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CARBON DIOXIDE EMISSIONS FROM FROND DECOMPOSITION IN OIL PALM PLANTATIONS ON TROPICAL PEAT

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ABSTRACT

Up to now, many studies have been trying to reveal the impact of oil palm plantations on tropical peat on the global carbon (C) balance. Although there are some publications on soil respiration in oil palm plantations on peat soil, information on carbon dioxide (CO_2) emissions from palm litter (pruned fronds) decomposition is limited. Therefore, we quantified the CO_2 emissions through frond decomposition in two different mature oil palm plantations established on peat, an industrial plantation in Riau and a smallholder plantation in Jambi, Indonesia. Frond decomposition was measured using a litter bag method and the decomposition rate constant was determined using a negative exponential equation. Annual CO_2 emissions from frond decomposition were estimated at 1.48 and 1.12 Mg C ha^{-1} yr^{-1}, respectively, in industrial and smallholder plantations. As a result, CO_2 emissions from frond decomposition accounted for 10%-14% of heterotrophic respiration from mature oil palm plantations on tropical peat.

Keywords: industrial plantation, mature plantation, palm litter, smallholder plantation.

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INTRODUCTION

Tropical peatland has become one of the most efficient carbon sinks on the earth and plays an important role in the global carbon (C) cycle. This ecosystem mostly concentrated in Southeast Asia (SEA), the upper Amazon and in Congo Basin, covers only 16% of global peatland areas but is stored up to 105 Pg of C (Dargie *et al.*, 2017; Page *et al.*, 2011). However, this huge C deposit is now becoming vulnerable to being changed as a massive C source due to the land conversion that promotes peat decomposition and peat fires (Hooijer *et al.*, 2012; Miettinen *et al.*, 2017).

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Driven by population growth and economic development, during the last two decades, many areas of tropical peat swamp forest in SEA have been converted to agricultural plantations, mostly for oil palm and acacia trees (Miettinen *et al.*, 2012). The total area of peat swamp forest in Peninsular Malaysia, Sumatra and Borneo has been estimated to decrease from 64 x 105 ha in 2007 to 46 x 105 ha, while oil palm plantations on peatland had extended up to 31 x 105 ha in 2015 (Miettinen *et al.*, 2016). The global demand for palm oil in the world is expected to double by 2030 compared to 2000 (Yan, 2017). Thus, the impact of this plantation on the global C balance could be large.

To date, there are several publications on oxidative peat decomposition or heterotrophic respiration in oil palm plantations on peat (e.g. Dariah *et al.*, 2014; Hergoualc'h *et al.*, 2017; Ishikura *et al.*, 2018; Manning *et al.*, 2019; Melling *et al.*, 2013 and Wakhid and Hirano, 2021a). Unfortunately, none of these have studied carbon dioxide (CO_2)

emissions through palm litter (pruned fronds) decomposition, except Wakhid and Hirano (2021a), which conducted the study on a young oil palm plantation (7 years old). More field experiments are necessary, particularly in mature oil palm plantations to understand the contribution of CO_2 emissions through frond decomposition to the C balance of oil palm plantations on peat. The objective of this study was to quantify how much CO_2 is emitted from the decomposition of pruned fronds left on the ground in mature oil palm plantations on peat soil.

MATERIALS AND METHODS

The study was conducted over one year from February 2018 to March 2019, in mature oil palm (*Elaeis guineensis* Jacq.) plantations in Sumatra, Indonesia. One site was an industrial plantation in Riau (0° 42′ 16″ N, 101° 42′ 52.8″ E), and another site was a smallholder plantation in Jambi (1° 14′ 20″ S, 103° 35′ 23″ E). The oil palm cultivar in Riau was Marihat and in Jambi was mixed between the Marihat and Socfin with a ratio of 4:1. Thus, weighting factors of 0.8 and 0.2 were applied to the data for Marihat and Socfin, respectively, for the calculation of the CO_2 emissions in Jambi. Further information about the study sites was described in Wakhid *et al.* (2022).

To estimate the decomposition, fresh fronds were cut down, separated into two parts (tip and base), and put into litter bags. The litter bags were 40 cm x 80 cm, with a mesh size of 2 mm. Before being inserted into the litter bags, the fresh weight of each frond was recorded. Each bag contained about 800 g of frond. Also, the initial values of dry weight and C content of fronds were measured (n = 3). In Riau, the litter bags were set on the top of frond heaps in February 2018 with a total of 100 bags for each tip and base. The bags were retrieved in September 2018, January 2019 and June 2019, but only 99 bags were in total because most of them were missing. In Jambi, 36 bags of tips and bases for each of Marihat and Socfin were set equally on the top of and under frond heaps, in February 2018. In total, six bags of each tip and base from the two positions were retrieved in September 2018, February 2019 and July 2019. Each litter bag was cleaned after being retrieved, and the dry weight and C content were measured.

The dry weight was measured by oven drying for 48 hours at 70°C. The C content was estimated by the loss of ignition method, using a conversion factor from organic matter to organic C of 0.58 (Agus *et al.*, 2011). The decomposition rate constant (k) was estimated using a negative exponential equation from the plot of the residual ratio of C amount (Y) against elapsed time (t) following Moradi *et al.* (2014) as shown in Equation (1).

$$Y = Y_0 \exp(-kt) \qquad (1)$$

where C loss through frond decomposition was estimated using the k and initial C amount (Y_0). Then, the annual CO_2 emission was calculated using pruned frond production × monthly amount of CO_2 emissions. The annual C input was estimated from annual pruned fronds × tree density × dry weight × C content. Statistical analysis (ANOVA, Tukey HSD test, and exponential graph) were conducted using Excel and R software (R Development Core Team 2019, version 3.5.3). Further detail about CO_2 emissions calculation was described in Wakhid and Hirano (2021a; 2021b).

RESULTS AND DISCUSSION

The C content of pruned fronds in Riau and Jambi was in the range of 53%-57% (*Table 1*). C and Nitrogen (N) contents of leaf were significantly different with rachis (*Table 1*). However, the C and N contents of the tip and base parts were not significantly different. CN ratio was significantly higher in rachis than in leaf. Socfin in Jambi has the lowest CN ratio than that of Marihat in Riau and Jambi, respectively (*Table 1*).

In Riau, the amount of litter bags in the second and third retrieving was smaller than that of the first retrieving (n = 45, 27 and 27 litter bags, respectively, for the first, second and third retrieving) because several bags were lost during the study. Thus, the k value was calculated using all retrieved samples without tip and base parts separation to be 1.86 yr^{-1} (*Figure 1*). The annual C input was 2.54 Mg C ha^{-1} yr^{-1}, and CO_2 emissions from frond decomposition were estimated at 1.48 Mg C ha^{-1} yr^{-1} *(Table 2).*

In Jambi, although, the k values among tip and base parts and between two cultivars were not significantly different, CO_2 emissions through frond decomposition should be different among the cultivars because the size of Socfin was 1.4 times larger than that of Marihat (*Table 1*). Thus, the k values were calculated using all data for each cultivar (n = 12), to be 1.57 and 1.81 yr^{-1}, respectively, for Marihat and Socfin (*Figure 1*). The annual C input and CO_2 emissions from pruned fronds were estimated at 2.07 and 1.12 Mg C ha^{-1} yr^{-1}, respectively *(Table 2).*

CO_2 emissions from frond decomposition in this study were higher than in a young oil palm plantation in Banjarbaru (Wakhid and Hirano (2021a): 0.38 Mg C ha^{-1} yr^{-1}). This discrepancy was most likely caused by the production of frond that was larger in mature than in young plantations. The CO_2 emissions (1.48 and 1.12 Mg C ha^{-1} yr^{-1}, in Riau and Jambi, respectively) accounted for 14% and 11% of heterotrophic respiration from mature oil palm

TABLE 1. INITIAL AMOUNT OF CARBON (C), NITROGEN (N), CN RATIO, AND WATER CONTENT (WC) OF FROND (MEAN ± 1 SD, n = 3).

Samples	C (%)	N (%)	CN ratio	WC (%)
Marihat (*M*) in Riau (dry weight = 2578 ± 509 g frond^{-1}, n = 5)				
Leaf (tip)	54.60 ± 0.54a	1.23 ± 0.58a	50.30 ± 19.10a	59.30 ± 0.30
Rachis (tip)	56.70 ± 0.28b	0.38 ± 0.13b	160.90 ± 58.90b	60.20 ± 8.30
Leaf (base)	55.00 ± 0.29a	1.62 ± 0.44a	35.40 ± 8.40a	59.10 ± 1.60
Rachis (base)	55.60 ± 0.35b	0.39 ± 0.06b	143.70 ± 20.00b	37.80 ± 6.60
Marihat (*M*) in Jambi (dry weight = 2254 ± 188 g frond^{-1}, n = 5)				
Leaf (tip)	54.00 ± 0.33a	1.90 ± 0.33a	29.20 ± 5.70a	54.90 ± 2.70
Rachis (tip)	57.10 ± 0.07b	0.66± 0.08b	87.20 ± 11.40b	65.90 ± 4.20
Leaf (base)	54.40 ± 0.40a	2.00 ± 0.19a	27.40 ± 2.30a	58.50 ± 2.30
Rachis (base)	56.90 ± 0.25b	0.60 ± 0.10b	96.20 ± 15.40b	71.10 ± 7.50
Socfin (*S*) in Jambi (dry weight = 3387 ± 567 g frond^{-1}, n = 5)				
Leaf (tip)	53.10 ± 0.89a	2.27 ± 0.16a	23.50 ± 1.50a	50.10 ± 11.40
Rachis (tip)	56.80 ± 0.09b	0.75 ± 0.13b	77.00 ± 13.30b	69.80 ± 3.70
Leaf (base)	53.60 ± 1.32a	2.15 ± 0.51a	25.90 ± 6.00a	56.50 ± 2.60
Rachis (base)	56.40 ± 0.11b	0.79 ± 0.20b	74.90 ± 20.60b	71.10 ± 4.80
ANOVA (*p*- value)				
Component (leaf *vs*. rachis)	<0.001	<0.001	<0.001	0.210
Position (tip *vs*. base)	0.76	0.64	0.68	0.50
Site (*M* in Riau *vs*. *M* in Jambi)	0.74	0.18	0.08	0.13
Cultivar (*M* *vs*. *S* in Jambi)	0.42	0.06	<0.05	0.16
Interaction (component-position)	<0.05	0.62	0.98	0.06

Note: Data of C (%) of Marihat and Socfin in Jambi was adapted from Wakhid and Hirano (2021b).
Different letters denote significant differences between leaf and rachis.

TABLE 2. CARBON (C) INPUT AND CARBON DIOXIDE (CO_2) EMISSIONS FROM FROND DECOMPOSITION IN RIAU AND JAMBI

Site and cultivar	Tree density (trees ha^{-1})	Frond production (dry weight, Mg ha^{-1} yr^{-1})	C input (Mg C ha^{-1} yr^{-1})	CO_2 emissions (Mg C ha^{-1} yr^{-1})
Industrial in Riau *(Marihat)*	148	4.58	2.54	1.48
Smallholder in Jambi	125	3.72	2.07	1.12
(Marihat)	100	2.71	1.51	0.80
(Socfin)	25	1.02	0.56	0.32

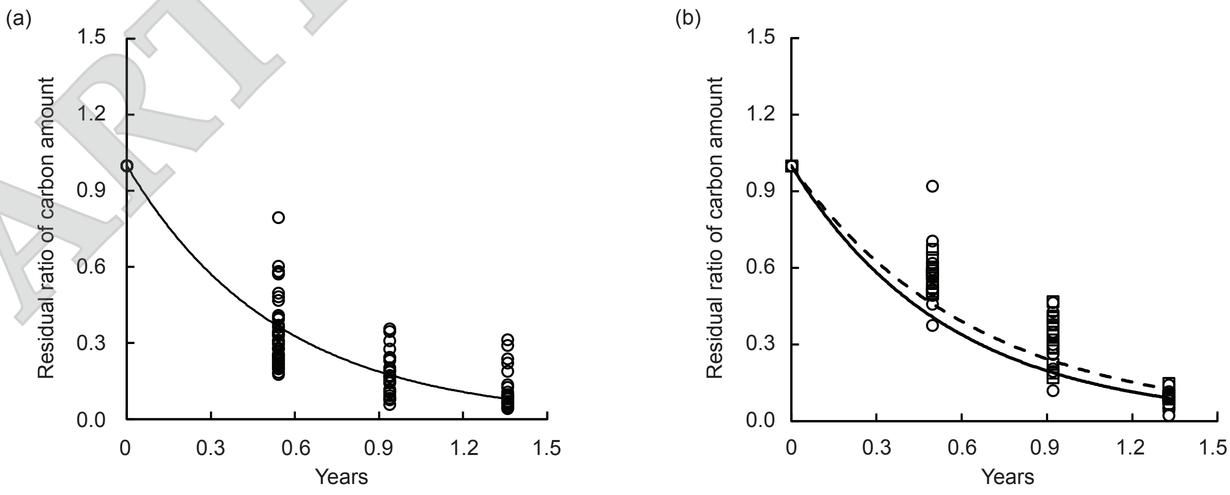

Figure 1. C loss pattern of a) Marihat in Riau and b) Marihat (squares, dash line) and Socfin (circles, solid line) in Jambi. An exponential curve is fitted for each retrievement time. Riau: $Y = e^{-1.86x}$ ($r^2 = 0.83$), and Jambi: $Ym = e^{-1.57x}$ ($r^2 = 0.90$), $Ys = e^{-1.81x}$ ($r^2 = 0.84$). Ym and Ys represent the equations for Marihat and Socfin cultivars, respectively.

plantations on tropical peat (Dariah *et al.* (2014): 15 years old, 10.4 Mg C ha^{-1} yr^{-1}). Also, accounted for 13% and 10 %, in Riau and Jambi, respectively, to a default CO_2 emission factor Tier 1 methodology of oil palm plantation on peat soil (11 Mg C ha^{-1} yr^{-1}) from the Intergovernmental Panel on Climate Change (IPCC, 2014). Following the amount of CO_2 emissions, the contribution in mature was larger than in young oil palm plantations (Wakhid and Hirano (2021a): Accounting for 2.4% of heterotrophic respiration).

Some data in Jambi from February 2018 to February 2019 was presented at International Conference on Sustainable Tropical Land Management (Wakhid and Hirano, 2021b). Unexpectedly, CO_2 emission in Jambi from February 2018 to February 2019 (Wakhid and Hirano (2021b): 1.09 Mg C ha^{-1} yr^{-1}) was similar to February 2018 to September 2019 (this study: 1.12 Mg C ha^{-1} yr^{-1}). Frond decomposition could likely be estimated in a short study as long as the disturbance and environmental changes are minimal. To our knowledge, previous studies on CO_2 emissions from frond decomposition were limited, thus more studies for comparison were not found.

The annual C input from pruned fronds and *k* values from this study were compared with some previous studies. Annual C input in this study (2.54 and 2.07 Mg C ha^{-1} yr^{-1}, respectively, in Riau and Jambi) was lower than the C input of pruned fronds from oil palm on mineral soil in Jambi (Kotowska *et al.* (2016): 2.89 Mg C ha^{-1} yr^{-1}). However, our result was higher than that of 1.33-1.79 Mg C ha^{-1} yr^{-1} of C input from pruned fronds in an oil palm plantation on mineral soil in North Sumatra (Lamade and Bouillet, 2005). *k* values of Marihat in Riau and Socfin in Jambi (*Figure 1*) were similar to the *k* value of pruned fronds from oil palms on mineral soil in Malaysia (1.80 yr^{-1}; Moradi *et al.*, 2014), but higher than that of another study also in Malaysia (0.73 yr^{-1}; Khalid *et al.*, 2000).

CONCLUSION

CO_2 emissions from frond decomposition were investigated in mature oil palm plantations on tropical peat, industrial and smallholder plantations, in Riau and Jambi. Using decomposition rate constant (*k*), initial carbon (C) amount, and pruned frond production, CO_2 emissions from frond decomposition were estimated to be 1.48 and 1.12 Mg C ha^{-1} yr^{-1}, respectively, in Riau and Jambi. These CO_2 emissions accounted for 10%-14% of heterotrophic respiration in oil palm plantations on peat. The contribution of frond decomposition is not large but should be considered in peat soil respiration calculation.

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