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Organic carbon sequestration at different age of tea [*Camelia sinensis*] plantation under the wet tropical area

Y Yulnafatmawita[1*], S Yasin[2], and Z A Haris[3]

[1] Soil Physics Laboratory, Agriculture Faculty Andalas University, Padang 25163, Indonesia
[2] Soil Chemical Laboratory, Agriculture Faculty Andalas University, Padang 25163, Indonesia
[3] University of Putra Indonesia, Kampus UPI Lubuk Begalung, Padang 25122, Indonesia

E-mail : yulnafatmawita@agr.unand.ac.id

Abstract. Soil organic carbon [OC] sequestration is affected by some factors, one of which is the vegetation living on it. Tea is a crop on which the part being harvested is the leaves, which are supposed to contribute to soil OC. The objective of the research was to determine the amount of OC sequestered at different crop age under tea plantation in wet tropical areas. The soil samples were taken from 3 different crop ages [36, 21, and 9 years old] under the same slope [>45%] and soil [volcanic] at ≥ 1,400 m *asl*. As a comparison, the soil was also sampled from the secondary forest around the research site. At each crop age and the forest, the soil was sampled for 100 cm depth with a 20 cm increment. Undisturbed soil samples were taken for soil BD and disturbed soil samples for OC. The result showed that SOC content decreased by soil depth, and the soil BD was not significantly different among the depths. Therefore, the amount of OC sequestered declined by decreasing soil depth. The SOC sequestration rate decreased by increasing the age of tea crop from 1.67 to 0.49 Mg/Ha/y/1-m depth respectively between 9-21 and 21-36 years old. Compared to the secondary forest, however, the OC sequestration under tea plantation improved by 1.50, 1.71, and 1.79 times as the age of tea crop increased from 9, to 21, and to 36 years old, respectively. It seems that tea cultivation is the potential to sequester OC even though the leaves are regularly harvested.

1. Introduction

Soil organic carbon is very important in improving soil properties especially for soil physical characteristics affecting soil degradation and environmental sustainability. This is found to be true that organic matter containing OC can decrease soil bulk density [BD], increase total soil porosity [TSP], hydraulic conductivity [HC], as well as soil aggregate stability [SAS] [1] determining the soil erodibility. It is needed to evaluate agricultural soils, especially for cultivating the sloping area. Additionally, OC sequestration in soil could reduce CO_2 emission to the atmosphere causing global warming. As stated by Lal [2] that soil could the sequester high amount of OC in terrestrial.

Many agricultural activities take place in the sloping area, either for seasonal or plantation crops. One of which is used to cultivate in the mountainous area, especially in Indonesia, is a tea crop. This is because tea is a kind of crops originated from the temperate regions having low temperatures. For good growth, tea crops need cool areas with high rainfall. Indonesia has high annual rainfall and temperature, therefore, tea plantation is generally cultivated in higher altitude to meet the climate, especially temperature, requirement. The sloping area under high annual rainfall is susceptible to erosion, otherwise, the soil has good soil physical properties.

Based on conservation rule, the land having slope > 25% is not allowed to cultivate for seasonal crops, it is supposed to be planted with trees or plantation crops [3] and for land having slope >45% supposed to be forested or let it as it is. However, tea plantation was conducted at the sloping area having a slope up to 100% even more. In soil conservation rule, the land-use change having a steep slope [>45%] from the forest into other land use is not allowed, because it is very risky for land degradation or erosion. Furthermore, the part of tea crops being harvested is the leaves, therefore it is not so much plant residue that can be contributed to the soil organic carbon. However, it was suggested that tea plantation can contribute to carbon sink in the soil of the plantation area in China [4]. The best soil quality was found under 23 years old compared to >50 years old tea plantation [5].

The sloping area tends to have less OM content. As reported that SOM content on the flat area under oil palm plantation was much higher than that under the top, middle, and lower slope [6]. This is due to the condition on which OM derived from the litter cannot stay longer in the sloping area. Based on the fact, the research was conducted to determine the amount of OC could be sequestered at different age of tea plantation in the sloping area under the wet tropical region.

2. Materials and method

This research was conducted using a survey method at local society Tea Plantation in Mt. Talang, Solok Regency, West Sumatra Indonesia from May to October 2019. The geographical position of the research site is between 100°36’24.978”-100°39’26.935” E and between 0°58’19.112’ – 1°1’18.826’ S, with the altitude, is >1,400 m above sea level [asl]. Soil samples were collected from three different crop ages [9, 21, and 36 years old] from the same slope [>45%] and soil order [Inceptisols]. For each crop age, there were 3 different sampling points [3 replications], and disturbed soil samples were collected from 5 different locations and then composited at each sampling point. Then, the soil was also sampled from the forest nearby as a comparison.

Soil samples were taken from a 1-m soil profile with a 20 cm increment. Disturbed soil samples for OC analyses were taken using bor Belgia, while undisturbed soil samples for bulk density measurements were taken using stainless steel rings. The samples were analyzed at soil laboratory Universitas Andalas, Padang West Sumatra, Indonesia. Disturbed soil samples were air-dried, separated from fresh organic matter, ground then sieved with 2 and 0.5 mm sieves. The water content of the ground soil samples was measured, and the rest of the samples were saved in plastic bottles for further analyses.

Soil bulk density was measured using the gravimetric method and SOC was analyzed using dichromate wet oxidation [Walkley and Black] method. The SOC data were corrected with the soil water content. Soil bulk density [ρb] was calculated based on the following formula:

$$'\rho b \ (\mathrm{Mg\ m^{-3}}) = \frac{\mathrm{Dw}}{\mathrm{Vt}} \quad [1]$$

Dw = Dry Weight [Mg] of soil
Vt = Total Volume [m^{-3}] of soil

The tock of OC was calculated based on the formula proposed by Yulnafatmawita and Yasin [7] as follows:

$$\text{The Stock of OC } (\mathrm{Mg\ ha^{-1}}) = \frac{\%SOC}{100} * \mathrm{d} * \rho\ \mathrm{b} * \frac{A}{Ha} \quad [2]$$

SOC = soil organic carbon content [weight based percentage]
‘d = Soil depth [m]
ρb = soil bulk density [Mg m^{-3}]
A= area [10,000 m^2]

Soil OC sequestration rate under tea plantation was calculated based on the following formula:

$$\text{SOC seq. rate } (\text{Mg ha}^{-1}\,\text{Y}^{-1}) = \frac{(\text{OC Stock}_{end} - \text{OC Stock}_{initial})}{(\text{Age}_{end} - \text{Age}_{initial})} \quad [3]$$

SOC seq. rate = SOC sequestration rate/ha/y
OC $Stock_{end}$= Organic carbon stock at older crop age [Mg ha^{-1}]
OC $Stock_{initial}$= Organic carbon stock at younger crop age [Mg ha^{-1}]
Age_{end} = Age of older crop [y]
$Age_{initial}$ = Age of the younger crop [y]

3. Results and discussion

Soil bulk density [BD] was analyzed from the top 0-20 until 100 m soil profile. This data was important to calculate the soil OC stock in each soil depth. Soil bulk density data were presented in Table 1. Based on the data resulted, the soil BD values under tea plantation in Batang Barus were mainly <1 Mg m^{-3} which was considered low. This supposed to be due to the effect of SOM content as well as the soil texture class. Generally, increasing soil OC content or stock will decrease the soil BD values, they are inversely related [1], [8]. However, in this site, soil BD was not correlated to the SOC but mainly affected by the parent rock. According to the geology map, the areas around mt. Talang on which tea was planted was formed from andesitic rocks. Based on the field observation, the soil from the top until 100 cm soil depth was very crumb and light. Some sites even had BD values lower in the deeper than that on the upper soil profile, even though the SOC stock was very low compared to that on the topsoil.

Table 1. Soil BD values of soil under tea plantation in Batang Barus, under the wet tropical region

Soil Depth [cm]	Age of Tea Plantation [Y]			Forest Land Use
	36	21	9	
		Mg m^{-3}		
0-20	0.52 ±0.17*	0.75 ±0.03	0.43 ±0.00	0.28
20-40	0.48 ±0.16	0.69 ±0.07	0.46 ±0.06	0.36
40-60	0.54 ±0.11	0.72 ±0.06	0.42 ±0.10	0.41
60-80	0.56 ±0.09	0.83 ±0.12	0.42 ±0.07	0.24
80-100	0.56 ±0.08	0.98 ±0.17	0.46 ±0.09	0.33
Average	0.53 ±0.03	0.79 ±0.11	0.44 ±0.02	0.32±0.06

Note: * = standard error

Soil BD affects soil OC the stocks, since the BD [ρb) is used to calculate SOC stock (equation 2]. The stock of OC under tea plantation [Table 2] increased as the crops become older. Soil OC stock within 1-m soil depth increased by 14.4% and 4.6% by increasing crop age from 9 to 21 years old and from 21 to 36 years old, respectively. This could be found to be true that OM residue derived from the litter as well as from root exudates of tea crops was accumulated since the soil is never cultivated after being planted by tea. This result agrees with the results reported by Sanderman *et al* [9], on which they found that the highest OC sequestration was found at 5-10 years old crops, and then it decreased and even reaching zero as the crop above 40 years old.

Table 2. Soil OC stock at tea plantation from different crop age under the wet tropical region

Soil Depth [cm]	SOC Stock						
	9-years old Tea		21-years old Tea		36-years old Tea		Forest
	Mg Ha^{-1}						
0-20	71.72	±0.64*	97.43	±1.12	79.97	±1.93	36.09
20-40	38.74	±6.92	28.84	±11.98	41.68	±20.75	25.97
40-60	13.17	±5.34	18.44	±9.25	24.49	±16.02	12.99
60-80	8.70	±2.39	3.59	±4.15	8.86	±7.18	8.12
80-100	6.82	±2.97	10.94	±5.15	11.52	±8.91	9.81

Note: * Standard Error

Within each crop age, SOC significantly decreased by increasing soil depth from the top 20 cm until 80 cm depth. This is because the OM source is mainly derived from the above soil surface, especially plant litter, compared to the below-ground source such as root exudates and senescence. Therefore, SOC on the topsoil was higher than the lower depths. This agrees with the results reported [7] that SOC stock in soil profile deceased by depth either in dry or wetland under the wet tropical region.

If it is compared to the total, the SOC stock on the top 20 cm was 48%, 61%, 52%, and on the top 40 cm, soil depth was 73%, 79%, 79%, respectively for 36, 21, and 9 years old tea plantation in the wet tropical region. These data were higher than those reported [10] that SOC stock under tea plantation in the temperate region in North East India was found about 46% on the top 30 cm and 65% on the top 50 cm soil depth.

However, the SOC stock was not significantly different between 60-80 and 80-100 cm soil depths. It even tended to increase at 80-100 cm than 60-80 cm soil depth. This could be due to the effect of mount Talang eruption since it is located on the sloping area of Mount Talang. Mount Talang big eruption happened between 1833-1883 [11]. Higher SOC stock at a deeper depth of soil profile was might be due to the surface soil being covered by new materials from the eruption.

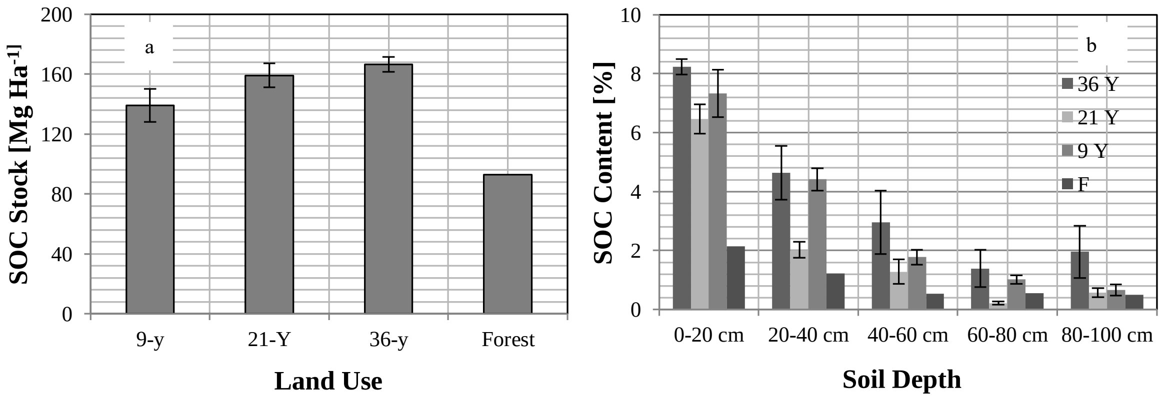

Figure 1. Soil OC stock within 1-m soil profile [a] and within each 20 cm soil depth on the profile [b] under local society tea plantation in Batang Barus, Solok Regency, West Sumatra, Indonesia

Total SOC stock on the top 1–m soil profile was presented in Figure 1. The figure shows that SOC stock linearly [R^2 = 0,932] increased by increasing crop age [Fig. 1a] and the SOC content decreased by depth in the soil profile [Fig. 1b]. As reported that soil OC stock increased by maturing the vegetation [12]. Then, the SOC content was the highest on the top and then decreased by depth in a soil profile [13], [7], [10].

If compared to the forest, SOC stock under tea plantation increased by increasing crop age from 9 to 21 and to 36 years old. This is found to be true since the soil under tea plantation is never cultivated, therefore the residue of the crops was accumulated in the soil. As suggested that C stocks in soil increased by increasing the age of plantation crops [14]. High OC sequestration in soil is very important to keep sustainable agriculture and environment since the SOC is considered as a soil quality indicator. It improves soil properties, mainly soil physical properties such as soil BD, TSP, hydraulic conductivity, infiltration, aggregate stability determining soil erodibility against erosion. Therefore, it is never reported yet that there is an erosion problem in tea plantation. It was found that tea plantation could be the best option to sequester OC in the soil for a long time [15].

Table 3. Sequestration rate of OC at the tea plantation in Batang Barus Solok, under the wet tropical region

Calculation	Age of Tea Crop [years]		
	9	21	36
SOC Stock [Tea/forest]	1.50	1.71	1.79
Sequestration rate [Mg/Ha/1m depth/y]	-	1.67	0.49

However, the rate of OC sequestration decreased by time. It was suggested that OC sequestration under poplar trees decreased by the time [12]. If it is compared to woody perennials [0.63 to 0.72 Mg C ha^{-1} $year^{-1}$] [16], the OC sequestration rate was higher at 21 years old and lower at 36 years old under tea plantation in the wet tropical region. This could be explained that soil having very low OC could hold all of the OC added to the soil, however, if it has high OM content, so the soil cannot hold all the added OC anymore. It seems that the soil has limited capacity in holding OC.

4. Conclusion

Soil OC sequestration at 1-meter soil profile increased [from 139.15 to 159.23, and 166.53 Mg Ha^{-1}], however, the rate decreased [from 1.67 to 0.49 Mg $Ha^{-1}y^{-1}$], by increasing crop age [from 9 to 21 and 21 to 36 years old] respectively, under tea cultivation. OC sequestered under tea plantation was higher than that under secondary forest nearby.

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