Carbon Dioxide Emissions at the Peatland in Oil Palm Plantations: Groundwater, Subsidence, and Climate

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Abstract. Land clearing for oil palm plantations is considered a contributor to the increasing concentration of carbon dioxide (CO_2) in the atmosphere. This study measured the influence of groundwater depth, subsidence rate, and climate on the CO_2 emissions in peatland from oil palm plantations. This study was conducted at the peatland of oil palm plantations in Siak District, Riau Province, Indonesia from June 2019 to June 2021. This study used an analytical method and was tested with linear regression. The results showed that the highest values of CO_2 emissions found in the groundwater depth > 0.6 m of 39.82 ton ha^{-1} $year^{-1}$. The groundwater depth significantly increases the value of CO_2 emissions at the peatlands in oil palm plantations with $r^2 = 0.206$. The deeper groundwater depth in peatlands then increased emissions of CO_2 produced. Subsidence, rainfall, soil temperature, and solar radiation insignificantly affect the emissions of CO_2 at the peatland in oil palm plantations, and its relationship was classified as weak.

Keywords: CO_2 emissions · peatland · rainfall · soil temperature · solar radiation

1 Introduction

The peatland area in Indonesia is around 14.91 million ha and spread in Sumatra, Kalimantan, and Papua were 6.44; 4.78; and 3.69 million ha, respectively (Ritung et al., 2011). Peatlands have the characteristics of soil pH ranged from acidic to very acidic, low content of macronutrients (N, P, K), low base saturation, and very high cation exchange capacity (CEC) but low adsorption capacity of peatland, thus the nutrients of K, Ca, Mg, and Na effortlessly leached (Hartatik et al., 2011). Furthermore, the peatlands in Indonesia had a thickness ranging from 0.5 to more than 10 m, therefore the carbon storage could be ranged by 300 to more than 6,000 tons ha^{-1} (Agus and Subiksa, 2008). This carbon storage in peatlands can be influenced by several environmental factors and can stimulate greenhouse gas (GHG) emissions (Agus et al., 2012). It has been reported that factors that can increase carbon storage in peatlands such as groundwater

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depth (Jauhiainen & Hooijer, 2012), soil temperature and climate (Farmer et al., 2011; Hirano et al., 2012), and also poor land management causes changes in the properties of peatland, including the availability of C-organic, soil pH, and peat maturity (Nusantara et al., 2014).

The management and use of peatlands for oil palm agroecosystems are one of the efforts to restore several of the carbon in the land with suitable water management (Sabiham & Sukarman, 2011). Oil palm plants can carbon sequestration until the 25 years aged by 35 to 55 tons of carbon ha^{-1} (Carlson et al., 2012; Henson et al., 2012). However, there was a negative perspective with increasing concentrations of GHG emissions in the atmosphere due to the conversion of peatlands into oil palm plantations.

The authentication that oil palm plantations are one of the main causes of the GHG effect must be analyzed with accurate data and researched periodically. One of the techniques can be conducted by measuring the CO_2 emissions of oil palm plantations such as groundwater depth of peatland, subsidence levels, and climate. This study was aimed to analyze the influence of the groundwater depth, subsidence rates, and climate on the CO_2 emissions in the peatland of oil palm plantations.

2 Material and Methods

2.1 Study Design and Area

This study was conducted at the peatland of oil palm plantations in Siak District, Riau Province, Indonesia with an area of 88.75 ha from June 2019 to June 2021. This study uses an analytical method using observational data of CO_2 emissions, groundwater depth, subsidence rates, soil temperature, rainfall, and solar radiation then linear regression analysis.

2.2 Determinants of CO_2 Emissions

The measurement of CO_2 emission was performed using an LI-COR (LI-850) with a close-chamber method (Fig. 1) every month at three sample locations. At each location, there are two points of installation with a distance of 50 and 150 m from the drainage channel. At each point, there are six chambers with the certainty that two chambers are installed on the weeding circle (1.5 m from oil palm plants), two chambers are installed on the interrow (4.5 m from oil palm plants) without trenching and two chambers other are with trenching (removing the roots in the chamber).

2.3 Determinants of Groundwater Depth in Peatland

The measurement of groundwater depth in peatland was conducted using a piezometer/dipwell from a PVC tube with the size of 4 in. along 1.5 m and installed at a distance of 50, 150, and 250 m from the drainage channel (Fig. 2A).

2.4 Determinants of Subsidence Rates

The subsidence rates were conducted every week at each location using a subsidence stake and measured from the ring of subsidence stakes to the surface of the peatland (Fig. 2B).

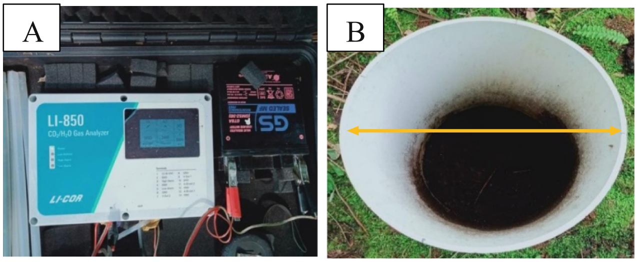

Fig. 1. The tools of CO_2 emissions measurement, A = LI-COR (LI-850); B = chamber.

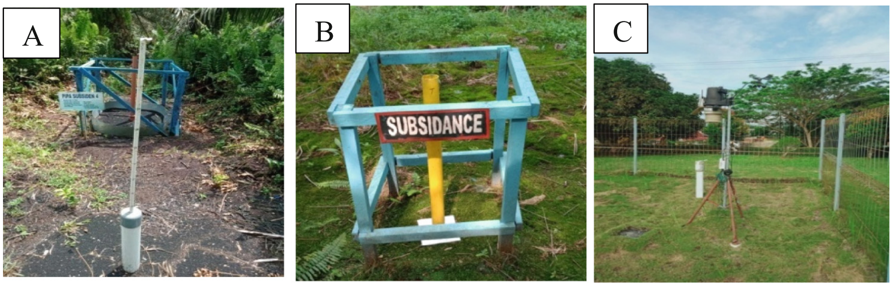

Fig. 2. Measuring groundwater depth in peatland with piezometer/dipwell (A), subsidence rate (B), and automatic weather station (C) for rainfall and solar radiation.

2.5 Climate Measurement

The climate observed includes soil temperature, rainfall, and solar radiation. The soil temperature was monitored at a height of ± 90 cm above the ground using a thermometer. Rainfall and solar radiation were observed using the Automatic Weather Station (AWS) is presented in Fig. 2C.

2.6 Data Analysis

The groundwater depth data was classified into four categories (<0.3 m; 0.3 to <0.4 m; 0.4 to 0.6 m; and >0.6 m) and rainfall data was classified into three climate classifications according to Schmidt and Ferguson (wet, humid, and dry). The parameters of groundwater depth, subsidence rate, rainfall, soil temperature, and solar radiation were tested for mean difference and analyzed using linear regression.

3 Results and Discussion

3.1 Carbon Dioxide Emissions

The value of CO_2 emissions in the peatland from oil palm plantations, Siak District, Riau Province varied each month of observation (Fig. 3), the lowest value of CO^2 emissions was found in June 2019 by 22.40 tons ha^{-1} $year^{-1}$, and the highest was found in March

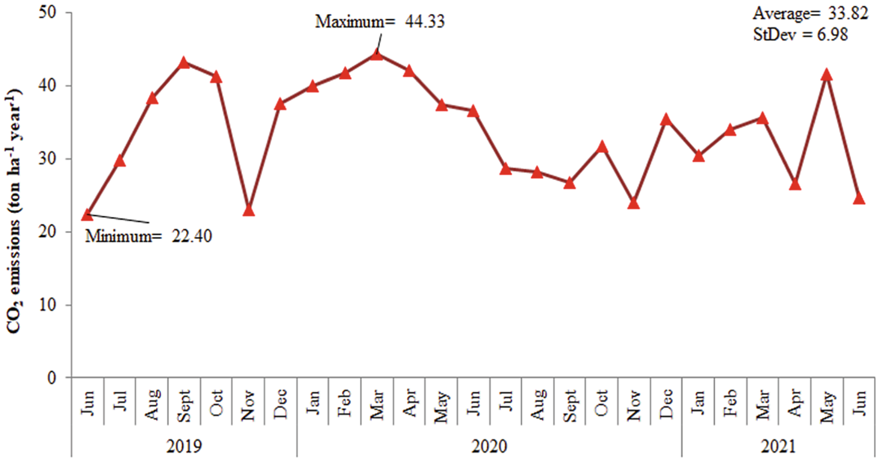

Fig. 3. The CO_2 emissions at the peatland in oil palm plantations, Siak District, Riau Province from June 2019 to June 2021.

2020 of 44.33 tons ha^{-1} $year^{-1}$. The annual average value of CO_2 emissions in this study of 33.82 ± 6.98 tons ha^{-1} $year^{-1}$. It could be influenced by the groundwater depth which significantly increases emissions of CO_2 (Fig. 4A). A similar result has been reported by Ishikura et al., (2017) that the decrease in groundwater depth increases the value of CO_2. Couwenberg et al., (2010); Ishikura et al., (2018) added that the groundwater depth is the main controlling factor of CH_4 emissions, an increase in CH_4 emissions significantly at the groundwater depth above 20 cm. Furthermore, Handayani et al., (2010) stated that the roots respiration in the rhizosphere zones in oil palm plantations on peatland showed higher CO_2 emissions, approximately 38% compared to the outside the rhizosphere zone.

3.2 Factors Affecting CO_2 Emissions

Factors affecting the value of CO_2 emissions at the peatland in oil palm plantations, Siak District, Riau Province are presented in Table 1 and Fig. 4.

The groundwater depth by classifying can be seen in Table 2, and the relationship to CO_2 emissions at the peatland in oil palm plantations could be seen in Fig. 4.

The results showed that the highest of CO_2 emissions was found in the groundwater depth by more than 0.6 m of 39.82 tons ha^{-1} $year^{-1}$ and the lowest was found in the depth of 0.3 m to less than 0.4 m of 31.09 tons ha^{-1} $year^{-1}$. In addition, linear regression analysis results also showed that the groundwater depth significantly increases the CO_2 emissions of peatland (*P*-value < 0.05). A positive correlation between CO_2 emissions with the groundwater depth ($r^2 = 0.2062$). It was indicated that the groundwater depth affects CO_2 emissions by 20.62%. It was caused the drainage system in this study is greatly managed by using overflow to regulate the groundwater depth. According to Hirano et al., (2012) that an increase in the groundwater depth of 10 cm will increase CO_2 emissions by 0.89 tons ha^{-1} $year^{-1}$ at the tropical peatlands in Palangkaraya. Prananto et al., (2020) also reported that the groundwater depth is less than 0.5 m could

Table 1. Factors of groundwater depth, rainfall, soil temperature, solar radiation, and subsidence on the value of CO2 emissions at the peatland in oil palm plantations

Observations		Groundwater depth (m)	Rainfall (mm)	Soil temperature (°C)	Solar radiation (FC)	Subsidence (cm)
2019	June	-0.44	199.83	24.79	174.00	-0.23
	July	-0.66	87.34	23.49	193.23	0.47
	August	-0.64	151.34	24.58	180.03	0.23
	September	-0.76	88.07	23.94	161.67	-0.38
	October	-0.75	171.55	24.50	175.58	0.21
	November	-0.52	288.40	24.50	180.87	-0.14
	December	-0.54	97.14	26.50	156.91	-0.07
2020	January	-0.64	100.75	25.89	180.51	0.30
	February	-0.63	79.70	25.81	194.13	0.12
	March	-0.63	354.27	29.14	194.13	-0.14
	April	-0.41	235.24	25.69	193.59	0.05
	May	-0.40	226.00	27.14	181.61	0.06
	June	-0.42	113.00	25.28	176.18	0.25
	July	-0.43	231.80	25.58	175.41	-0.02
	August	-0.53	76.80	24.78	204.63	0.50
	September	-0.53	173.80	28.51	185.12	-0.14
	October	-0.44	260.60	27.67	196.36	0.02
	November	-0.44	198.00	26.25	166.01	-0.05
	December	-0.56	108.80	28.72	173.01	0.67
2021	January	-0.47	97.00	27.83	158.22	-1.58
	February	-0.54	13.00	26.67	158.71	2.24
	March	-0.38	267.60	31.82	197.47	-0.09
	April	-0.31	291.20	26.18	163.11	-0.14
	May	-0.48	191.60	29.14	186.09	0.48
	June	-0.51	216.20	28.00	193.73	-0.04

contribute 66% of CO_2 emissions, meanwhile the deeper groundwater depth ($\geq$0.5 m) contribute 84% of CO_2 emissions.

In other factors such as rainfall, soil temperature, solar radiation, and subsidence were an insignificant effect (P-value > 0.05) on the CO_2 emissions in the peatland of oil palm plantations (Fig. 4B–E). The rainfall had a positively correlation to the CO_2 emissions ($r^2 = 0.0231$). It was indicated that rainfall affects CO_2 emissions by 2.31%. It was due to the greatly-managed drainage system in this study, thus the water is still

Table 2. Classifying of the groundwater depth on the CO_2 emissions.

Groundwater depth (m)	CO_2 emissions (tons ha^{-1} $year^{-1}$)
<0.3 m	-
0.3–<0.4 m	31.09
0.4–0.6 m	31.54
>0.6 m	39.82

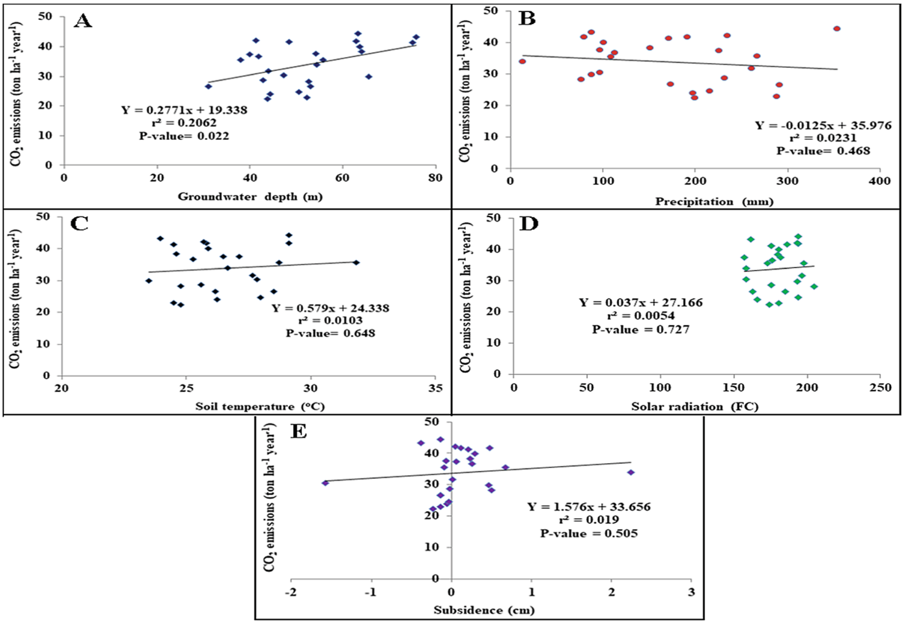

Fig. 4. Relationships of the groundwater depth (A), rainfall (B), soil temperature (C), solar radiation (D), and subsidence (E) on the CO_2 emissions in the peatland of oil palm plantations.

available at optimum conditions. Soil temperature showed a positively correlation ($r^2 = 0.0103$) to the CO_2 emissions. It was indicated that the soil temperature affects CO_2 emissions of 1.03% and the higher the soil temperature, the greater of CO_2 emissions produced.

Solar radiation had a positively correlation to the CO_2 emission ($r^2 = 0.0054$). It was indicated that solar radiation affects CO_2 emissions by 0.54% and the higher the solar radiation, the greater CO_2 emissions produced. Subsidence also had a positively correlation to the CO_2 emissions ($r^2 = 0.019$). It was indicated that the subsidence rate affects CO_2 emissions by 1.90% and the faster the subsidence rate, thus the CO_2 emissions also increase.

4 Conclusions

The deeper groundwater depth in peatland could be increased the emissions of CO_2 produced. The groundwater depth is more than 0.6 m had the highest values of CO_2 emissions of 39.82 tons ha^{-1} $year^{-1}$. Subsidence, rainfall, soil temperature, and solar radiation factors were an insignificant and relatively weak effect on the CO_2 emissions in peatland from oil palm plantations.

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