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"THE PROPER USE OF TROPICAL PEATLAND"

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SOIL GREENHOUSE GASES EMISSIONS FROM VARIOUS LAND USES IN TROPICAL PEATLANDS IN INDONESIA

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ABSTRACT

Accurate estimation of greenhouse gases (GHGs; CO_2, N_2O and CH_4) fluxes from tropical peatlands is important because of their high GHGs emissions. Soil GHGs fluxes from several land uses (natural forest, burnt forest, cropland, acacia plantation) in Indonesian tropical peatlands were measured monthly through one year, and the relationship between the fluxes and soil environmental variables was studied. Soil CO_2 flux was higher in cropland and smaller in forest and burnt forest, intermediate in plantation. Several peaks of the CO_2 flux were observed in rainy season. Soil N_2O flux also showed peaks in rainy season in all landuses, however, the N_2O flux was considerably high in cropland compared with other lands. Soil CH_4 flux was higher in burnt forest than other land uses due to flooding in burnt forest during rainy season. Average water table depth correlated significantly to average CO_2 flux positively, average N_2O flux exponentially, and average CH_4 flux negatively. However, the contribution of CH_4 emission to global warming potential (GWP) was negligible in water table above peat surface due toflooding. The GWP increased from 40 to 140t CO_2 ha^{-1} yr^{-1} with drop of water table from 0 to 100 cm, in which CO_2 emission increased from 40 to 100 t CO_2 ha^{-1} yr^{-1}, and N_2O emission contributed to the GWP gradually after water table became deeper than 50 cm.

Keywords : *Carbon dioxide, ground water table, methane, nitrous oxide, tropical peatland*

INTRODUCTION

Tropical peatlands include huge amount of carbon (C) in the small land area, that is 70 GtC in 50Mha, which is 5% of total soil C in 0.3% of the world total land area. Indonesia is the country where more than 80% of tropical peat distributes (Maltby and Immirzi 1993). In the peatlands, exploitation has been conducted with clear cutting of the forests and constructing drainage channels. Drainage of the peatlands generally induces peat subsidence with peat decomposition (Couwenberg *et al*., 2010), and peat decomposition accounts for 50 - 70% of the subsidence (Murayama and Bakar, 1996 a, b; Hatano *et al*., 2010). Hatano *et al*. (2010)

estimated that peat decomposition per unit peat subsidence ranged from 4.3tC ha^{-1} cm^{-1}in a drained natural forest to 6.8 tC ha^{-1} cm^{-1}in a burnt forest in Palangkaraya, Central Kalimantan, Indonesia. Couwenberg *et al*., (2010) estimated annual rate of peat decomposition per 10 cm of additional drainage depth as 2.5tC $ha^{-1}yr^{-1}$ in maximum. Peat decomposition induces the emissions of GHGs (CO_2, CH_4 and N_2O), due to release of huge amount of C and N contained in peat (Melling *et al*., 2005a, b; Melling *et al*., 2007, Jauhiainen *et al.*, 2005; Takakai *et al*., 2006). Plots of CO_2 emission from soil surface against average water table depth in tropical peatlands showed a tendency that the CO_2 emission increased with a drop of water table depth, although the relationship was not significant (Hooijer *et al*., 2006). Based on the tendency, CO_2 emission from peat decomposition in tropical peatland in South Asia was estimated as 170 MtC y^{-1}, which is half of the Japanese emission (Hooijer *et al.*, 2006). Emissions of N_2O and CH_4 from tropical peatlands have not been yet estimated widely, however, as N_2O production is exponentially correlated to CO_2 production (Mu *et al*., 2009), the contribution of N_2O emission can be increased significantly by increase of peat decomposition. CH_4 emission from tropical peatlands relatively low (Jauhiainen *et al.,* 2005; Melling *et al*., 2005b) compared with the CH_4 emissions from boreal and temperate peatlands (Couwenberg *et al*., 2010), rather CH_4 is absorbed by peat with the water table depth deeper than 50 cm (Watanabe *et al*., 2009). But, as previously shown, drop of water table depth increases CO_2 and N_2O emissions. Therefore, more study for the evaluation about GHGs emissions associated with land uses of tropical peatland is required in order to create proper managements reducing GHGs emissions in tropical peatlands. In this study, we investigated the relationship between GHGs emissions and soil environmental factors in various kinds of land use in tropical peatlands of Indonesia.

MATERIALS AND METHODS

Four land uses, cropland, burnt forest, drained natural forest and plantation, were investigated in this study. Three sites of cropland area, three sites of burnt forest area, one site in drained natural forest area were chosen in Kalampangan near Palangkaraya city in Central Kalimantan, and six sites in acacia plantation area in Langgam near Kerinci city in Riau. Peat subsidence, CO_2, N_2O and CH_4 fluxes from the soil and soil environmental factors (water table depth, soil temperature, soil moisture content, soil pH, soil electrical conductivity (EC), soil ammonium (NH_4^+-N) and nitrate (NO_3^--N) contents, water soluble soil organic matter content (WSOC)) were measured once a month from September 2008 to August 2009. Total amount of precipitation during the period of the investigation was similar in Palangkaraya (2146 mm) and Kerinci (2187 mm), but monthly pattern of the precipitation was different. Rainy season, which was defined as the period more than two months with monthly precipitation more than 200, was found from November to April in Palangkaraya, but in Kerinci, rainy season was divided into two periods from September to November and from March to April. Bulk density of top 0-10 cm was 0.38 - 0.42 g cm^{-3} in cropland, 0.13 g cm^{-3} in natural forest, 0.13 - 0.22 g cm^{-3} in burnt forest and 0.09 - 0.15 g cm^{-3} in acacia plantation.

CO_2, N_2O and CH_4 fluxes were measured by using closed chamber method.Above ground green parts were cut and eliminated before the measurements. Peat subsidence was measured by iron pipe inserted to under-layered mineral soil or PVC pipe inserted to 2 m depth. Water table depth was measured by 2 m long perforated PVC pipes. Soil temperature at 4 cm depth was measured by thermometer, and water temperature was measured during flooding instead of soil temperature. Volumetric soil moisture content in 0 to 6 cm depth was measured by TDR moisture meter. Soil pH and soil EC was measured using suspension of 1:20 peat and water mixture. Soil NH_4^+-N content was measured in the extraction of 1:20 peat and 2M-KCl solution mixture. Soil NO_3^--N and WSOC contents were measured in the extraction of 1:20 pea and water mixture.

RESULTS AND DISCUSSION

Monthly change in soil temperature, water table depth, soil moisture content in cropland, natural forest and burnt forest, and acacia plantation are shown in Figure 1. Soil temperature was higher in cropland and burnt forest than in natural forest and acacia plantation, due to open canopy of the vegetation in cropland and burnt forest. Water table depth was deeper in cropland than in other land uses. In burnt forest, flooding was shown in the rainy season. Soil moisture content was high in cropland and low in acacia plantation compared with that in forest and burnt forest.

Monthly change in CO_2, N_2O and CH_4 fluxes in cropland, forest and burnt forest and acacia plantation are shown in Figure 2. CO_2 flux was high in cropland and low in forest and burnt forest, compared with that in plantation. Melling *et al*. (2005) showed CO_2 flux was higher in tropical peatland with lower humidity due to open canopy, higher bulk density and deeper water table depth, this explained well the results obtained in this study. However, there were several peaks of CO_2 flux in rainy season. This may indicate that microbial activities were influenced by water stress in dry season (Couwenberg *et al*., 2010). N_2O flux was extremely high in cropland, which was about 40 times large compared with that in other land uses, as previously shown (Takakai *et al*., 2006). There were peaks of N_2O flux in rainy season in all land uses. CH_4 flux was absorbed in dry seasons, but high in rainy season when water table depth became shallow, as shown in previous reports (Jauhiainen *et al*., 2005; Melling *et al*., 2005b; Watanabe *et al*., 2009). Especially in burnt forest where flooding happened, the CH_4 flux was about 10 times large compared with that in other land uses, but it was 3800 μgC m^{-2} hr^{-1} in maximum which was low compared with that from the boreal and temperate peatlands (Couwenberg *et al*., 2010).

Figure 3 shows that the relationship between average CO_2 flux and average soil temperature, average soil moisture content and average water table depth. CO_2 flux was significantly correlated with soil moisture content negatively and with water table depth positively, but not significantly correlated with soil temperature. Correlation coefficient in the relationship between CO_2 flux and water table depth was higher than soil moisture content.

Figure 4 shows the relationship between average water table depth and average N_2O flux, and average CH_4 flux. Average N_2O flux was logarithmically correlated to water table depth. This indicates that N_2O emission is more sensitive to change in water table depth than CO_2 emission, as shown previously (Mu *et al*., 2009). CH_4 flux was negatively correlated with water table depth, which is the same tendency as previous report (Watanabe *et al*., 2009; Couwenberg *et al*., 2010).

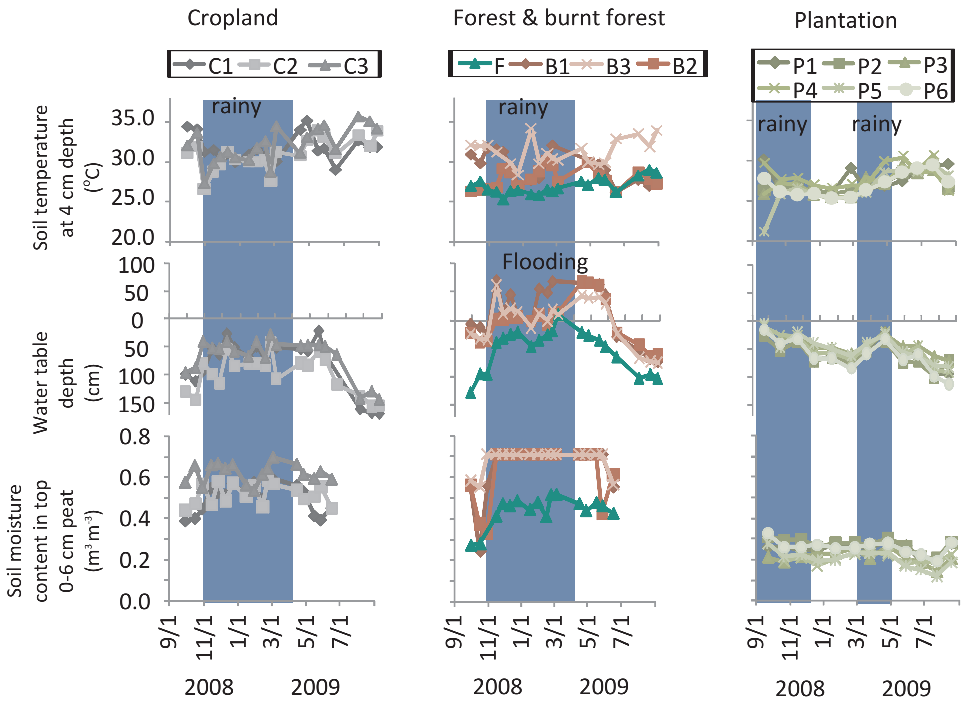

Figure 1. Monthly change in soil temperature, water table depth and soil moisture.

Results of regression analysis between the gas fluxes and soil environmental variables are shown in Table 1. Water table depth was most important factor for controlling GHGs emissions. In addition, soil EC and soil NO_3^--N content were well correlated with the GHGs emissions. Soil NO_3^--N content was highly correlated with N_2O flux. Taking into consideration peaks of N_2O flux in rainy season, denitrification is thought to be main process for N_2O emission. Increase of soil EC indicates an increase of soil nutrient concentrations, which is associated with organic matter decomposition, N mineralization and nitrification. This leads to denitrification consequently. Takakai *et al.*, (2006) showed more N_2O emission in the year with higher precipitation, and Hashidoko *et al.* (2008) showed the development of a unique denitrifer in NO_3^--N rich peat soil.

CH_4 flux,which increased during a period of flooding, was significantly correlated to WSOC content. Increase of WSOC indicates a reduction of oxidative decomposition of soil organic matter due to decrease of O_2 gas supply into soil from the atmosphere by flooding. Consequently, CH_4, which was produced from Co_2 and acetate in soil, can be emitted from the soil surface without CH_4 oxidation (Conrad, 1999). However, increase of WSOC also indicates excess CO_2 production due to act of soil organic acid as electron acceptor (Yao and Conrad, 2000).

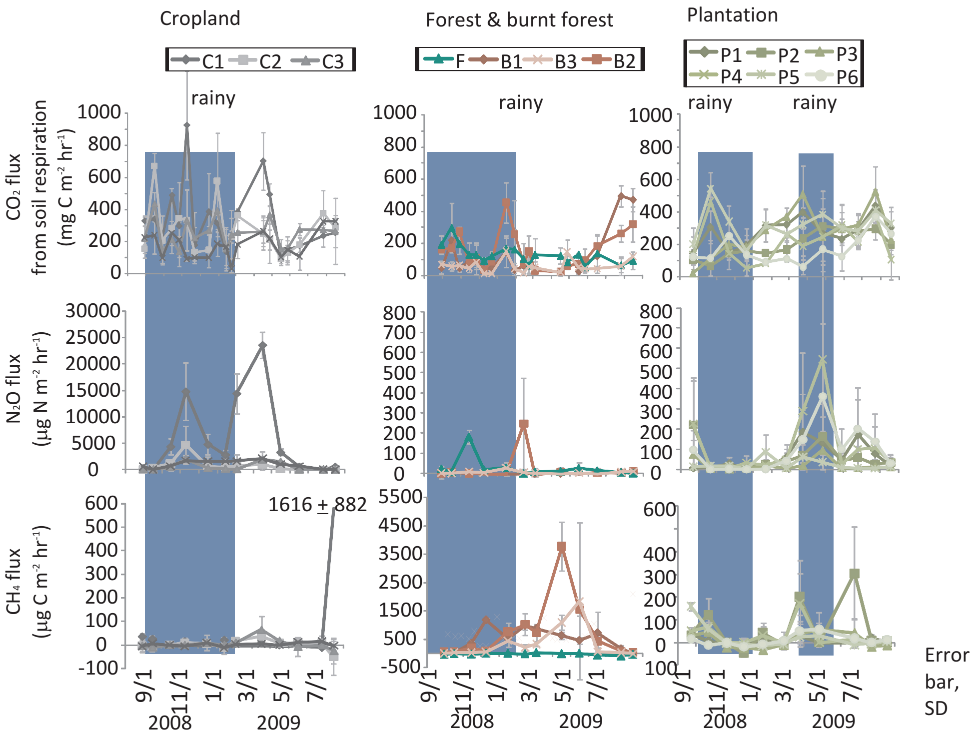

Figure 2. Monthly change in CO_2, N_2O and CH_4 fluxes.

Table 1. Results of regression analysis between the gas fluxes and soil environmental variables

	CO_2		$log(N_2O)$		CH_4	
Soil temperature	0.009		0.279		0.123	
Water table depth	0.784	**	0.863	**	-0.828	**
Soil moisture	-0.592	*	-0.359		0.666	
Subsidence	0.366		0.343		-0.236	
pH	0.186		0.423		-0.041	
EC	0.689	**	0.590	*	-0.555	*
WSOC	-0.360		-0.423		0.544	*
NH_4^+-N	0.029		-0.205		-0.283	
NO_3^--N	0.671	*	0.715	**	-0.407	

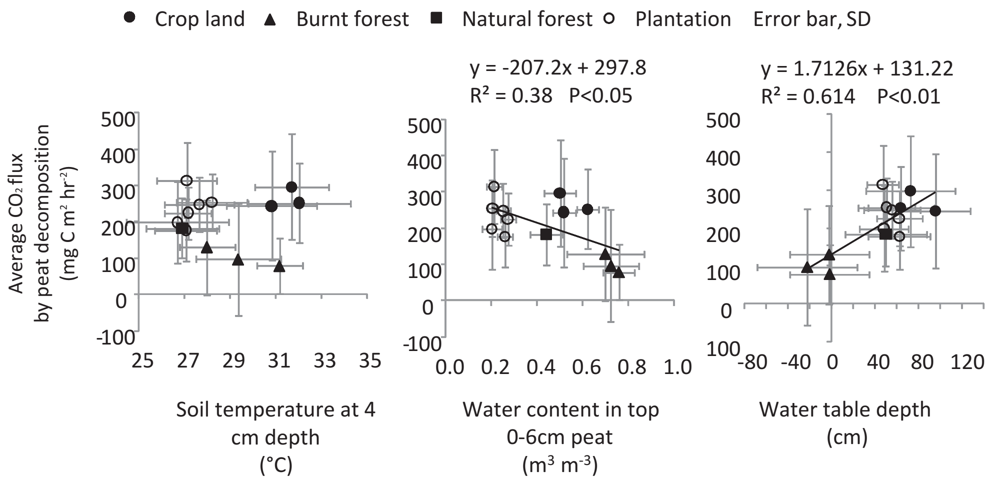

Figure 3. Relationship between average peat decomposition and average soil environmental factors.

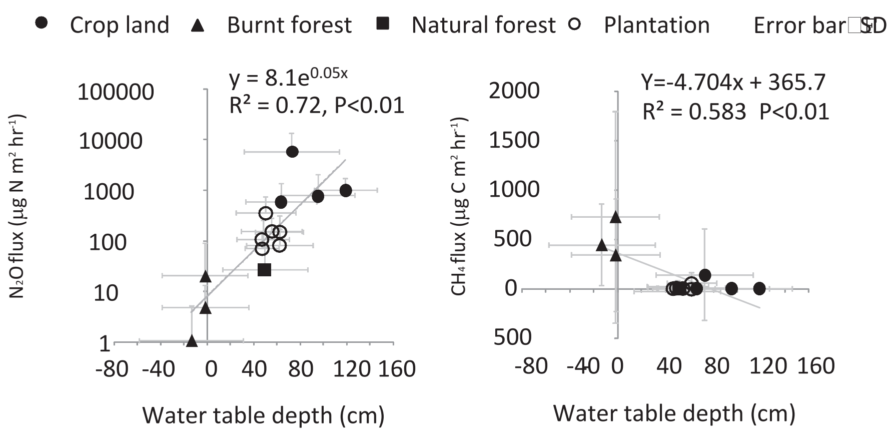

Figure 4. Relationship between water table depth and the fluxes of N_2O and CH_4.

Peat subsidence was not correlated with the gas fluxes. However, increase of subsidence increased CO_2 and N_2O fluxes and decreased CH_4 flux. Peat subsidence is influenced by bulk density, and peat subsidence associated to the decomposition of peat with higher bulk density produces more CO_2.

Figure 5 shows the relationship between global warming potential (GWP) and water table depth. The GWP of CO_2 base was converted from GHGs emissions using the factors which 25 g CO_2 for 1g CH_4 and 298 g CO_2 for 1 g N_2O at the 100-year time horizon (Forster *et al*., 2007).

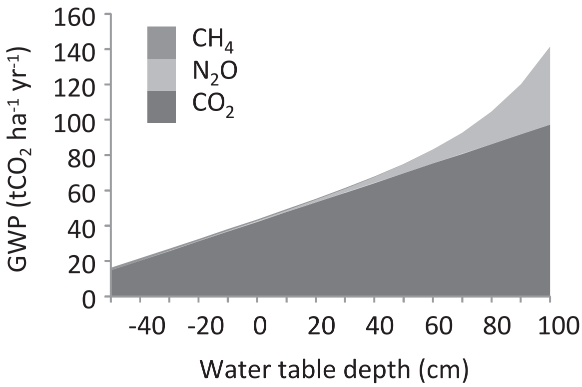

Figure 5. Relationship between water table depth and global warming potential (GWP)

GWP was estimated to increase from 40 to 140 t CO_2 ha^{-1} yr^{-1}, when water table dropped from 0 to 100 cm. N_2O emission significantly contributed to the GWP, when water table became deeper than 50 cm, and it occupied 29 % of GWP at water table depth of 100 cm. However, the contribution of CH_4 emission to GWP was small even during the period of flooding.The relationship between CO_2 emission and water table depth given by Hooijer *et al*. (2006) was a straight line which CO_2 emission increases from 0 to 80 t CO_2 ha^{-1} $yr^{-1}$when water table dropped from 0 to 100 cm. Therefore, the result from this study will make considerably (75%) large estimation of peat decomposition compared with Hooijer *et al*. (2006). Concerning the CO_2 emission from flooded tropical peatland, several researchers reported the values of the CO_2 emission from the peatland, where the annual water table depth ranged from -5 to 2 cm and was -0.6 cm in average, ranged from 4.1 to 88 t CO_2 ha^{-1} $yr^{-1}$and was 32t CO_2 ha^{-1} yr^{-1} in average (Chimner, 2004; Chimner & Ewel 2004; Furukawa *et al*., 2005; Hadi *et al*., 2001; Jauhiainen *et al*., 2001; Darung *et al*., 2005). The average value of CO_2 emission may be similar as net primary production (NPP) of natural tropical forest. Hirano *et al*. (2007) showed that net ecosystem CO_2 exchange (NEE = soil CO_2 emission - NPP) was 3.7 and 29.0 t CO_2 ha^{-1} yr^{-1} in a natural swamp forest and a well flooded burnt forest in Palangkaraya, respectively. The difference between the values of NEE in natural and burnt forests (25 t CO_2 ha^{-1} yr^{-1}) can be an estimation of NPP of trees of natural forest of Palangkaraya. However, Couwenberg *et al*., (2010) reported that NEE values in temperate peatlands were negative (which means the absorption of CO_2 by the ecosystem) when water table depth existed in 0 to 10 cm, and around -5 t CO_2 ha^{-1} yr^{-1} at 0 cm of water table depth. These findings indicate that large amount of peat is always decomposed even in natural forest in tropical peatlands. Vegetation fixes CO_2 emitted from soil as well as Co_2 in atmosphere, so the loss of vegetation from the peatlands indicates that CO_2 emitted from soil is converted into the atmosphere. Therefore, in order to reduce NEE, proper plantation to increase NPP is also important as well as the decrease of CO_2 and N_2O emissions from peatland by the maintenance of water table depth.

CONCLUSION

Water table depth was a significant factor for determining GHGs emissions from tropical peatlands. CO_2 emission from the peatlands increased from 40 to 100 t CO_2 ha^{-1} yr^{-1} with drop of water table from 0 to 100 cm. Increase of peat decomposition promoted N_2O emission due to increase of N mineralization and nitrification followed by denitrification in wet season. N_2O emission significantly contributed to GWP at the water table depth deeper than 50 cm. CH_4 emission increased with flooding, but it was not significant in GWP.

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