (C) just reached 65 % of that in the forest.

The highest amount of OM sequestration (367.9 Mg Ha^{-1}) was determined under land unit 2 (B). It was about 98% of the SOM stock under primary forest. Besides at land unit 2, SOM stock under land unit 1 and 6 were comparable (97-98%) of that under primary forest. It means that the coffee plantation can sequestered OM in the soil as primary forest in a rather coarse (>60% coarse fraction) texture soil. Very steep slope tended to be less SOM sequestered in the soil.

However, the age of coffee did not show the tendency of increasing SOM stock by increasing crop age. Even, the amount of SOM stock under 3 years-old coffee crops (land Unit 5) was comparable (about 97%) of that under primary forest. Then, the amount reached 149% of that under land unit 3 (C) which was 84 years old crop. Then, the 6 years-old crop (land unit 4) had lower SOM stock than that of 3 years-old crop.

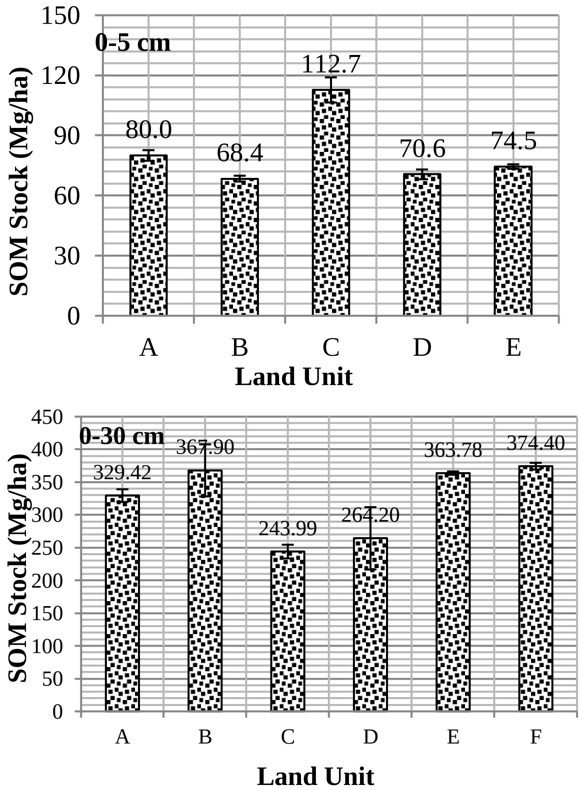

Figure 3. Soil OM stock at the top 5 cm and 30 cm soil profile under coffee plantation in Sibarasok Maninjau

High OC content and SOM stock under youngest coffee crops was seemed to be due to the fact that land being planted with the new crops was originally old coffee plantation. In the area, the coffee crops during Ducth colonialism were not productive anymore, so the local society was replanted with the new ones. Therefore, the previous OM was still sequestered in the land. Then, as the age of the new crops increased from 3 to 6 years-old, the amount of the OM being sequestered decreased due to enzymatic oxidation as the soil surface exposed longer to the sun shine. Organic matter decomposing organisms become more actives as the soil exposed to atmosphere and sun light as long as the soil moisture is enough for the activites.

3.3 Soil physical properties

Soil physical properties being analyzed were soil texture, soil bulk density (BD), total soil porosity, soil hydraulic conductivity, and soil aggregate stability. The data of the soil properties were presented in Tabel 2 and 3. Data of soil particle size distribution and soil texture class at 0-5 and 0-30 cm soil depth were presented in Table 2.

Table 2. Particle size distribution and texture class of soil at 0-5 cm and 0-30 cm soil profile under coffee plantation and primary forest in Sibarasok Maninjau.

Land Unit		Sand (%)	Silt (%)	Clay (%)	Texture Class
0-5 cm soil depth					
1	A	30.8 ± 0.4	40.8 ± 0.5	28.4 ± 0.1	Clay Loam
2	B	51.4 ± 1.7	43.0 ± 1.2	5.7 ± 0.5	Sandy Loam
3	C	30.6 ± 0.4	46.2 ± 0.2	23.2 ± 0.2	Loam
4	D	37.1 ± 5.6	42.8 ± 8.5	20.1 ± 2.9	Loam
5	E	33.9 ± 1.5	45.4 ± 3.1	20.7 ± 1.6	Loam
0-30 cm soil depth					

1	A	28.7 ± 0.7	44.8 ± 1.7	26.5 ± 2.4	Loam
2	B	51.8 ± 1.5	22.7 ± 2.1	25.5 ± 3.6	Sandy clay loam
3	C	19.6 ± 1.0	48.2 ± 1.0	32.2 ± 2.0	Silt Clay Loam
4	D	46.0 ± 2.0	26.8 ± 1.0	27.2 ± 1.0	Sandy clay loam
5	E	40.8 ± 1.5	29.6 ± 2.8	29.6 ± 1.4	Clay Loam
6	Primary Forest	50.1 ± 1.5	25.6 ± 2.0	24.3 ± 0.5	Sandy clay loam

Based on Table 2, soil texture in the research site was dominated by coarse particles which were approximately 70% (sand + silt) for both soil depths. Therefore, the soil texture was classified into loam, from sandy loam to sandy clay loam. The average of sand particles was almost the same (36.75% at the top 5 cm and 39.49% at the top 30 cm soil depth), however the clay content on the top 5 cm was only 71% of that at 0-30 cm soil depth. This was due to the soil was still being developed. The soil was developed from new volcanic deposit from mount Tinjau which erupted about 52 thousand years ago [16]. The research site is the top of mount Tinjau caldera, while the caldera is filled by water to be Maninjau Lake. Since soil texture is one of soil physical properties that cannot change for a long time, it will affect some other soil properties, especially soil physical properties such as soil BD, soil TSP, soil hydraulic conductivity, and soil aggregate stability.

At Table 3 was seen that soil BD ranged between 0.74 to 1.14 Mg m^{-3} (0.97 Mg m^{-3} in average). It meant that the soil BD was generally classified as medium criteria. Actually, soil having high coarse texture, which dominated by sand particles, will have high soil bulk density. However, since the soils had high OC content or SOM stock, the soil bulk density slightly lower. As stated by Yulnafatmawita and Yasin [12], soil BD is affected by particle size and the OM of the soils. Higher soil bulk density of primary forest was due to high sand percentage in the forest land and some material non soil like gravel was found

Soil BD inversely relates to total soil porosity. At the research site, the TSP belonged to medium criteria (63.44% in average) or it ranged between 57 to 72%. Coarse particle soils are used to have low TSP but it is dominated by macropores which can transmit water fast. The TSP of the soil in the research site was considered in medium criteria because it had high SOM. Soil OM can create water stable aggregates and micro pores within the aggregates which can hold more water than that at low OM content.

High sand content as well as high SOM stock in the soil had led the soil to have high hydraulic conductivity values. As it can be seen in Table 3, soil hydraulic conductivity ranged from 8.75 to 29.4 cm h^{-1}. This was classified as very rapid criteria. Sand particles will give high soil macropores which can allow water to pass the pores easily. Then, SOM will cause the aggregates to be stable, therefore they were not collapse by water. Both reasons will cause high soil hydraulic conductivity.

Soil OM also affects soil aggregate stability. Organic matter will create high soil aggregate stability which is stable within water. However, coarse soil texture will be harder to be aggregated than finer (clay) texture soils. Therefore, the soil aggregate stability in the research site ranged from less stable (<50%) into highly stable (>100%). As presented in Table 3 that soil aggregate stability at land unit 2 and primary forest was categorized as less stable. This was due to high (>50%) sand particles in the soils, even though the SOM stock was high enough (98% of the SOM stock of the primary forest). It meant that, aggregate stability of soils was more determined by the texture than the OM content or stock of the soils. This could be understood that coarse texture soils, especially sand particles, did not have colloids that can create metal-OM–metal between the soil particles.

Table 3. Soil bulk density, total soil porosity, hydraulic conductivity, and soil aggregate stability of soil at 0-30 cm soil profile under coffee plantation and primary forest in Sibarasok Maninjau.

Land Unit		BD (Mg m^{-3})	TSP (%)	Hydraulic Cond. (cm h^{-1})	SAS (%)
1	A	0.98 ± 0.02	63.00 ± 0.87	18.01 ± 0.91	120.46 ± 9.21
2	B	0.94 ± 0.02	64.43 ± 0.66	8.75 ± 0.28	49.16 ± 2.74

3	C	1.06 ± 0.04	59.97 ± 1.51	12.14 ± 2.24	119.98 ± 1.86
4	D	0.74 ± 0.01	72.26 ± 0.21	19.27 ± 3.56	95.70 ± 0.23
5	E	0.95 ± 0.02	64.02 ± 0.84	12.09 ± 1.41	103.76 ± 18.54
6	Primary Forest	1.14 ± 0.02	56.98 ± 0.82	29.04 ± 7.05	45.22 ± 2.90

3.4 Correlation between SOM stock and soil physical properties

Soil carbon stock showed different effect on soil aggregate stability. Soil OM stock tended to decrease (R^2=0.4024; r=-0.63), while labile OC tended to increase (r=0.45) the soil aggregate stability under coffee plantation having coarse texture. This was due to the effect of labile OC fraction which is able to bind soil aggregates. Soil LOC stock under coffee plantation having coarse texture tended to decrease (R^2=0.6466; r=-0.80) hydraulic conductivity.

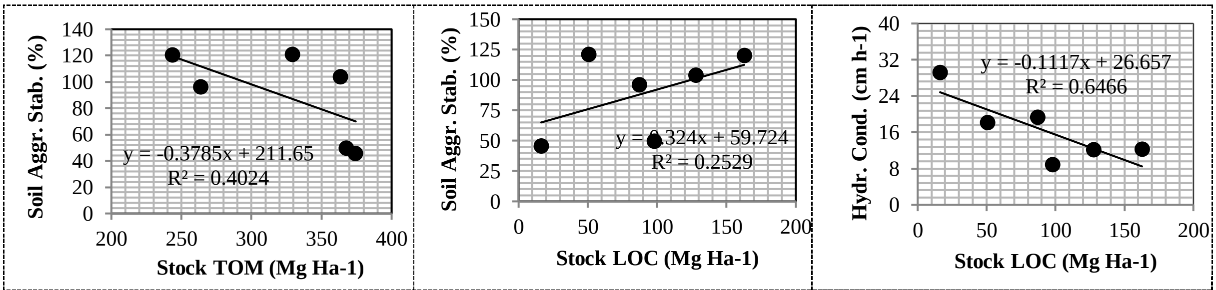

Figure 4. Correlation between carbon stock and some soil physical properties under coffee plantation in Sibarasok Maninjau

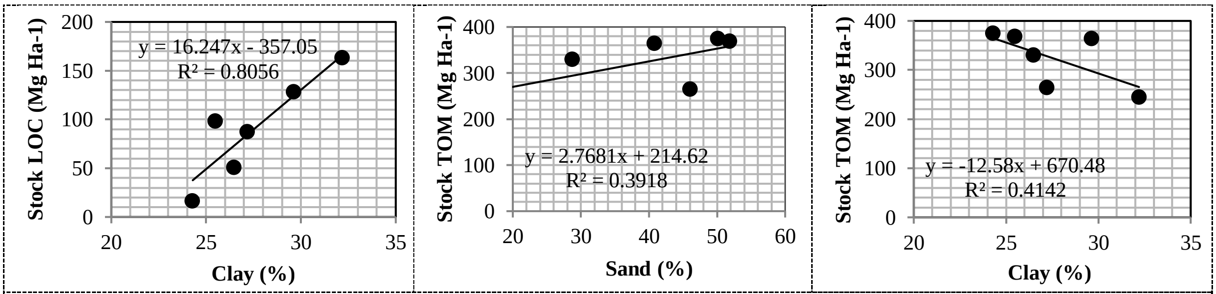

Figure 5. Correlation between soil particles and stock carbon soil under coffee plantation in Sibarasok Maninjau

Figure 5 showed that clay content tended to increase (R^2=0.8056; r=0.91) stock labile-organic carbon but decreased (R^2=0.4142; r=-0.64) stock total organic matter. This could be due to the fact that labile OM is able to bind clay particles through metal bridges. Sand particles showed a tendency of increase (R^2=0.3918; r=0.63) of total OM stock. This seemed to be the effect of coarse particles which can allow OM to easily move from the top to the soil profile.

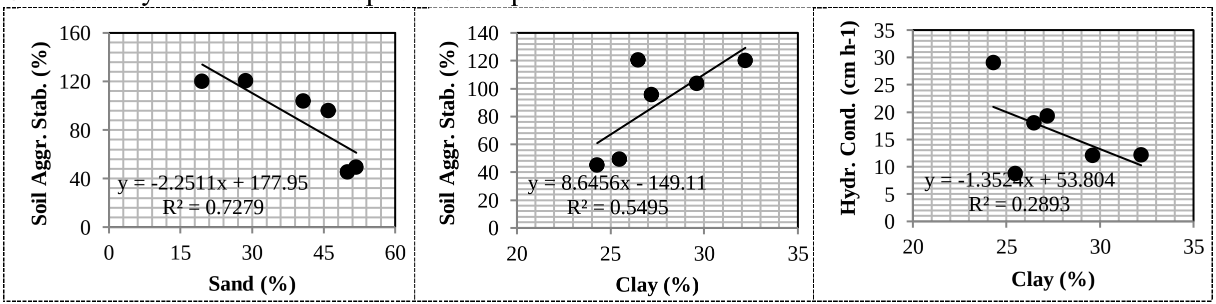

Figure 6. Correlation between soil particles and some soil physical properties under coffee plantation in Sibarasok Maninjau

In Figure 6 IT can be seen that increasing sand particles tended to decrease (R^2=0.7279; r=-0.85) while clay content tended to increase (R^2=0.5495; r=0.74) soil aggregate stability. This was due to the nature of the clay particles which some is in colloid form being able to bind soil aggregates through the ligand association. Since the sand particles did not have colloids, the organic matter was only bound through wrapping, which is not as strong as ligand association. Furthermore, clay content showed a tendency of negative correlation (R^2=0.2893; r=-0.54) with hydraulic conductivity rate of the soil. High clay means less soil macropores that can pass the water freely.

4. Conclusion

It can be concluded that OC content under 84 years coffee plantation in Sibarasok Maninjau was quite high either on the top 5 cm (8.37%-12.58%) or on the top 30 cm (4.44% to 7.39%). It was comparable to the percentage of OC under primary forest (6.35% on the top 30 cm soil) in adjacent site. The OC content was classified as labile fraction for 7-18% on the top 5 cm and 15-65% on the 0-30 cm soil depth. Soil OM stock was not much affected by the crop age, since the new planted crops (3 and 6 years old) was on old plantation. However, slope showed different SOM stock. The lowest SOM stock was found under very steep (>45%) slope. The SOM stock under coffee plantation after 84 years reached up to 98% of that under primary forest. The SOM stock affected some soil physical properties, LOC improve soil aggregate stability and decrease soil hydraulic conductivity in coarse texture soil.

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