Carbon Dioxide Emissions Due to Forest Fires in Bukit Batu Area, Bengkalis Regency, Indonesia

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Abstract. High concentration of carbon dioxide in the atmosphere is the major cause of global warming. This study focuses on estimation of carbon emissions from forest fires in Indonesia, especially Bukit Batu area, Bengkalis Regency. Peatlands in this area are widely used as an agricultural cultivation and plantations. The aim of this study is to measure the concentration of CO₂ emitted based on the relationship of physical and chemical properties of peat soil. Measurements carried out on these peatlands with different vegetation covered, i.e. bush land, palm plantations and secondary forests. Methods used in this research were Infrared Gas Analyzer and Gas Chromatography. The average of CO₂ emissions obtained of bush land, palm plantations, and secondary forest were 497.4 ppm; 523. 2 ppm; and 457.2 ppm, respectively.

1. Introduction

Indonesia has total land area in about 188.2 million hectares, consists of 148 million hectares of dry land and 40.2 million hectares of wetlands. Approximately 20.6 million hectares of the total wetlands are peatlands [1]. Riau is a province that has the largest peat land in Sumatra reached of 4,360,740 hectares and 803,891 hectares in Bengkalis Regency [2]. Peatland is one form of a wetland as a substrate of acidic and generally marginal lands for agricultural purposes and plantations. Nonetheless, in the last two decades there has converted to the peatland for agriculture and plantations on a large scale.

Converted peatlands have usually preceded by deforestation or clearing of forest and burning the land. Then, followed by drainage or excavation of canals and ditches those lead to wetland loss of substantially water. Therefore, the water level in the peat that has converted to shrinking so that peatlands are no longer stagnant and becomes more porous surface layer and aerobic [3]. This condition can lead to the decomposition of peat [4]-[5]. As a deposit of organic material, peat has a very large carbon content. Every one meter of peat layers expects to store around 700 tons Carbon yr⁻¹ ha⁻¹, when it decomposed releases carbon in the form of CO₂ gases [5]. Carbon dioxide is one of the most important greenhouse gas, which contributed to global climate changes [6].

The release of CO₂ from peat land as palm plantations, bush land and secondary forest were done by [7] in the Province of Central Kalimantan and West Kalimantan. This research conducted in the Riau Province, especially in Bukit Batu area, Bengkalis Regency. Three type of peatlands (palm plantations, bush land and secondary forest) analyzed using Gas Chromatography equipped with Thermal Conductivity Detector and Gas Chromatography equipped with Thermal Conductivity Detector (Porapack Q column i.d. 2 m × 3 mm film thickness). As a carrier gas was used H₂ with flow rate of 50 mL min⁻¹, and Infrared Gas Analyzer instrument.
2. **Experimental method**

Equipment used in this research were a chamber made of PVC (diameter 280 mm and height 460 mm, the data recorder (VR-71, T & D Japan Co.), stopwatch, GPS (Global Positioning System), thermometer, batteries (GM 7Z-4A 12 V-8AH), 30 mL glass vial, Gas Chromatography with Thermal Conductivity Detector (GC-TCD) Shimadzu 2014, Infrared Gas Analyzer (GMT221 Vaisala, Finland). Materials used were hydrogen gas (H₂) as a carrier gas at Gas Chromatography with Thermal Conductivity Detector (GC-TCD) Shimadzu, 2014.

Measurements and sampling analysis include: (1) site selection; (2) the installation of the chamber; (3) measurement of physical and chemical properties of peat that covers the depth of the ground water level, peat temperatures, and pH (H₂O); (4) measurement of CO₂ flux. Sampling location was Bukit Batu areas, Bengkalis Regency. The coordinate was 35°N, 136°E). Based on physiographic types of land, the type of land that are bush land, palm plantations and secondary forests. The different characteristics of each property was determined based on the physical and chemical conditions such as depth of water table peat soil, peat temperature and pH (H₂O).

![Figure 1. Sampling Sites (Bukit Batu Area)](image)

Measurement of CO₂ flux in this area determined by two methods: Infrared Gas Analyzer and Gas Chromatography. Bush land samples and Secondary Forest analyzed using Infrared Gas Analyzer method. Samples measured through several points based on the distance between the main drainage channels with a sampling point. The placement point determined by making transects using Global Positioning System (GPS). The type of the selected transect is a straight line drawn from 5 m, 25 m, and 40 m to the main drainage channels in those area. While, GC method used only for palm plantation samples. Chamber used cylinder made of PVC with a diameter of 280 mm and height of 460 mm. Three chambers installed in the form of a triangular formation on the surface of the land for each sampling point. Each chamber has many holes as an entry of the roots of plants. Capturing and measuring CO₂ flux one day after the installation of the chamber. The chamber also was equipped with a slit septum for a syringe fitted to the bottom of the chamber. The flux of CO₂ trapped in the chamber took as many as 30 mL and then transferred into a glass vial. The sampling time interval starts at 0.3 and 6 minutes after the lid fitted [4]. CO₂ flux calculated using the following formula:

\[
fc = \frac{Ph}{RT} \times \frac{dC}{dt} \tag{1}
\]

where, \(fc\) = CO₂ flux (µmol m⁻²sec⁻¹); \(P\) = pressure based on IR data GA (Pa), \(h\) = chamber height \(R\) = gas constant (8.314 Pa m³/K/mol), \(T\) = temperature (K), \(dC/dt\) = CO₂ concentration change [8].

Gas samples analyzed by GC-TCD at Kyoto University, Japan. Gas Chromatography equipped with Thermal Conductivity Detector (Porapack Q column i.d. 2 m × 3 mm film thickness. Hydrogen used as a carrier gas with flow rate of 50 mL min⁻¹.

3. **Results and discussions**

The amount of CO₂ emitted flux of peat is highly dependent on the characteristics of the peat, and therefore the need to analyze the condition of the turf.
The results of measurement of the condition of the peat covering the physical and chemical properties of peat soil in the form of temperature, pH (H$_2$O), and the depth of the ground water level shown in Table 1.

### 3.1. CO$_2$ flux

![Figure 2. Characteristic of three type vegetation (a); bush land (b) palm plantations; and (c) secondary forest.](image)

**Table 1. Average Temperature of Soil, pH (H$_2$O), and Depth of Water Table**

| Land Types       | Soil Temperatures (°C) | pH (H$_2$O) | Depth of Water Table (cm) |
|------------------|------------------------|-------------|--------------------------|
| Bush Land        | 31.1±0.77              | 6.3±0.51    | 37.0±22.07               |
| Palm Plantation  | 29.7±1.44              | 6.0±0.46    | 46.7±37.39               |
| Secondary Forest | 24.2±0.63              | 6.4±0.44    | 77.7±16.66               |

![Figure 3. Relationship between soil temperatures and CO$_2$ Flux](image)

Relationship between soil temperatures and CO$_2$ Flux showed in Figure 3. It shows strong positive correlation (R = 0.983). An average measurement of each type of sampling sites toward soil temperature presented on Figure 4. There were 497.4 ppm CO$_2$ flux (bush land), 523.2 ppm (palm plantation), and 457.2 ppm (secondary forest). Furthermore, Figure 5 and Figure 6 show an average of pH (H$_2$O), and the depth of water table on each location.

![Figure 4. Comparison of soil temperature on peat soil of bush land (n = 9), palm plantations (n = 9), and secondary forest (n = 9). Sign different letters (a, b, c) indicate significant differences at α = 0.05.](image)
Figure 5. Comparison of pH (H$_2$O) on peatland vegetation of bush land (n = 10), palm plantation (n = 10), and secondary forest (n = 10). Sign different letters (a, b, c) indicate significant differences at $\alpha = 0.05$.

Figure 6. Comparison of the depth of the ground water level in the peat land with vegetation such as shrubs (n = 10), palm plantations (n = 10), and secondary forests (n = 10). Sign different letters (a, b, c) indicate significant differences at $\alpha = 0.05$.

Figure 7. Average of CO$_2$ fluxes of bush land (n = 9), palm plantations (n = 9), and secondary forest (n = 9). Same letter shows no significant differences at $\alpha = 0.05$.

Effect of the peat soil temperature toward CO$_2$ fluxes of measured for nine time replicates were done with different methods of analyses. Fig 8 and Fig. 9 showed the measurement of CO$_2$ flux for the bush land and secondary forest using Infrared Gas Analyzer. While, the CO$_2$ Flux measurement of palm plantations showed in Fig. 10.

3.2. Effect of soil temperatures

Table 2. Measurements of CO$_2$ Flux and depth of water table on the bush land using Infrared Gas Analyzer.

| Distance between sample and canal (m) | Depth of water table (cm)* | CO$_2$ Flux (µmol m$^{-2}$ sec$^{-1}$)* |
|--------------------------------------|---------------------------|----------------------------------------|
| 5                                    | 77.3                      | 7.5                                    |
| 25                                   | 70.6                      | 5.2                                    |
| 40                                   | 64.2                      | 6.4                                    |
*) 17-20 replicates.

![Figure 8](image1.png)

**Figure 8.** Effect of soil temperature toward CO$_2$ flux conducted in bush land use Infrared Gas Analyzer.

![Figure 9](image2.png)

**Figure 9.** Effect of soil temperature toward CO$_2$ flux of secondary forests using Infrared Gas Analyzer.

![Figure 10](image3.png)

**Figure 10.** Effect of soil temperature toward CO$_2$ flux carried on palm plantations using Gas Chromatography.

### 3.3. Discussions

Based on the degree of decomposition of peat soil, the general types of peat in the study area belong to the Haplosaprist [9]. At the same location, peat soil in the study area has a dark brown color to dark black [10]. When viewed from the level of fertility of soil, peat soil is classified into types oligotrophic with the fertility is low and reacted sourly until very surly.
The average depth of the water table for bush land is 37.0 cm, 46.7 cm palm plantation and secondary forests of 77.7 cm. The depth of water table of the land affected by the type of cover vegetation growing on it. Secondary forest is a type of land that has deeper water. This is due to the characteristics of the soil on that land have pores larger than the bush land and palm peat structure. In addition, the number of roots of vegetation also affect the availability of water adsorbed on the land. Peat water has a characteristic brown and sour with a pH range of about 3.5 \cite{11}. The acidity of peat water caused by organic acids content in peat colloids. According \cite{8} increasing the pH of peat caused by the length of the land use, application of fertilizers, as well as the high level of groundwater. The average pH of the water of bush land, palm plantations and secondary forests were 6.3, 6.0, and 6.4, respectively. Results of research conducted by \cite{2} on the same type of peat (oligotrophic) in Central Kalimantan have the higher pH values ranging from 3.27 to 3.75. The low level of acidity of any land in this study because the measurements were conducted during the rainy season so that the pH of the water is no longer pure pH of the mixture of peat water but rainwater to seep into the peat.

Based on the results of temperature, bush land is the area that have a higher soil temperature of 31.1°C, when it compared to palm plantations and secondary forests i.e. 29.7°C and 24.2°C. The high temperature of the soil in bush land caused by the vegetation cover of the land such as ferns, grasses, as well as various types of broadleaf plants. The results of measurements of soil temperature at this research is not much different from the research carried out by \cite{12} on a bush and secondary forest with soil temperature around 34.5°C and 28.1°C.

3.4. Emissions of greenhouse gases (GHG)

The big difference from the type of vegetation that covered the floor of peat and the depth of the ground water level, soil temperature, and pH (H₂O) creates large flux generated by each land supposed to be different. Otherwise, in this study, the difference in the flux of each land is not too sharp. Duncan test results conducted on $\alpha = 0.05$ also shows that there is no significant difference between the land. CO₂ flux measured from bush land, palm plantations, and secondary forest were 497.4 ppm, 523.2 ppm; and 457.2 ppm, respectively. CO₂ flux generated in this study rated exceed the concentration limit of clean air. As reported by \cite{13} that the boundary between the clean air has a range of 310-330 ppm, while in this area in a range of 350-700 ppm. It means that the air around this area polluted.

Generally, peatlands as secondary forest produce CO₂ fluxes higher than the bush land and palm plantations. This condition occurred because there were a lot of peat sorb in the process of weathering. Furthermore, it is also because of the respiration of the roots of the forest vegetation. The same result was reported by \cite{14} on research conducted in Central Kalimantan. In addition, the differences occur in this study was also supported by other factors such as time and method used for measuring gas samples at different secondary forest with methods that do to the bush and palm plantation. The occurrence of the time difference and the current method of sampling due to the limited number of the chamber at the time so that the sampling time in the bush land and palm plantation early do than secondary forests.

The measurements of CO₂ flux at each peatland showed a positive correlation between soil CO₂ flux with temperature, pH (H₂O), and the depth of the ground water level. An average depth of the water level were 56.0 cm, 31.7 cm and 29.8 cm, respectively. As stated \cite{14}, the higher the production of CO₂ emitted flux peat caused the changes of soil conditions from anaerobic into aerobic. It causes change in the rate of organic matter decomposition process. Decomposition during aerobic conditions flux of CO₂ produced 50 times faster than anaerobic. Aerobic conditions will trigger the availability of oxygen in the soil so that the microbial decomposition as media gets more energy to accelerate the process of mineralization of organic C to produce CO₂ \cite{15}. In contrast to anaerobic conditions, there is no oxygen availability due to water-saturated soil conditions so that the process of mineralization of organic C tends to produce CH₄ than CO₂.

Temperature of peat soil in bush land ranging between 25-33°C and palm plantations from 27.5 to 31.5°C. The results of both the land of each field have different optimum temperature limits. At the optimum temperature, the enzyme system works very well and remain stable for a longer time. Otherwise, at low temperature enzymes also stable but they cannot serve as biocatalyst. While at higher temperatures, enzymes undergo denaturation that causes loss of the catalytic properties (Salampak et al., 2014). The secondary forest covered lot of trees, so the influence of temperature changes on the release of CO₂ flux not seen.
4. Conclusions
Based on the research, it can conclude as follows:
1. The average flux of CO$_2$ emitted by palm plantations was 523.2 ppm, higher than the bush land and secondary forests of 497.4 ppm and 457.2 ppm, respectively. It does not show any significant differences at $\alpha = 0.05$.
2. The pattern of the relationship between CO$_2$ flux with depth of the ground water level, pH (H$_2$O), and the temperature of the ground at each land has a positive correlation, except for the relationship between of ground water depth with CO$_2$ emissions on secondary forests.

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