Organic carbon sequestration at different age of tea \([\text{Camelia sinensis}]\) plantation under the wet tropical area

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Abstract. Soil organic carbon \([\text{OC}]\) 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 \text{OC}. The objective of the research was to determine the amount of \text{OC} sequestered at different crop ages under tea plantation in wet tropical areas. The soil samples were taken from 3 different crop ages \([36, 21, \text{and} 9 \text{years old}]\) under the same slope \([>45\%]\) and soil \([\text{volcanic}]\) at \(\geq 1,400 \text{ m asl}.\) 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 \text{OC}. The result showed that \text{SOC} content decreased by soil depth, and the soil BD was not significantly different among the depths. Therefore, the amount of \text{OC} sequestered declined by decreasing soil depth. The \text{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 \text{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 \text{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 \text{OC} can decrease soil bulk density \([\text{BD}]\), increase total soil porosity \([\text{TSP}]\), hydraulic conductivity \([\text{HC}]\), as well as soil aggregate stability \([\text{SAS}]\) [1] determining the soil erodibility. It is needed to evaluate agricultural soils, especially for cultivating the sloping area. Additionally, \text{OC} sequestration in soil could reduce \text{CO}_2 emission to the atmosphere causing global warming. As stated by Lal [2] that soil could the sequester high amount of \text{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 \( \rho_b \) was calculated based on the following formula:

\[
\rho_b (\text{Mg m}^{-3}) = \frac{D_w}{V_t}
\]  

\[D_w = \text{Dry Weight [Mg]} \text{ of soil}
\]

\[V_t = \text{Total Volume [m}^3\text{]} \text{ of soil}
\]

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

\[
The \text{Stock of OC (Mg ha}^{-1}) = \frac{\sum SOC}{100} \times d \times \rho_b \times \frac{A}{H_n}
\]  

\[SOC = \text{soil organic carbon content [weight based percentage]}
\]

\[d = \text{Soil depth [m]}
\]

\[\rho_b = \text{soil bulk density [Mg m}^3\text{]}
\]

\[A = \text{area [10,000 m}^2\text{]}
\]

Soil OC sequestration rate under tea plantation was calculated based on the following formula:
\[ \text{SOC seq. rate (Mg ha}^{-1} \text{Y}^{-1}) = \frac{(\text{OC Stock}_{\text{end}} - \text{OC Stock}_{\text{initial}})}{(\text{Age}_{\text{end}} - \text{Age}_{\text{initial}})} \]  

\[ \text{SOC seq. rate} = \frac{\text{SOC sequestration rate/ha/y}}{\text{Age end - Age initial}} \]

\[ \text{OC Stock}_{\text{end}} = \text{Organic carbon stock at older crop age [Mg ha}^{-1}] \]
\[ \text{OC Stock}_{\text{initial}} = \text{Organic carbon stock at younger crop age [Mg ha}^{-1}] \]

\[ \text{Age}_{\text{end}} = \text{Age of older crop [y]} \]
\[ \text{Age}_{\text{initial}} = \text{Age of the younger crop [y]} \]

### 3. Results and discussion

Soil bulk density (BD) was analyzed from the top 0-20 until 100 cm 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 |                |
| 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 \[9\] 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] | 9-years old Tea | 21-years old Tea | 36-years old Tea | Forest |
|----------------|----------------|----------------|----------------|--------|
| 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 decreased 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] |
|------------------------------|------------------------|
| SOC Stock Tea/forest         | 9          21          36 |
| 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.

References

[1] Yulnafatmawita, Adrinal, and Anggriani F 2013 Role of fresh organic matter in improving soil aggregate stability under wet tropical region J Tanah Tropika 18 33-44
[2] Lal R 2019 Conceptual basis on managing soil carbon: Inspired by nature and driven by science J Soil and Water Cons 74 29A-34A
[3] Sumarniasih MS and Antara M 2017 Conservation planning on eroded land based on local wisdom in Kintamani sub-district province of Bali IOP Conf Ser: Earth Environ Sci. 54 012-010
[4] Zhang M, Fan D, Zhu Q, Pan Z, Fan K, and Wang X 2017 Temporal Evolution of Carbon Storage in Chinese Tea Plantations from 1950 to 2010 Pedosphere 27 121-28
[5] Li W, Zheng Z, Li T, Zhang X, Wang Y, Yu H, He S, and Liu T 2015 Effect of tea plantation age on the distribution of soil organic carbon fractions within water-stable aggregates in the hilly region of Western Sichuan China Catena 133 198-205
[6] Yasin S and Yulnafatmawita 2018 Effects of Slope Position on Soil Physico-chemical Characteristics Under Oil Palm Plantation in Wet Tropical Area West Sumatra *Indonesia Agrivita* 40 328-337

[7] Yulnafatmawita and Yasin S 2018 Organic carbon sequestration under selected land use in Padang city West Sumatra Indonesia *IOP Conf. Series: Earth and Environ Sci* 129

[8] Yulnafatmawita and Adrinal 2014 Physical Characteristics of Ultisols and The Impact on Soil Loss During Soybean (*Glycine max* Merr) Cultivation In A Wet Tropical Area *Agrivita J Agr Sci* 36 57-64

[9] Sanderman J, Farquharson R, and Baldock J 2009 Soil Carbon Sequestration Potential: A review for Australian agriculture CSIRO Land and Water 81 p file:///E:/REFERENCE/SOC%20Sequestration%20potential--csiro-soil-c-reviewpdf

[10] Kalita RM, Das AK, and Nath AJ 2016 Assessment of Soil Organic Carbon Stock Under Tea Agroforestry System in Barak Valley North East India *Int J Ecol Envir Sci* 42 175-182

[11] Kriswati E, Pamitro YE, and Basuki A 2010 Mekanisme Gempa Vulkanik Gunung Talang Pasca Gempa Tektonik Mentawai Tahun 2007-2009 Sumatra Barat *Jurnal Geologi Indonesia* 5 209-18

[12] Gupta N, Kukal SS, and Bawa SS 2009 Soil organic carbon and aggregation under poplar based agroforestry system in relation to tree age and soil type *Agrofor Syst* 76 27-35

[13] Guan F, Tang X, Fan S, Zhao J, and Peng C 2015 Changes in soil carbon and nitrogen stocks followed the conversion from secondary forest to Chinese fir and Moso bamboo plantations *CATENA* 133 455-60

[14] Cheng J, Lee X, Theng BKG, Zhang L, Fang B, and Li F 2015 Biomass accumulation and carbon sequestration in an age-sequence of *Zanthoxylum bungeanum* plantations under the Grain for Green Program in karst regions Guizhou province *Agric and Forest Meteor* 203 88-95

[15] Mishra G, Giri K, Jangir A, and Francaviglia R 2020 Projected trends of soil organic carbon stocks in Meghalaya state of Northeast Himalayas India Implications for a policy perspective *Sci Total Environ* 698 134266

[16] Agostini F, Gregory AS, and Richter GM 2015 Carbon Sequestration by Perennial Energy Crops: Is the Jury Still Out? *Bioenergy Res* 8 1057–80

**Acknowledgment.**

The authors would like to say thank the General Director of Higher Education of the Republic of Indonesia for the research funding under the fundamental research scheme in 2019-2020. The authors also thank the Manager of Tea Plantation in Batang Barus, Solok Regency, West Sumatra Indonesia for its permission.