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Soil carbon dioxide emissions from a rubber plantation on tropical peat

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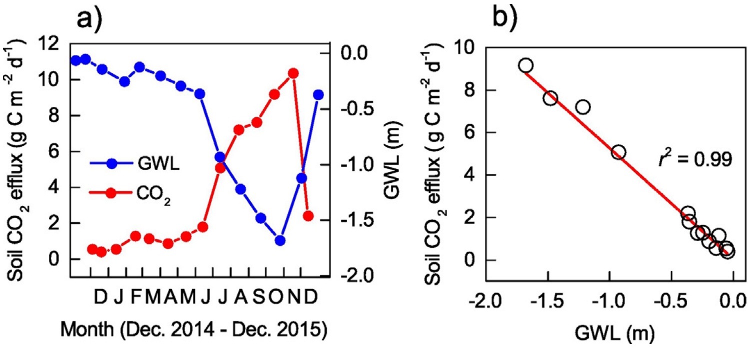
HIGHLIGHTS

- CO_2 efflux through peat oxidation was directly measured in a strong El Niño year.
- Soil CO_2 efflux showed negative relationship with groundwater level.
- Oxidative peat decomposition accounted for 43% of total soil respiration.
- Peat elevation varied seasonally in parallel with groundwater level.
- The contribution of peat oxidation to subsidence was 25% on average.

GRAPHICAL ABSTRACT



CO2 efflux from peat soil through oxidative peat decomposition showed a clear seasonality in reverse parallel with groundwater level (GWL) from December 2014 through December 2015 during a strong El Ni no year (the left panel (a)). The strong linearity between soil CO2 efflux and GWL indicates that oxidative peat decomposition can be simply assessed from GWL (the right panel (b)). Each soil CO2 efflux is the mean of three trenching plots.

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ABSTRACT

Land-use change in tropical peatland potentially results in a large amount of carbon dioxide (CO_2) emissions owing to drainage, which lowers groundwater level (GWL) and consequently enhances oxidative peat decomposition. However, field information on carbon balance is lacking for rubber plantations, which are expanding into Indonesia's peatlands. To assess soil CO_2 emissions from an eight-year-old rubber plantation established on peat after compaction, soil CO_2 efflux was measured monthly using a closed chamber system from December 2014 to December 2015, in which a strong El Niño event occurred, and consequently GWL lowered deeply. Total soil respiration (SR) and oxidative peat decomposition (PD) were separately quantified by trenching. In addition, peat surface elevation was measured to determine annual subsidence along with GWL. With GWL, SR showed a negative logarithmic relationship ($p < 0.01$), whereas PD showed a strong negative linearity ($p < 0.001$). Using the significant relationships, annual SR and PD were calculated from hourly GWL data to be 3293 ± 1039 and 1408 ± 214 $g\,C\,m^{-2}\,yr^{-1}$ (mean ± 1 standard deviation), respectively. PD accounted for 43% of SR on an annual basis. SR showed no significant difference between near and far positions from rubber trees ($p > 0.05$). Peat surface elevation varied seasonally in almost parallel with GWL. After correcting for GWL difference, annual total subsidence was determined at 5.64 ± 3.20 and 5.96 ± 0.43 $cm\,yr^{-1}$ outside and inside the trenching, respectively. Annual subsidence only through peat oxidation that was calculated from the annual PD, peat bulk density and peat carbon content was 1.50 $cm\,yr^{-1}$. As a result, oxidative peat decomposition accounted for 25% of total

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subsidence (5.96 cm yr^{-1}) on average on an annual basis. The contribution of peat oxidation was lower than those of previous studies probably because of compaction through land preparation.

1. Introduction

Peat soil represents an accumulation of organic matter over millennia, storing huge carbon as a thick layer. Despite covering only 11% of global peatland areas, tropical peatlands contain about 88.6 Gt (15–19% of the global peat carbon (C) pool), of which 77% were distributed in Southeast Asia (Page et al., 2011a). Indonesia has the largest area of tropical peatlands, which covers 2.48×10^7 ha and stores 68.5 Gt of carbon mainly in Sumatra, Kalimantan and Papua Islands; 11.3 Gt of carbon is stored as peat even only in Kalimantan (Page et al., 2011a; Ritung et al., 2011; Wahyunto et al., 2014). Peatlands in Central Kalimantan are one of prominent ecosystem carbon pools, which have accumulated throughout the Late Pleistocene and Holocene (Page et al., 2004). However, high demand for plantations has increased land clearing in Indonesia's peatlands during the last decades (Miettinen et al., 2012). In Central Kalimantan, peatlands have been converted to plantations since the failure of the large-scale land development (Mega Rice Project: MRP), through which peatlands of about more than half a million hectares were deforested, drained and burnt in 1995–1997 (Hooijer et al., 2014).

Land-use change in peatland is usually related to large carbon dioxide (CO_2) emissions due chiefly to drainage, which lowers groundwater level (GWL) and disturbs the peat soil condition (Furukawa et al., 2005; Couwenberg et al., 2009). Moreover, land-use change potentially changes peatland from an important carbon sink into a huge source of CO_2 to the atmosphere and increases fire risks (Page et al., 2002; Page et al., 2011b; Agus et al., 2013; Schrier-Uijl et al., 2013). It is reported that annual carbon loss due to peat drainage and fires is on average 28 times larger than the pre-disturbance rate (Dommain et al., 2014). El Niño events bring about drought in most part of Indonesia, including peatland areas. In El Niño years, the dry season is prolonged, and consequently GWL lowers more (Hamada et al., 2002; Hirano et al., 2015). As a result, large-scale peat/forest fires frequently occur, and oxidative peat decomposition potentially accelerates.

CO_2 emissions from peat soil have been typically assessed using two methods: the subsidence and chamber methods. The subsidence method measures the relative elevation of peat surface along with carbon content and bulk density of peat. On the other hand, the chamber method directly measures CO_2 emission rates (efflux) from peat soil surface. The thickness of the peat layer reduces because of compaction, shrinkage, consolidation and oxidative peat decomposition which releases CO_2 to the atmosphere. The subsidence method has an advantage as backwards interpretation of soil carbon loss. The principal question of the method is how to determine the resultant extent of peat oxidation (Hooijer et al., 2010). Although many researchers have attempted to determine the contribution of peat decomposition to total subsidence, it's still unclear. The role of peat oxidation in subsidence of the drained peat layers has not been sufficiently quantified yet (Couwenberg et al., 2009). As for the chamber method, there are several studies in farmland or plantations on tropical peat (Melling et al., 2005; Ali et al., 2006; Hirano et al., 2009; Jauhiainen et al., 2012; Marwanto and Agus, 2014; Husnain et al., 2014; Jauhiainen et al., 2014). However, there are still a small number of studies that measured oxidative peat decomposition directly in the field (Comeau et al., 2016; Dariah et al., 2014; Husnain et al., 2014; Jauhiainen et al., 2012; Hirano et al., 2014; Melling et al., 2013). The direct measurement of soil CO_2 emission, excluding root respiration, is critical to quantify CO_2 emissions arising solely from peat decomposition. Moreover, to reduce uncertainties in the assessment of peat CO_2 emissions, it is indispensable to understand the variability of peat decomposition with environmental factors.

Indonesia is the world's second largest natural rubber exporter after Thailand, with the largest area of rubber plantations in the world (Global Business Guide Indonesia, 2015). Rubber plantations with about 3.5 million ha in area are the third largest plantation in Indonesia after oil palm and coconut (Indonesia Directorate General of Estate, 2013). On peat, although the area of rubber plantation is still limited in comparison with those of oil palm and acacia plantations, rubber plantation has been expanding year by year. Thus, the impact of the land use conversion into rubber plantations on peat CO_2 emissions should be assessed using field data. To our knowledge, there is only a few study to measure peat CO_2 efflux in the rubber plantation (Husnain et al., 2014; Nurzakiah et al., 2014). The measurement of peat decomposition is important to make a meaningful comparison of the vulnerability of peat carbon among different sites and diverse vegetation covers (Melling and Henson, 2011). Therefore, we measured total soil CO_2 efflux (total soil respiration: SR) and CO_2 efflux through peat decomposition (PD) by the trenching approach (Epron, 2009) using the chamber method along with peat subsidence in a rubber plantation on tropical peat throughout a year. Our objectives are 1) to investigate the seasonal variations of SR and PD in relation to GWL, 2) quantify annual SR and PD separately and 3) determine the contribution of oxidative peat decomposition to total subsidence, using the year-round field data.

2. Material and methods

2.1. Study site

Soil CO_2 efflux was measured in a rubber (*Hevea brasiliensis*) plantation (02°29′50″S, 114°11′20″E) on peat soil in Jabiren, Central Kalimantan, Indonesia, from December 2014 to December 2015. A strong El Niño event occurred in the period (Schiermeier, 2015). The peat depth was 5 m on average. The study site was originally a peat swamp forest, but was deforested and drained through MRP in the late 1990s. The site was abandoned after MRP and burnt by peat fire in El Niño years. In 2007, rubber trees were planted for latex harvest at intervals of 3 m and 6.5 m with intercropping pineapple plants between tree rows (Fig. 1) after peat compaction using heavy machinery. The age of rubber trees was eight years old, and the tree height was approximately 6 m. Rubber trees defoliated in the dry season from June to November, which resulted in large accumulation of leaf litter on the ground. A combination of chemical and organic (manure) fertilizers was applied in the first two years at a rate of 1.5 ton yr^{-1}, which was equivalent to 185 kg N ha^{-1}, 185 kg P_2O_5 ha^{-1}, 183 kg K_2O ha^{-1} and 120 kg S ha^{-1}, by piling up the fertilizer at tree bases. For the top 0.75-m-thick peat, bulk density (BD) was 0.23 g cm^{-3}, C and nitrogen (N) contents were 42.8% and 2.34%, respectively, and consequently the C/N ratio was 18.3. Mineral content showed an increase tendency below 0.5 m (detailed in Table 3). For the top 0.5-m-thick peat, pH was 3.4 and 3.5, respectively, in the dry and wet seasons (personal communication).

2.2. Experimental design

To exclude root respiration and directly measure CO_2 efflux through oxidative peat decomposition (PD), three square trenching plots with a respective area of 1×1 m^2 were established in June 2014, which were about 40 m distant from a drainage canal (Fig. 1). We began flux measurement six months after trenching, waiting for the calming of extra CO_2 emissions through the decomposition of dead roots produced by trenching (Epron, 2009). Each plot was trenched 1 m deep into peat

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