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EFFECT OF DRAINAGE ON THE CARBON LOSS FROM SOIL ECOSYSTEMS IN TROPICAL PEATLANDS OF CENTRAL KALIMANTAN

Siti Sundari[1*], Takashi Hirano[2] and Hiroyuki Yamada[2]

[1]*Research Center for Biology, Indonesian Institute of Science (LIPI), Indonesia*
[2]*Research Faculty of Agriculture, Hokkaido University, Japan*

**Corresponding author: ssundari1977@gmail.com*

SUMMARY

Effect of drainage on the carbon loss from soil ecosystems in tropical peatlands had been conducted at two tropical peat swamp forests in Central Kalimantan, undrained forest (UF) and drained forest (DF) sites from July 2010 to December 2011. Carbon loss was assessed by the summation of soil respiration (RS) and groundwater dissolved organic carbon (DOC) flux. Field data in 2004 and 2005 were used to make an empirical model to calculate RS from July 2010 to December 2011, while DOC flux through groundwater from July 2010 to December 2011 was calculated by multiplying groundwater DOC concentration by groundwater flux. Cumulative RS at the UF and DF sites were estimated at 599 and 640 gC m^{-2}, respectively, for six months in 2010. Annual RS in 2011 at the UF and DF sites were 1427 and 1256 gC m^{-2} y^{-1}, respectively. Cumulative groundwater DOC flux at the UF and DF sites were estimated at 14 and 52 gC m^{-2}, respectively, for six months in 2010. Annual groundwater DOC flux in 2011 at the UF and DF sites were 33 and 94 gC m^{-2} y^{-1}, respectively. Carbon loss from soil ecosystems at the UF and DF sites were summed up to 613 and 692 gC m^{-2}, respectively, for six months in 2010. Carbon loss in 2011 at the UF and DF sites were 1460 and 1350 gC m^{-2} y^{-1}, respectively. Carbon loss from soil ecosystems at the DF site was larger than that at the UF site in 2010, suggesting a drainage effect. However, it was larger at the UF site than at the DF site in 2011. The discrepancy in carbon loss from soil ecosystems between 2010 and 2011 was due to interannual variation in groundwater level (GWL) that affected RS that contributes much larger to the carbon loss from soil ecosystems than groundwater DOC flux.

Keywords*: carbon loss, dissolved organic carbon, drainage, soil respiration, tropical peatlands*

INTRODUCTION

Tropical peatlands are widely distributed at the mainlands of East Asia, Southeast Asia, the Caribbean and Central America, South America and Southern Africa. The largest area of tropical peatlands occurs in Southeast Asia, where they are found in Indonesia (predominantly Sumatra, Kalimantan and West Papua), Malaysia (Peninsular Malaysia, Sarawak and Sabah), Brunei and Thailand (Rieley and Ahmad-Shah, 1996). In Southeast Asia, Indonesia has the largest peatland area about 20 million ha, 80% of the total peatlands in this area (Page *et al*., 2010). However, peatland ecosystems have been devastated by logging, land development and management since the 1970‘s. Peat degradation occurs most rapidly and extensively in Indonesia, where 47% of tropical peatlands are located (Page *et al.*, 2011). There, peat is degraded by fires, drainage and deforestation of swamp forest (Couwenberg *et al.*, 2010; Hergoualc'h and Verchot, 2011; Hooijer *et al.*, 2010; Murdiyarso *et al.*, 2010). Burning of peat releases CO_2 intensively but occasionally, whereas drainage raises CO_2 emissions steadily through accelerated aerobic peat and deforestation simply halts CO_2 uptake by trees. Therefore, under such anthropogenic pressure, tropical peatlands present the threat of switch from a role as a global carbon sink to a role as a huge carbon source to the atmosphere (Hirano *et al*., 2009).

The main controlling factors in several variations of soil respiration (RS) may depend on the type of ecosystems and climate (Luo and Zhou, 2006). Furukawa *et al*. (2005) made monthly measurement in Sumatra using the chamber technique and reported that RS in a drained forest was three times larger than that in an undrained forest. Jauhiainen *et al*. (2005) showed microtopographical difference in RS from hummocks and hollows of the forest floor in Central Kalimantan. The RS was almost independent of GWL on hummocks, where it decreased as GWL rose on hollows. Hirano *et al*. (2009) showed that CO_2 emissions from tropical peatlands ecosystems were strongly controlled by GWL in the undrained and drained peat swamp forests in Central Kalimantan. In the undrained forest, soil CO_2 flux sharply decreased when GWL rose above -0.2 and 0.1 m for hollows and hummocks, respectively. The sharp decrease suggests that the contribution of surface RS to total soil CO_2 flux is large. In the drained forest, soil CO_2

flux increased as GWL decreased below -0.7 m probably because the fast aerobic decompositions continued in lower peat.

Dissolved organic carbon (DOC) is defined as the organic matter that is able to pass through a filter (filters generally in size 0.45 µm). The DOC is the main form in which organic carbon is transported downwards into the subsoil where it can be mineralized, stabilized or further leached to the groundwater. Peat soils are a major source of DOC to surface waters. DOC is an important component of the carbon cycle within peat soils and peat soil are a vital store of terrestrial carbon. The DOC flux is important on watershed scale through river flow because in the flux of DOC will result in a significant regional redistribution of terrestrial carbon and DOC loss would be important for determining peatlands carbon balances (Moore *et al*., 1997; Billet *et al*., 2004). Moore *et al*. (2011) analysed concentration of DOC and particulate organic carbon (POC) of river water sampled from the source to the mouth of the Sebangau River in Central Kalimantan during the dry and wet seasons in 2008/2009 and estimated an annual total organic carbon (TOC) flux. This equates to a fluvial TOC flux per unit area over the entire Sebangau catchment of 88 gC m^{-2} y^{-1}, with annual DOC flux and POC flux were estimated at 83 and 5 gC m^{-2} y^{-1}, respectively.

Methane (CH_4) emissions are restricted to high water levels when methanogenesis occurs under anaerobic conditions closed to the surface and re-oxidation of methane is limited. In comparison to temperate and boreal peatlands, CH_4 emissions from tropical peatlands are low (Couwenberg *et al*., 2010). Low CH_4 emissions from tropical peatlands relate to the poor substrate quality of the peats (high polyphenol contents, e.g. lignin). Although CH_4 is produced under anaerobic conditions, the global warming potential (GWP) of the CH_4 flux was small in the tropical peatlands (Hirano *et al*., 2012). In areas of tropics which are expected to experience reduced rainfall and more prolonged drought, peatlands may become less important source of atmospheric CH_4. Therefore, the contributions of CH_4 and POC could be neglected to the total carbon loss from soil ecosystems in tropical peatlands of Central Kalimantan because their contributions were small, so the total carbon loss from soil ecosystems in tropical peatlands was assessed by the summation of RS and DOC flux (Sundari, 2012). The purposes of this study are to assess carbon loss from soil ecosystems from July 2010 to December 2011, evaluate the effect of drainage on the carbon loss from soil ecosystems, and compare the contribution of soil respiration and groundwater DOC to the carbon loss from soil ecosystems in tropical peatlands.

METHODS

Study site

This study was conducted at two tropical peat swamp forests in Palangkaraya, Central Kalimantan. The two peat swamp forest sites were located near each other, with Sebangau River between them. In Central Kalimantan, a large peatland area was deforested and drained during the late 1990's, mainly to develop farmlands according to a national project, Mega Rice Project (MRP). However, the project was terminated in 1999 consequently a vast peatland was left. One site was an undrained peat swamp forest (UF) in Sebangau area. The other was a drained peat swamp forest (DF) in Kalampangan area (Hirano *et al*., 2012; Sundari *et al*., 2012).

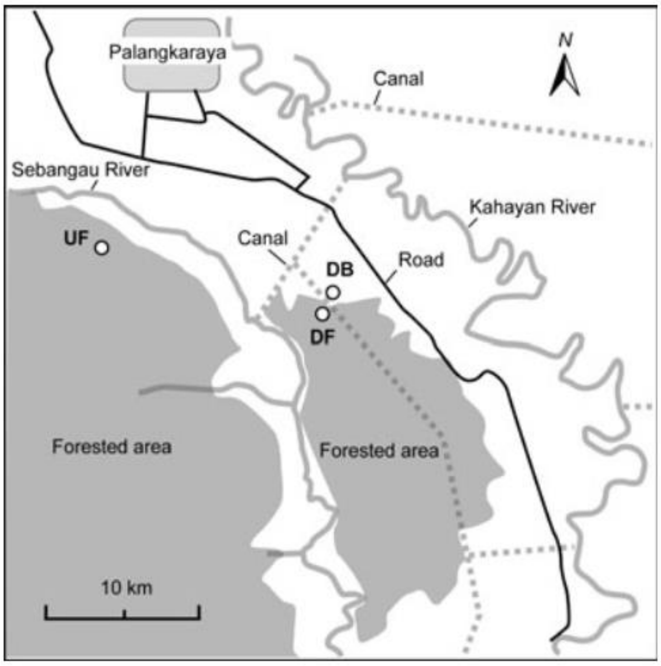

Figure 1: Map of the study site: undrained forest (UF) and drained forest (DF) in Central Kalimantan, Indonesia (Hirano *et al*., 2012).

The UF site (2.32ºS, 113.90ºE) had been logged selectively until the late 1990s, so that it is an almost secondary forest. Although no large canal has been excavated in this area, a network of small canals for illegal logging remains influencing forest hydrology. The peat depth of UF was 2–3 m. A 35-m-high tower was built at the site in 2004 for flux measurement. The soil surface was covered with thick debris, mainly comprising leaf litter. Few herbaceous plants existed on the soil surface. The DF site (2.35ºS, 114.14ºE) is a secondary forest remaining in Block C of the MRP. The forest had also been selectively logged until the end of the 1990s. The peat depth of DF was 4 m. A large canal (25 m wide x 3.5-4.5 m deep) that was excavated in 1996 and 1997 has function effectively to facilitate drainage of the forest. A 50-m-high tower was built for flux measurements. The condition of soil surface resembled those at the UF site (Hirano *et al*., 2012; Sundari *et al*., 2012).

Soil respiration

RS in the UF and DF sites from July 2010 to December 2011 was calculated from GWL using an empirical model, which was made using field data in 2004 and 2005 (Sundari *et al*., 2012). The equation that was used to calculate RS in the UF and DF sites was based on the relationship between the spatially averaged RS and GWL.

In the UF site: When $GWL > -0.1$ m, $RS = 3.53 – 9.83\ GWL$

When $GWL < -0.1$ m, $RS = 4.66 + 0.5\ GWL + 2.11\ GWL^2$

In the DF site: $RS = 4.03 + 2.41\ GWL + 1.69\ GWL^2$

Groundwater dissolved organic carbon flux

DOC flux through groundwater was calculated by multiplying groundwater flux by groundwater DOC concentration. Ground water flux was obtained using a single tank model which was based on a premise that water flux has been increased in proportion to water content in the tank (Sugawara *et al*., 1983). Groundwater level and evapotranspiration data were used to calculate groundwater flux. Groundwater level was measured continually every 10 minutes at three wells in the UF and DF sites, and evapotranspiration was measured on towers at the two sites. Groundwater samples were collected every two weeks from July 2010 to December 2011 at three wells in the two sites and analysed for groundwater DOC concentration using Total Organic Carbon (TOC) analyser (Sundari *et al*., 2012; 2013).

Carbon loss

Carbon loss from soil ecosystems at the UF and DF sites was estimated by the summation of RS and groundwater DOC flux from July 2010 to December 2011.

RESULTS

The results of annual soil respiration (RS), groundwater dissolved organic carbon (DOC) flux, and total carbon losses were specifically described for the UF and DF sites. The data were available for six months in 2010 and 2011, respectively in Table 1 and Table 2.

Table 1: Cumulative soil respiration, groundwater DOC flux, and total carbon loss for six months in 2010

Site	RS (gC m^{-2})	Groundwater DOC flux (gC m^{-2})	Carbon loss (gC m^{-2})
UF	599	14	613
DF	640	52	692

Table 2: Annual soil respiration, groundwater DOC flux, and total carbon loss in 2011

Site	RS (gC m^{-2} y^{-1})	Groundwater DOC flux (gC m^{-2} y^{-1})	Carbon loss (gC m^{-2} y^{-1})
UF	1427	33	1460
DF	1256	94	1350

Table 1 showed that cumulative RS, cumulative groundwater DOC flux and carbon loss for six months in 2010 were larger at the DF site than at the UF site. These results were due to a drainage effect. Drainage to lower groundwater level potentially increases CO_2 emissions from soil through the enhancement of aerobic peat decomposition and DOC production leaching through groundwater flow (Sundari, *et al*., 2012; 2013). Contrarily, table 2 showed that annual RS and annual carbon loss in 2011 were larger at the UF site than at the DF site, although the annual groundwater DOC flux was larger at the DF site than at the UF site. The drainage effect did not influence the carbon loss from soil ecosystem in 2011 because the RS in 2011 at the UF site was larger than that at the DF site (Table 2). It means that the drainage effect also did not influence the RS in 2011. These results related to the comparison between soil respiration and groundwater dissolved organic carbon to the carbon loss from soil ecosystems at the both sites. It showed that the contribution of soil respiration was much higher than that of groundwater dissolved organic carbon flux to the carbon loss from soil ecosystems.

DISCUSSION

The assumption of RS is greater at the DF site than at the UF site because of the enhancement of peat decomposition under aerobic condition by drainage is relevant to the result of cumulative RS for six months in 2010. However, the assumption is not relevant to the result of annual RS in 2011 because it was larger at the UF site than at the DF site. The result in 2011 showed that the effect of drainage which lowering GWL do not support the annual value of RS at the DF site, although peat decomposition is expected, in theoretical terms, to be greater in the DF site. This discrepancy was probably due to the difference in forest productivity at the both sites (Sundari *et al.*, 2012). The UF site retains a relatively intact peat swamp forest, whereas the DF site is secondary peat swamp forest which had been drained and illegal logged for many years, so that the forest productivity was higher at the UF site than that at the DF site. According to this result, effect of drainage was unable to explain the difference in annual RS between the two forest sites in 2011. This fact indicates a large contribution of surface soil and litter to RS and to soil CO_2 efflux (Hirano *et al.*, 2009). Therefore, flooding duration is a key determinant of annual RS at the UF site. When GWL is underground, lowered GWL slows litter decomposition because of desiccation of the litter, but it facilitates the decomposition of deeper peat through enhanced aeration. Conversely, elevated GWL increases litter decomposition but decreases deeper peat decomposition. In fact, RS can be regarded as including two components that are oppositely affected by GWL. Therefore, lowering of GWL does not necessarily increase RS (Muhr *et al.*, 2011; Page *et al.*, 2011). Furthermore, the peat decomposition in deeper soil profile would have increased more under unsaturated conditions than the RS decrease in surface soil and litter decomposition attributable in desiccation.

The groundwater DOC fluxes in the both years at the DF site were higher than at the UF site, suggesting a drainage effect that influences the production of DOC at the DF site through the enhancement of peat decomposition by increasing the aerobic zone. The DOC was produced during the decomposition of organic matter in soil and also is used as a substrate for microbial activity which involves the production of DOC which resulted in higher DOC production and groundwater DOC concentration. In addition, much water was out of the drained peatlands increased the groundwater flux at the drained forest site, consequently groundwater DOC flux became high. The groundwater DOC flux directly related to the amount of water flowing through peat soil, so it enhanced in the high water flow.

Cumulative carbon loss in 2010 and annual carbon loss in 2011 were larger at the UF site than at the DF site because of a large contribution of RS in 2010 an in 2011, respectively, to the total carbon loss from soil ecosystems in tropical peatlands. It also showed that the contribution of RS was much larger than that of groundwater DOC flux to the total carbon loss in both years. This fact supports that RS is one of the largest fluxes in the global carbon cycle which produces CO_2 in the soil and transports CO_2 from the soil to the atmosphere. This result suggested that mostly carbon losses from soil ecosystems were much larger to the atmosphere than leaching through ground water flow in the form of DOC because the components of soil respiration are attributable to the heterotrophic respiration by decomposers and autotrophic respiration by roots and mycorrhizas. Hirano *et al*. (2009) and Sundari *et al*. (2012) showed that CO_2 emissions from tropical peatlands ecosystems in Central Kalimantan were chiefly affected by groundwater level (GWL). The discrepancy in carbon loss from soil ecosystems between 2010 and 2011 was due to interannual variation in GWL that affected soil respiration at the both sites. Hooijer *et al*. (2012) investigated in detail the parameters involved in subsidence and carbon loss in tropical peatlands of Riau and Jambi. They concluded the investment in water management is needed to achieve water levels that reduce subsidence and reduce carbon loss, while at the same time protecting forest and peat resources in the surrounding peatland.

CONCLUSION

Carbon loss from soil ecosystems in tropical peatlands was assessed by the summation of soil respiration and groundwater dissolved organic carbon flux. Cumulative carbon loss, soil respiration, and groundwater dissolved organic carbon for six months at the drained peat swamp forest were greater than at the undrained peat swamp forest. Annual groundwater DOC flux in 2011 was also larger at the drained peat swamp forest than at the undrained peat swamp forest. These results suggested a drainage effect. However, annual carbon loss and soil respiration in 2011 were greater at the undrained peat swamp forest than at the drained peat swamp forest, and showed that drainage effect was unable to explain this result because of the difference in forest productivity between undrained peat swamp forest and drained peat swamp forest. Additionally, the contribution of soil respiration was much larger than that of groundwater dissolved organic carbon flux to the total carbon loss from soil ecosystems in tropical peat swamp forests of Central Kalimantan.

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