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DISTURBANCE HISTORY AND MANAGEMENT OF TROPICAL PEATLANDS EFFECT ON N_2O FLUXES

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SUMMARY

We quantified *in situ* N_2O fluxes during dry- and wet seasons and compared them with CO_2 and CH_4 fluxes at sites representing differing land uses and land use change intensities, i.e. non-drained and drained selectively logged peat swamp forest, deforested drained and burned peat, and agriculture on peat in Central Kalimantan, Indonesia.

The widest N_2O flux amplitude was detected in the moderately drained forest. At the other flux monitoring sites the flux amplitude remained about 10× smaller. Annual cumulative peat surface N_2O emissions expressed as CO_2 equivalents of the total greenhouse gas (N_2O, CO_2 and CH_4) emissions was typically ~1%, but at the highest 9.2%.

KEY WORDS : GHG flux dynamics, Indonesian peatlands, nitrous oxide, water table depth

INTRODUCTION

Soil is considered to be one of the key sources of N_2O emitted into the atmosphere as it contributes approximately 60% of the emissions globally (Ehhalt et al., 2001). Processes involved in the dynamics of N_2O, CO_2 and CH_4 exchange between soil and the atmosphere are controlled by several factors, including soil moisture status, temperature and mineral nitrogen concentration (Melling *et al.*, 2007; Maljanen *et al.*, 2010). Maximum emissions of N_2O are typical when intermediate conditions between aerobic and anaerobic states in soil prevail (Davidson *et al.*, 2000). CH_4 emissions are at their highest under strictly anaerobic conditions in soil, whereas CO_2 emissions predominate under aerobic conditions (Moore and Knowles, 1989).

Since 1990, 5.1 Mha of the total 15.5 Mha of peatland in the Peninsular Malaysia, and the islands of Borneo and Sumatra, which represent the main tropical peat deposit areas, have been deforested, drained, burned and converted to agriculture (Miettinen and Liew, 2010). Most of the remainder of this region’s peat swamp forests have been logged intensively. Agriculture necessitates permanent drainage of peatlands as there is a need to secure oxygen availability for the roots of crop species grown on peat soils. N_2O emissions may be high if substantial N-fertilizer applications are made to increase agricultural productivity and plantation forestry on nutrient deficient peat soils (Murdiyarso *et al.*, 2010).

The objective of this study was to quantify N_2O exchange dynamics between the peat and the atmosphere and to estimate the importance of this greenhouse gas under typical tropical peat land uses. Research questions were: 1) does the land use, defined by differences in vegetation cover and peat water table conditions result in differences in N_2O flux? 2) to what extent does annual N_2O flux balance compare with the balances of the other two main greenhouse gases in peat (i.e. CO_2 and CH_4)? Drainage was expected to increase the N_2O fluxes in sites characterized by forest. In the drained areas, vegetation type was expected to have greater importance for N_2O fluxes than differences in water table depth. The presence of vegetation and drained conditions were expected to enhance the GWP impact of cumulative N_2O and CO_2 emissions, but to decrease it for CH_4.

MATERIAL AND METHODS

Study sites were located within ~20 km of Palangka Raya city in Central Kalimantan Province, Indonesia. The climate in the area is characterized by a relatively unvarying temperature, high humidity, and high rainfall intensity. The mean monthly temperature varies between 24 and 27°C. The mean annual rainfall varies between 1900 and 3000 mm along the southern coast of Borneo, with an overall mean of around 2700 mm in the study area (Hooijer *et al.*, 2008).

The study included four land use types. Two of them had forest cover; these were the undrained forest (UF) and drained forest (DF). Land use types on clear-felled drained open peat areas included drained burned peat (DBP) and land drained for agriculture (AP_Ka). Details of the sites' management history can be found in Jauhiainen *et al.* (2012).

Air samples were taken from each site. Square, open-top aluminium frames with the dimensions (W×L×H) 60 × 60 × 40 cm were used for collecting the air samples. Gas samples were transported in glass vials to Finland for analyses. Details of the CO_2 and CH_4 analyses are provided in the references cited in Table 1.

RESULTS

The majority of the N_2O flux readings were found to be less than 0.02 mg N_2O-N m^{-2} h^{-1} at most of the sites. The drained DF forest site cumulative (±SD) N_2O emission (1581.3±41.7 mg N_2O-N m^{-2} y^{-1}) was the highest among the four sites. The UF site annual N_2O emission was 55.9±10.3 mg N_2O-N m^{-2}, for the deforested DBP site mean annual emission was 76.4±2.8 mg N_2O-N m^{-2}, and for the agricultural AP_Ka peatland site it was 20.6±7.8 mg N_2O-N m^{-2}. Carbon dioxide was quantitatively the main emitted GHG from all sites, and contributed 98% or more of the total GWP in the form of emissions of CO_2, CH_4 and N_2O. The highest cumulative N_2O contribution to the total GWP (9.2% of the total) occurred at the DF site (Table 1). It is worth noting that the DF site cumulative CO_2 emission was the highest (7283 g m^{-2} y^{-1}) in this study, which further adds absolute and relative significance to the N_2O contribution. Cumulative CH_4 losses only exceed those of N_2O at the UF site (Table 1).

Table 1. Annual cumulative N_2O (N_2O-N), CO_2 and CH_4 fluxes (mean±SD) in peat. Actual and relative contribution of three gases to the total GWP, and the total GWP of the gases are shown. Cumulative CO_2 and CH_4 flux rates refer to references shown on respective rows.

Site/ Abbreviation	Time period	N_2O-N mg m^{-2} y^{-1} (g CO_{2e} m^{-2} y^{-1}) [% GWP]	CO_2 (1 g m^{-2} y^{-1} (-) [% GWP]	CH_4 (1 g m^{-2} y^{-1} (g CO_{2e} m^{-2} y^{-1}) [% GWP]	Total GWP (2 g CO_{2e} m^{-2} y^{-1}
Undrained forest/ UF	09.1994 – 08.1995	55.9 ± 10.3 (26.2 ± 4.9) [0.9%]	2895 ± 335 (-) [98.0%]	1.36 ± 0.57 (34.00 ± 14.25) [1.2%]	2955
Drained forest/ DF	07.2005 – 06.2006	1581.3 ± 41.7 (740.4 ± 19.5) [9.2%]	7283 ± 1787 (-) [90.9%]	-0.37 ± 0.09 (-9.22 ± 2.20) [-0.1%]	8014
Deforested burned peat/ DBP	07.2005 – 06.2006	76.4 ± 2.8 (35.8 ± 1.3) [1.3%]	2809 ± 278 (-) [98.5%]	0.28 ± 0.14 (6.88 ± 3.60) [0.2%]	2852
Agricultural peat/ AP_Ka	365 d (typical conditions)	20.6 ± 7.8 (9.6 ± 3.6) [0.6%]	1716 ± 16 (-) [99.3%]	0.11 (2.75) [0.2%]	1728

1 References for CO_2, CH_4 and water table depth data; NDF, Jauhiainen et al. (2005); DF and DBP, Jauhiainen et al. (2008), and AP_Ka, Hirano et al. (2009).
2 Radiative forcing in 100 years perspective, i.e. CO_2 = 1, CH_4 = 25, N_2O = 298 (Solomon *et al*., 2007), are applied in calculus of CO_2 equivalents (CO_{2e}).

CONCLUSIONS

Drainage of tropical ombrotrophic forest systems increases organic matter mineralization rates in peat, although the litter deposition into peat may remain relatively unaffected. This results in enhanced GHG emissions, especially as CO_2 and N_2O. The drained forest mean N_2O flux was >10-fold in comparison to the fluxes for other sites, including mean flux in undrained peat swamp forest. For clear-felled sites (agricultural areas and deforested burned peat) emission rates were relatively modest, and this is associated with low N-availability in the peat substrate. Therefore, enhanced N_2O emission rates from drained peat after land use change can be a transient phenomenon when the nitrogen availability is not maintained at a high level from biological or artificial sources. The N_2O flux rates show some degree of spatial and temporal variation in drained forest and deforested drained peatland. More intensive flux monitoring investigations on tropical peat soils are required in order to be confident that the impacts of very high, but potentially short-lived, fluxes are properly determined. Carbon dioxide has an outstanding GWP impact (>90%) in tropical peat when concurrent CO_2, CH_4 and N_2O fluxes are compared across various land use types. For CH_4 and N_2O gases, the GWP impact is usually <2% of the total of all three gases.

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