The organic carbon dynamics of peat soil under liberica coffee cultivation

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Abstract. The exploitation of peat soil considered enrich CO\textsubscript{2} gas emissions in the atmosphere and contribute to global warming. The farmers in Jambi and Riau province have been cultivated Liberica coffee on peat soil since 1940. This study evaluated the effect of Liberica coffee cultivation to peat carbon conservation. The study was arranged as an observation method at the Liberica coffee trees aged 1) 4-6 years (young productive plants) and 2) > 10 years (mature productive plants). Each observation consisted of 16 trees. The results showed that the average CO\textsubscript{2} emissions from the peat cultivated Liberica coffee around 23.7 Mg CO\textsubscript{2}/ha/year, while it from peat soil under natural forests were reported to be 20-40 Mg CO\textsubscript{2}/ha/year. The litters of the productive Liberica coffee trees return organic C to the peat about 0.35 to 4.7 Mg/ha/year. Compost of 13.5 Mg/ha of Liberica coffee cherries cascara and parchment, applied by farmers as a fertilizer also returned 7.38 Mg/ha/year of organic C, while the number of organic C carried by 1.5 Mg/ha/year of the Liberica coffee green beans was only 825 kg/ha/year, approximately. This study showed that the Liberika coffee cultivation on peat soil is a safe way to conserve C in peat soil.

Keywords: Liberica coffee, CO\textsubscript{2} emissions, organic C, peat soil

1. Introduction

Indonesia has 21 million ha of peat soil approximately, and 6 million ha of them is feasible to be used for agricultural land [1]. Around 6 million ha of peat soil spread over three large islands, namely in Sumatra, Borneo, and Papua are 2.25, 1.52 and 2.27 million ha, respectively. Although peat soil is a potential land for agriculture, however, the environmental experts are concerned about its utilization, because there is a large risk of CO\textsubscript{2} emissions from the peat if in its utilization is careless. Dewi et al, [6] reported that 21 million ha of Indonesian peat save carbon as much as 37 gigatonnes and 63\% of greenhouse gas (GHG) emissions i.e. 1.79 gigatonnes of CO\textsubscript{2} derive from the peat land use. Overall the peat soil contributes 25\% of total GHG emissions in Indonesia.

In some peat soil areas, especially on the east coast of Sumatra, farmers use the tidal peatland for Liberica coffee cultivation, such as in Tanjung Jabung Barat, Jambi Province, and Meranti, Riau Province. The farmers also use peat soil for Liberica coffee cultivation on small scale areas in the Kotawaringin Barat, Central Kalimantan. In Tanjung Jabung Barat, the farmers have planted Liberica coffee on peat soil since the 1940s. Now, there is about 3,000 ha of smallholder Liberica coffee plantations in Tanjung Jabung Barat [4] and 1,000 ha in Meranti Regency, Riau Island Province [8].

Besides a better economic value (the price of Liberika coffee beans Rp 43,000 / kg were higher than Robusta coffee beans, Rp 18,000 / kg), the Liberica coffee trees are also considered having good
potential as an absorber of atmospheric CO$_2$. Otalvaro et al. [12] reported, to form a kg of coffee cherries, the coffee trees fixed 1.068 kg of CO$_2$ or equivalence of 8.9 Mg of CO$_2$/ha/year. Even Segura and Andreade [15] reported an amount of 2.6 – 6.23 kg of atmospheric CO$_2$ fixation for every kg of the coffee cherry. In connection with carbon stock, the traditional poly-cultures coffee farming has carbon stocks 42.5 Mg per ha in the vegetation. It was much higher than unshaded monocultures i.e. 10.5 Mg / ha [14]. Hergoualc et al. [10] also reported that in an unshaded coffee monoculture the carbon stocks was 14.1 Mg/ha and 32.4 Mg/ha in an Inga-shaded monoculture. Therefore it is necessary an analysis to find out the dynamics of organic C of peat soil under Liberica coffee cultivation as an indication of its potential to conserve the peat organic carbon.

2. Methods
The Site of the study was in Betara Sub-District, Tanjung Jabung Barat Regency, Jambi Province. The study was carried out on a Liberika coffee plantation owned by farmers in Paritomo, Mekar Jaya Village, Betara District. The study period was from March 2017 to December 2018. The chemical properties of the peat soil of Liberica plantation for each kind of peat (fibric, hemic and sapric) are presented in Table 1 [9].

Table 1. The chemical characteristics of peat soil in Betara sub-district, Jambi Province

| Peat   | Dusk (%) | OM (%) | organic-C (%) | pH (H$_2$O) | N (%) | P (ppm) | Exchanged. K (cmol(+)/kg) |
|--------|----------|--------|---------------|-------------|-------|---------|--------------------------|
| Fibric | 4,82     | 95,19  | 55,21         | 3,70        | 1,51  | 48,22   | 1,28                     |
| Hemic  | 9,34     | 90,67  | 52,59         | 3,34        | 1,38  | 39,68   | 1,39                     |
| Sapric | 15,13    | 84,88  | 49,23         | 3,35        | 1,29  | 37,22   | 0,68                     |

Source: Hafif et al, [9]  

The research was arranged on an observation method. The observation objects were a performance of different age Liberica coffee trees and the nature of peat soil especially the peat C content, influenced by the Liberica coffee trees growth. In the study area, the Liberica coffee trees were planted with a spacing of 3 x 4 m and 3 x 3 m. There were 800 to 1000 population of Liberica coffee per hectare, approximately. The Liberica coffee trees observed were 1) the age of 4 - 6 years old (young productive plants) and 2) age of > 10 years old (mature productive plants). A sample number of coffee trees observed were 16 trees for each age and they were selected, randomly.

Peat soil samples were collected in the area under the canopy of each different age of coffee trees, using a spade and pooled to form a composite sample. Three-peat samples influenced by different age of coffee trees were put in a plastic bag and carried to the Integrated Laboratory of Industrial and Beverages Crops Research Institute (Balittri) in Sukabumi.

The variables observed were coffee yields (coffee beans), litter under the coffee canopy, organic C of peat and in biomass of Liberika coffee trees such as leaves and cherries with its component (skin, pulp, parchment, and seeds). Especially for total yield, it was also compared to the yield of farmer harvesting.

2.1. Analisis of organic-C (%)  
Analysis of organic C content (%) in plant tissue and peat soil was using a dry ashing method or the loss on ignition (LOI) method. The workings of this analysis are by burning all organic matter in the plant tissue and peat soil with a temperature of 550°C for 6 hours, so all organic materials will evaporate and left behind only residual material or inorganic materials. Furthermore, the weight of organic material is converted to the weight of organic C using a factor of 1 / 1,724.

2.2. Interpretation of CO$_2$ gas emissions from peat soil  
The interpretation of CO$_2$ gas emissions from the peat soil was based on changes in the C stock in peat at a certain period [2]. Decreasing carbon stocks is the incarnation of CO$_2$ gas emissions and an
increase in carbon stock is the incarnation of sequestration or C. For this reason the observation of peat organic C was carried out at 2 times i.e. at the beginning and the end of 2 years. Differences in the reserves of organic C between the two observation times (beginning and end) were used as the basis for the interpretation of the amount of CO₂ emissions. Then the lost organic C was multiplied by the value of 3.67, which is the conversion rate of organic C into the flux of CO₂. The value of 3.67 derived from 44/12, where 44 is the molecular weight of CO₂ and 12 is the atomic weight of C [5].

3. Results and Discussion

3.1. Performance of Liberica coffee growth
In general, the smallholder Liberica coffee plantations have not been well managed. The age of the coffee tree varies but it was dominated by the age of more than 10 years old. Coffee trees are generally grown in an intercropping system with areca nut plants. The function of areca nut also a shading plant for coffee trees, they are a source of an additional income for the farmers.

In the study area, the Liberica coffee was also called as an excelsa coffee. However, Hulupi [11] said the two coffees were different. Puslitkoka [11] had also released and developed a superior variety of Liberica, named as a Liptukom (Liberika Tungkal Komposit). In some areas, especially on the peatland having a relatively shallow water surface (<40 cm), the growth of some Liberica coffees did not looks well. One of the reasons was poor drainage mainly during high tides. Excess water caused the increasing of fungal attack which damage plant roots and even damage the Liberica coffee trees. As a farmer reported, the overflow of water during high tide damaged 2 ha of his Liberica coffee trees. There are two peak harvesting seasons in a year, i.e from May to July and from November to January, however, there is also a small harvest in every month. Young Liberica coffee trees (4-6 years old) in every main harvesting produce green beans around 600 g/tree and in every small harvesting produce 200 g/tree, on average, while Liberica coffee trees > 10 years old, produces green beans 3 kg/tree in every peak harvesting and around 1 kg/tree in every small harvesting. The performance of productive Liberica coffee trees aged 4-6 years old (A) and > 10 years old (B) are shown in Figure 1.

![Figure 1](image)

**Figure 1.** Performance of Liberica coffee trees with age of 4 – 6 years old (A) and > 10 years old (B)

3.2. Organic C dynamic in peat under the Liberica coffee trees
One of the factors influencing the loss of carbon from the peat ecosystems is land use [3]. Measurement results of organic C in the peat under smallholder Liberica coffee plantation with
different age of coffee trees, indicated that under the young productive trees (4-6 years old), the organic C tended to decrease up to 37.48 Mg/ha in almost 2 years, while under the elder coffee Liberika trees (> 10 years old) the organic C content tended to increase around 26.71 Mg/ha in two years (Table 2). Considering that there is C lost from peat (under the coffee trees 4-6 years old) and increased in peat (under the coffee trees > 10 years old), the average CO₂ emission from the two peat areas (loss minus addition) was 10.77 Mg which was equivalent to CO₂ gas emissions of 23.7 Mg/ha/year (Table 2). The average CO₂ gas emission was still considered within the range of annual CO₂ emissions of peatland, in Indonesia. As reported by Dewi et al. [6] that amount of CO₂ emissions from Indonesian peatlands in the range of 20 to 40 Mg CO₂/ha/year.

The loss of organic C, especially from peat under the young Liberica coffee trees, needs to be watched out for. The large area of peat under young trees exposed to the surface is a major cause of increasing CO₂ flux. One of the best options is to use the area between the young coffee trees for seasonal crops. Another option is to conduct limited peat clearance, i.e. only on the area where the Liberica coffee seedlings will be planted.

Table 2. Organic C dynamic and CO₂ flux prediction from the areas under Liberica coffee trees with different age

| Peat under the canopy of Liberica coffee trees | Organic C in March 17 (%) | Stock C in Mach 17 (Mg/ha) | Organic K in Dec. 18 (%) | Stock C in Dec. 18 (Mg/ha) | Δ Stock C after 20 months (Mg/ha) | ±Fluxes of CO₂/ha/years |
|-----------------------------------------------|---------------------------|-----------------------------|--------------------------|-----------------------------|----------------------------------|--------------------------|
| 4 - 6 years old                               | 48.29                     | 579.54                      | 45.17 b                  | 542.06 b                    | -37.48                           | 82.52                    |
| 10 years old                                 | 49.11                     | 589.38                      | 51.34 a                  | 616.09 a                    | 26.71                            | -58.82                   |
| Sig.                                          | 0.771                     | 0.771                       | 0.054                    | 0.054                       | 0.771                            | 0.771                    |
| CV (%)                                        | 6.55                      | 5.60                        | 8.70                     | 8.71                        |                                  | 23.70                    |
| Total emissions of CO₂ (A - B)                | - 10.77                   | 23.70                       |                          | 23.70                       |                                  |                          |

Notes: Values followed by the different letter are significantly different at p < 0.10, according to T test BD of peat ± 0.2 g/cc and CO₂ = C x 3.67

3.3. Contribution of Liberica coffee trees in sequestration and loss of peat organic C

The dynamics of organic C (loss and sequestration of C) of peat under Liberica coffee trees were affected by CO₂ gas emissions as a result of microbial metabolism and organic matter decomposition. Sequestration of peat organic C was by C of the Liberica coffee trees biomass, especially litter (leaves, twigs and some cherries). The C content of the litter and Liberica coffee pruning as a part of coffee trees cultivation will enrich organic C of the peat, while cherries especially coffee green beans will carry organic C to out of peat ecosystem. The C content in the Liberica coffee biomass is presented in Table 3.

Table 3. Content of organic C in Liberica coffee biomass

| Biomass of Liberica Coffee Tree | Organic C (%) |
|---------------------------------|---------------|
| Leaves                          | 52.24         |
| Cherries residue¹⁾              | 53.81         |
| Coffee Beans                    | 54.12         |

Note: ¹⁾cascara and parchment,

The weight of dry litter under the Liberica coffee trees of 10 years old was around 9 Mg/ha/year. It was more than 10 times that the litter under young productive trees (4-6 years old). Through the litter,
the Liberika coffee trees of > 10 years old were estimated to contribute organic C of the peat as much as 4.7 Mg/ha/years, while young coffee trees (4-6 years old) only contributed to the peat organic C as much as 0.35 Mg/ha/year. As discussed earlier, organic C of peat under the Liberika coffee trees of > 10 years old, tends to increase 26.71 Mg/ha per 20 months (Table 2).

The other part of the coffee trees that contributes to the sequestration of peat organic C was crop yield residues. In general, green beans production of Liberica coffee trees of > 10 years old in the study area was about 2,500 kg/ha/year. The green beans were derived from the cherries of Liberica coffee trees of > 10 years old as much as 25.7 Mg/ha/year (green beans percentage in cherries 9-10%), so cherry residues weight was 23.1 Mg/ha/year, approximately. Compost of cherries residual was returned by the farmers to peat, and about 12.4 Mg/ha/year of them was organic C (Table 5).

**Table 4. Contribution of Liberica coffee litter in sequestration of peat organic C**

| Liberica Coffee Age (year) | Litter (kg/ha/year) | *Total organic C returned to the Peat (ton/ha/year) |
|---------------------------|--------------------|--------------------------------------------------|
| 4-6                       | 667 b              | 0.35                                             |
| >10                       | 8,996 a            | 4.70                                             |
| Sig.                      | .002               |                                                  |
| CV (%)                    | 5.21               |                                                  |

Values followed by the different letter are significantly different at p < 0.05 according to T test.

*Average organic C of litter of Liberica coffee trees was 52.25%*

**Table 5. Contribution Liberica coffee yield residue in sequestration of peat organic C**

| Age of coffee trees (year old) | ¹⁾Coffee cherry yield (kg/ha/yr) | ²⁾Coffee beans (kg/ha) | ³⁾Cherry residues (kg/ha/yr) | ⁴⁾Organik C in residue, returned to the peat (kg/ha/yr) | ⁴⁾Organic C carried by coffee bean to out (kg/ha/year) |
|--------------------------------|----------------------------------|------------------------|----------------------------|---------------------------------------------------------|--------------------------------------------------------|
| 4 - 6                          | 4,800 b                          | 480                    | 4,320                      | 2,324.42                                                | 259.8                                                  |
| >10                            | 25,700 a                         | 2,570                  | 23,130                     | 12,445.33                                               | 1,390.9                                                 |
| Sig.                           | .000                             |                        |                           |                                                         |                                                        |
| CV                             | 8.27                             |                        |                           |                                                         |                                                        |

Note: Values followed by the different letter are significantly different at p < 0.05 according to T test. ¹⁾Plant populations = 1000 / ha, ²⁾10% of coffee cherries, ³⁾cascara and parchment, ⁴⁾Cherry residues organic C = 53.8%, ⁴⁾Coffee beans organic C = 54.1%

As stated by Polzot [13], the coffee production system stored the most amount of carbon/ha. Otalvaro et al. [12] reported the amount of CO2 fixation by coffee trees was as much as 8,941 kg/ha/year. Even Sagura and Andrade (2012) reported the amount of 13.1 kg CO2 for every kg of coffee green beans which was the equivalence of 2.6 kg of CO2 per kg of coffee cherry. If there was 25,700 kg/ha of Liberica coffee cherries that mean it was the equivalence of fixation of 66,820 kg (66.8 Mg) CO2/ha/year. By the potential, it can be argued that the use of peat soils for Liberika coffee cultivation will be capable to control the flux of CO2 from peat soils.

4. Conclusion

On average, CO2 emissions from the peat under the smallholder Liberica Coffee plantation in the study area were 23.7 Mg CO2/ha/year. The CO2 emission was derived from peat planted by young
productive Liberica coffee trees (4-6 years old) and old Liberica coffee trees (> 10 years old). The amount of the CO₂ emission was still in the range of on average CO₂ emissions from peatland under natural forests reported 20 to 40 Mg CO₂/ha/year in Indonesia. The litters of Liberica coffee trees could return the organic C to the peat about 0.35 to 4.7 Mg/ha/year, while compost of 13.5 Mg/ha of Liberica coffee cherries cascara and parchment, applied by farmers as a fertilizer also returned 7.38 ton/ha/year of organic C. The cultivation of Liberica coffee could be used as an approach in utilization of peatland for sustainable agriculture.

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