Soil CO$_2$ emissions from a rubber plantation on tropical peat during a strong El Niño year

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Abstract. El Niño event potentially enhances the soil CO$_2$ emissions due to the prolonged of the dry season which lowers the groundwater level more. However, field information on the effect of the El Niño years on the soil respiration is limited in Indonesia’s peatlands. The aim of this study is to compare the soil respiration between normal and El Niño years. We measured soil CO$_2$ efflux using a closed chamber system monthly, in near and far positions from rubber trees, on the dry season from July to October, in normal year of 2014 and strong El Niño year of 2015, on a rubber plantation established on peat soil. No significant relationship was found between soil respiration with groundwater level or soil temperature. We found that soil respiration in the strong El Niño year of 2015 of 9.56 μ mol m$^{-2}$ s$^{-1}$ was significantly larger than that in the normal year of 2014 at 5.11 μ mol m$^{-2}$ s$^{-1}$. We expected this finding can be used as the first baseline information regarding soil CO$_2$ emissions under different climatic conditions and challenging how to manage the peatland for mitigating high soil CO$_2$ emissions during El Niño events.

1. Introduction

Tropical peatland is one of the largest carbon (C) stores on the earth. Despite only 11% of the global peatland areas, tropical peatland was estimated to store about 81.7 to 91.9 Gt (19%) of total C stocks in global peatlands [1]. Therefore, tropical peatland has an important role in the global carbon cycling. Most of tropical peatlands are distributed in Southeast Asia, with the largest area is in Indonesia, in which is distributed in Sumatra, Kalimantan and Papua Islands [2, 3]. Only in Central Kalimantan, the C stock of peatlands was estimated up to 1220 Mg C ha$^{-1}$ [4]. Recently, peatlands have been recognized as important issues in international climate negotiations because of their ability to store a high amount of carbon, as well as to emit organic C once these ecosystems are disturbed [5]. Over past few years, the rates of tropical peat swamp forest conversion were estimated to be 3.7% between 1990 and 2010 [6]. Most of this conversion is driven by the increasing demand of industrial plantation [7], and smallholder plantation. Therefore, peat soil C emissions from drained peatlands are inevitable in Indonesia’s peatland. In Central Kalimantan, peatlands have been degraded since the failure of the large-scale land development called Mega Rice Project (MRP), that converted about more than half a million hectares of peatland in the late 1990s [8]. Peatland conversion commonly accompanied by drainage, that promote aerobic mineralization of peat soil and results large carbon dioxide (CO$_2$) emissions [9-11]. It has been reported that CO$_2$ emissions from tropical drained peatland are an important part of the global carbon cycle [12], hence it is important to quantify soil respiration (soil CO$_2$ emission) on its converted peatlands.

Rubber plantation is one of main plantation in Indonesia [13], and part of commodities that has been expanding year by year through monoculture as well as agroforestry on tropical peat. Moreover, most
of the rubber plantation in Indonesia was cultivated by smallholder rather than a large-scale plantation [13], where the emission dynamics still yet known well [14]. Thus, the impact of its conversion on peat soil respiration must be studied. In addition, recently, [5] published soil CO$_2$ emission factors from plantations developed on tropical peatland, such as oil palm and acacia plantations. However, emission factor for the rubber plantation is not yet shown. Hence, more field data of soil respiration should be accumulated in rubber plantations.

In 2015, these peatlands area was experienced a historic drought during the El Niño event [15]. In those years, the precipitation is dropped, dry season is prolonged, GWL lowers more [16], and potentially accelerates soil respiration. Thus, an understanding of the peat soil respiration response to El Niño event compared to normal years is important for assessing the magnitude of peatlands CO$_2$ emission feedbacks to the atmosphere. Peat soil respiration (SR) represents the sum of all soil metabolic processes that produce carbon dioxide, consists mainly of organic matter decomposition (microbial respiration), root respiration and litter decomposition. SR was measured using closed chambers. In this study, we aimed to investigate how SR was responding to the change of climatic condition under El Niño event in the context of smallholder rubber plantation in Indonesia, by comparing the soil respiration on the dry season in a normal and a strong El Niño years. Also, to investigate the relationship between soil respiration and environmental factors under climate change. We hypothesized that SR will increase on the dry season in strong El Niño event compared to normal years. This paper presents the first baseline information regarding soil respiration under different climatic condition and provides valuable scientific information for ecosystem adaptation management toward C emission and climate change mitigation strategies.

2. Materials and methods

2.1. Site location
The study was conducted in a smallholder rubber plantation on peat soil in Pulang Pisau, about 25 km south of the city of Palangkara Raya, Central Kalimantan Province, Indonesia [17]. The study site was originally a peat swamp forest, in a watershed of the Kahayan River, that was converted through MRP in about 1997. The former site was abandoned peatland that experienced peat fires particularly on the dry season of El Niño years.

2.2. Experimental design and sampling procedure
The measurement was conducted on the dry seasons of 2014 and 2015. A strong El Niño event occurred in 2015 [15], while in 2014 coincided with normal years. The dry season was defined as months with monthly precipitation less than 100 mm [16]. The dry season in 2015 was measured for four months from July through October [17]. Therefore, in this study, the soil respiration (SR) was directly measured on chamber base using closed chamber system monthly from July through October both in 2014 and 2015. Root respiration (RR) depended on the distance from trees in acacia [18] and oil palm plantations [19], where roots are relatively localized around each tree. Thus, to examine the contribution of RR, the observation points were categorized into two groups i.e. near (NT: 1.5 m) and far (FT: 3 m) positions by the distance from rubber trees. In each category, 6 chamber bases (diameter: 21 cm, height: 2 cm) were inserted at 3 cm deep, for a total of 12 chamber bases that aligned between tree rows (figure 1). The chamber bases had grooves on their tops that allowed them to be filled with water. SR reflects a combination of heterotrophic emissions (organic matter decomposition and litter decomposition) and root respiration. SR data obtained from the “far from trees” monitoring locations were defined as “heterotrophic emissions”. The data from the “near to trees” locations include respirations from both roots and organic matter decomposition and hence defined as “total soil respiration”. Mean daytime autotrophic respiration was calculated by subtracting the mean of the soil respiration measured at the “far from trees” locations from that of the “near to trees” locations.

SR was measured by using a portable infrared gas analyzer (GMP343; Vaisala, Helsinki, Finland) that attached to an opaque PVC chamber with 30 cm in diameter and 20 cm in height. To improve the
time response, CO$_2$ analyzer was operated in an open-path mode by removing its filter. Also, to increase the accuracy, the gas analyzer was calibrated every six months using standard gases. The chamber also equipped with DC data logger (LR 5042, HIOKI, Nagano, Japan) and temperature data logger (LR5011, HIOKI). During the measurements, the chamber was placed securely over the chamber base by water-sealed after the chamber was ventilated using a fan. Air temperature and CO$_2$ concentration in chamber headspace were measured every 10 seconds for three minutes on each chamber base. Also, soil temperature was measured at a depth of 5 cm using an automatic logger near chamber bases. The measurement was replicated three times a day (8:30-10:30, 11:30-13:30 and 14:30-16:30) to cover the different range of soil temperature. Soil respiration (μmol m$^{-2}$ s$^{-1}$) was calculated using air temperature (Ta, °C) and the increasing rate of CO$_2$ concentration (dC/dt, μmol m$^{-2}$ s$^{-1}$) using Eq. (1):

\[
\text{Soil respiration (SR)} = \frac{(dC/dt)}{V/(V'(273.2 + T_a)/273.2)/A}
\]

Where $dC/dt$ is CO$_2$ concentration change (μmol m$^{-2}$ s$^{-1}$), V is chamber volume (0.0144 m$^3$), V' is molar volume of air at 0°C (0.0224 m$^3$ mol$^{-1}$), $T_a$ is air temperature (°C) and A is covered ground area by the chamber (0.0707 m$^2$). $dC/dt$ was calculated from CO$_2$ concentrations during the last two minutes of measurement using the least-square method.

![Figure 1](image.png)

**Figure 1.** Experimental plots and the distribution of chamber bases and ground sensors (NT: near rubber trees and FT: far from rubber trees).

2.3. Soil environments

Groundwater level (GWL), which was defined as the relative elevation of the groundwater surface to the ground surface, was measured hourly using a water pressure sensor (Hobo U20, Onset, Massachusetts, United States) in a perforated PVC pipe inserted vertically deep into soil. Soil temperature also was recorded hourly using a temperature data logger (Thermochron SL type, KN laboratories, Osaka, Japan) installed at a depth of 5 cm.

3. Results and discussion

3.1. Seasonal variations in environmental factors

In 2014, months with monthly precipitation < 100 mm was measured only in August. In 2015, a strong El Niño year with less of precipitation, the months with monthly precipitation < 100 mm was recorded for four months from July through October (figure 2a). Mean GWL from June through November was -91.9 and -136 cm, in 2014 and 2015, respectively. Mean GWL in 2015 was lower 44 cm than in 2014.
GW L was varied between -158 and -83 cm in 2014 and between -196 and -128 cm in 2015. The minimum GWL in 2015 was lower than that in 2014 because of the strong El Niño event in 2015 (figure 2b). However, the lowest GWL was measured in October, the same as between in 2014 and 2015. Even the lowest precipitation in 2014 was recorded in August, but the lowest GWL was measured in October. Also, in 2015, even the lowest precipitation was remeasured in August, but the lowest GWL was measured in October. Mean soil temperature was 27°C, both in 2014 and 2015 (figure 2c). Daily soil temperature ranged between 26 and 29°C in 2014, and between 25 and 28°C in 2015.

![Variations in daily values of (a) precipitation, (b) groundwater level (GWL) and (c) soil temperature from July to October of 2014 (red line) and 2015 (black line), respectively.](image)

Figure 2. Variations in daily values of (a) precipitation, (b) groundwater level (GWL) and (c) soil temperature from July to October of 2014 (red line) and 2015 (black line), respectively. Precipitation was measured in Palangka Raya [20], which was a distance of 25 km from the study site.

### 3.2. Seasonal variations in total soil respiration (SR)

Total soil respiration was not significantly different among three replications (morning: 8:30 to 10:30, noon: 11:30 to 13:30 and afternoon: 14:30 to 16:30) within a day on all chamber bases ($p > 0.05$). Therefore, data from those three replications were averaged on each day for each chamber base both in 2014 and 2015. Soil respiration was averaged in each group of near and far positions from tree bases. Even only 4 months, soil respiration showed a large seasonal variation (figure 3). Soil respiration was varied from 3.89 to 5.97 μmol m$^{-2}$ s$^{-1}$ in 2014, and from 7.82 to 11.2 μmol m$^{-2}$ s$^{-1}$ in 2015 (mean of near
and far positions). Soil respiration averaged at 5.11 and 9.56 μmol m⁻² s⁻¹ in 2014 and 2015, respectively (average of near and far positions, n = 12). The means of soil respiration in near and far positions from the tree bases were not significantly different (p > 0.05). Soil respiration in 2014 was significantly lower than in 2015. Mean of soil respiration in 2015, a year with strong El Niño event was almost two times larger than in normal year of 2014.

![Figure 3](image)

**Figure 3.** Variations in daily mean soil respiration from July to October of 2014 and 2015 (SR, near and far positions from tree bases). n= 6, both for in 2014 and 2015.

In 2014, although GWL was lowest in October (figure 2b), the highest soil respiration was measured in July. Whereas, in 2015, the highest soil respiration was measured in October, in coincidence with the lowest GWL (figures 2b and 3). Soil respiration showed no significant correlation with soil temperature or GWL (p > 0.05).

Soil respiration was not significantly different among three replications within a day (p > 0.05), even soil temperature was usually higher in the afternoon. The low temperature sensitivity of soil respiration probably was attributed to the small amplitude of soil temperature in this site. However, in plantations, soil temperature was found to positively affected the soil respiration [21, 22]. However, [23] found that the effect of soil temperature rise on soil respiration was small even at an open area of peatland when GWL was low. The relationship between soil respiration and GWL was also not significant. It might be caused by the short data series of soil respiration in this study. Another possibility was because soil respiration consists of peat decomposition, root respiration, and litter decomposition that resulted a bias relationship within each component.

Soil respiration was measured at near and far positions from rubber trees to examine the difference of root respiration. It is reported that soil respiration depends on distances from trees and is expected to be free of root respiration contribution at far positions in acacia and oil palm plantations [18, 19]. Unexpectedly, however, no significant difference was found in soil respiration between at near and far positions from rubber trees (p > 0.05). This result indicates that root respiration did not decrease with a distance from trees to 3 m, around the middle of tree rows. Seven years after planting, the roots of rubber trees were reported could reach the middle of tree rows [24]. Moreover, the compacted peat condition in this site probably supported the growth of rubber root [25].
4. Conclusions
Soil respiration on the dry season of a strong El Niño year of 2015 was almost twice larger than that on the dry season of a normal year of 2014. In 2015, the soil respiration increased sharply as groundwater level (GWL) went deeply in October. In contrast, in 2014, the highest soil respiration was measured in July, even the lowest GWL was recorded in October. This result showed that probably the effect of GWL to total soil respiration was clearer to be investigated on a deep GWL condition than that on a low GWL. We also found that soil respiration at near and far positions from rubber trees were not significantly different. This result indicates that root respiration in a rubber plantation does not depend on a distance from the tree bases.

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