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SPATIAL DISTRIBUTION OF N_2O FLUX FROM AGRICULTURAL FIELD ON TROPICAL PEATLAND, KALIMANTAN, INDONESIA

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SUMMARY

Nitrous oxide (N_2O) is one of major greenhouse gases emitted from agricultural field. In drained tropical peatland, significant amount of N_2O emission (maximum 698 kg N ha^{-1} y^{-1}) has been reported from an agricultural field in Palangka Raya, Kalimantan, Indonesia. Due to high organic matter and mineral nitrogen supply by peat decomposition, N_2O was mainly produced by denitrification process in rainy season and not mainly from applied nitrogen fertilizer. However, it is unknown whether large amount of N_2O emission can be observed from other agricultural fields on drained tropical peatland in the region. In this study, N_2O fluxes from 10 agricultural fields located in the same village and analyzed controlling factor of N_2O flux were investigated. In rainy (February, 2006) and dry (September, 2006) seasons, N_2O fluxes were measured at 10 fields, in which vegetables were cultivated, soil physical- and chemical-properties were measured. N_2O flux in rainy season (0.008-3.46 mg N m^{-2} h^{-1}) was significantly ($P < 0.01$) higher than in dry season (0.008-0.205 mg N m^{-2} h^{-1}). Positive relationships were observed between N_2O and CO_2 fluxes ($R^2 = 0.56$, $P < 0.01$) and soil nitrate concentration ($R^2 = 0.30$, $P < 0.10$) in rainy season indicated that N_2O production was influenced by peat decomposition and denitrification. Significant positive correlation between N_2O flux and soil sulfate concentration was also observed in rainy season ($R^2 = 0.86$, $P < 0.001$). Land drainage status might not influence N_2O production, because spatial distribution of N_2O flux was not related to canal location and water filled pore space. Soil C and N concentrations and C:N ratio did not influenced N_2O flux in rainy season. Field management practice such as multiple cultivation, plowing, and soil improving material application as well as nitrogen fertilizer application might influence peat decomposition cause large N_2O emission.

***Keyword**: Nitrous oxide, peat soil, agricultural field, soil characteristics, organic matter decomposition*

INTRODUCTION

Table 1. Landuse type, duration of cultivation, and cultivars in rainy and dry seasons in the study field.

Site	Landuse	Cultivation Period (yr)	Cultivars Rainy season	Dry season
A	Upland	26	*Solanum melongena*	*Spinacia oleracea*
B	Upland	26	*Pennisetum purpureum*	*Pennisetum purpureum*
C	Upland	Not detected	*Spinacia oleracea*	*Spinacia oleracea*
D	Upland	10	*Arachis hypogaea*	*Spinacia oleracea*
E	Upland	26	*Zea mays*	*Zea mays*
F	Upland	19	*Manihot esculenta*	*Zea mays*
G	Upland	16	Fallow	*Solanum melongena*
H	Upland	24	*Cucumis sativus*	*Solanum lycopersicum*
I	Upland	26	*Manihot esculenta*	*Cucurbita moschata*
GL	Meadow pasture	26	Not detected	Not detected

Site A~C and GL were the same fields as CL-A, CL-B, CL-C, and GL studied in Toma *et al*. (2011).

Peat soil is widely distributed in Southeast Asia. Especially in Indonesia, tropical peatland contributes approximately 47% (206950 ha) to that in Southeast Asia (Page *et al*. 2011). However, tropical peatland in Indonesia has been disturbed due to land development and annual burning, and part of them have been cultivated for food production. In the recent study conducted in tropical peatland in Indonesia, large amount of nitrous oxide (N_2O) has been emitted from upland field. Toma *et al*. (2011) reported that annual soil N_2O emission reached to 698 kg N ha^{-1} yr^{-1}, which is currently the highest value reported not only in tropical peatland but all around the world. In the upland field, soil N_2O flux increased especially in rainy season and positively correlated with soil nitrate (NO_3^-) concentration (Takakai *et al*. 2006). In addition, nitrogen (N) fertilizer application did not influence on N_2O production, while N_2O was mainly produced in surface soil layer (0-15 cm depth) (Toma *et al*. 2011). Hashidoko *et al*. (2008) isolated denitrifying bacteria, *Janthinobacterim* sp., which was acid-tolerant and had high potential of N_2O production under the existence of organic matter. Those study were based on long-term field monitoring in four experimental fields, then, we still do not know there are other upland fields in which large amount of N_2O was emitted from tropical peat soil. Production and emission of N_2O from soil are strongly influenced by the environmental factors (eg.topography and soil characteristics) and land management practice. Therefore, to find out the main factors affecting soil N_2O emission are necessary to quantify soil N_2O emission and develop strategies for reducing soil N_2O emission from upland field in tropical peatland. In this study, spatial distribution of soil N_2O flux in rainy and dry seasons and analyzed the relationship between soil N_2O flux and environmental factors were investigated.

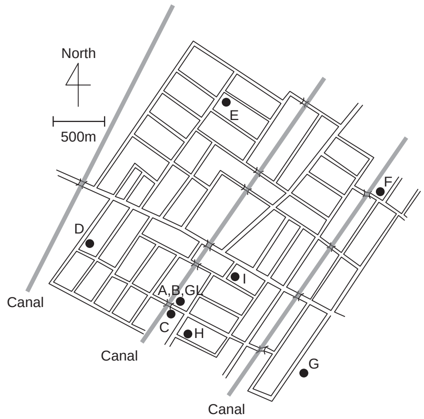

Fig. 1: Location of the study site in Kalampangan village, central Kalimantan, Indonesia.

METHODS

This study was conducted in Kalampangan Village (2°17'S, 114°1'E) near Palangka Raya City in central Kalimantan, Indonesia. Soil type is classified as *Typic Tropofibrists*, and detail chemical characteristics were provided in Takakai *et al*. (2006). Nine upland fields and one meadow pasture were selected (Fig. 1; Table 1). Site A~C and GL were the same fields as CL-A, CL-B, CL-C, and GL described in Toma *et al*. (2011). Soil greenhouse gas (N_2O, CH_4 and CO_2) fluxes were measured in both rainy (February 2006) and dry (September 2006) seasons using closed chamber methods at three replications. Details of the method for gas measurement were provided in Toma *et al*. (2011). After the measurement of soil greenhouse gas fluxes, undisturbed soil samples (0-5 cm depth) were collected using stainless steel core (φ5 cm and 5.1 cm height) from each point where chambers were installed. We measured soil pH, ammonium (NH_4^+) concentration, nitrate (NO_3^-), sulfate (SO_4^{2-}) and water soluble organic C (WSOC) concentrations, total carbon (C) and N concentrations, soil C:N ratio, and water filled pore space (WFPS). Easily oxidizable sulfur (EOS) in soil collected during rainy season were estimated by measuring difference in sulfate concentration before and after the hydrogen peroxide application under heating condition. Duration of cultivation and history of land management were obtained from farmers. Amount of applied N fertilizer was unknown in the study fields. We used "R" software for statistical analysis.

RESULTS

Soil N_2O fluxes were higher in rainy season than dry season, except for site I (Fig. 2). Highest soil N_2O flux was observed in C, and mean soil N_2O flux in rainy season was 1.06 mg N m^{-2} hr^{-1} (0.0084－3.46 mg N m^{-2} hr^{-1}), which was similar range of soil N_2O flux (0.00-9.27 mg N m^{-2} hr^{-1}) observed in Toma *et al.* (2011). In dry season, mean soil N_2O flux was 0.070 mg N m^{-2} hr^{-1} (0.0081－0.20 mg N m^{-2} hr^{-1}). Soil N_2O flux in rainy season was approximately 23 times higher than dry season (P < 0.01). Canal location, duration of cultivation, and cultivar did not clearly influence soil N_2O flux in both seasons. In rainy season, soil CO_2 flux, soil NO_3^- and SO_4^{2-} concentrations were positively correlated with soil N_2O fluxes (Fig. 3). Tradeoff relationship between soil N_2O and CH_4 fluxes was observed in rainy season (Fig. 3d). Other environmental factors were not correlated with soil N_2O fluxes in both season. Difference in soil N_2O flux between in rainy and dry seasons (ΔN_2O flux) was positively correlated with difference in soil SO_4^{2-} concentration (ΔSO_4^{2-} concentration), except for site F which had higher concentration of SO_4^{2-} in dry season compared to other sites (Fig. 4). On the other hand, EOS did not influence soil N_2O flux in rainy season (Fig. 5).

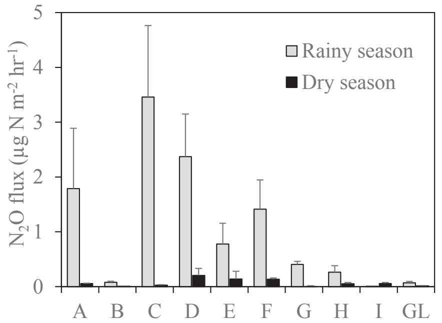

Fig. 2: Soil N_2O fluxes in rainy and dry seasons. Error bars represent standard deviations.

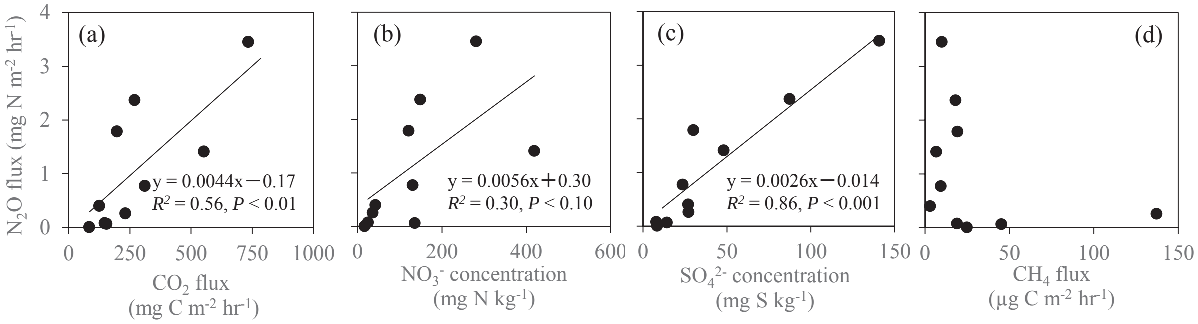

Fig. 3: Relationships between soil N_2O flux and CO_2 flux (a), NO_3^- (b), SO_4^{2-} (c) concentrations, and CH_4 flux in rainy season.

DISCUSSION

Variation of soil N_2O flux is generally influenced by land management, such as fertilization and plowing, and timing of rainfall. Soil N_2O flux from upland field measured in tropical peatland in Indonesia depended on the dry and rainy seasons rather than other factors of management practice (Takakai *et al*. 2006; Toma *et al*. 2011). In this study, higher soil N_2O flux in rainy season than in dry season showed that the investigation of spatial variation of soil N_2O flux in rainy season can determine the location that has higher or lower potential of soil N_2O emission, leading to more understanding of absolute controlling factors for N_2O production and emission from upland field on tropical peatland. In addition, no effect of canal location and WFPS to spatial variation of soil N_2O flux indicated that topography may not be main factors affecting spatial variation of soil N_2O flux.

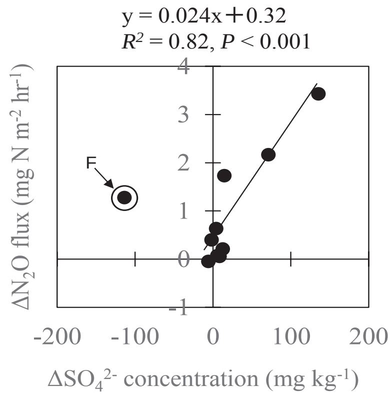

Fig. 4: Relationship between ΔN_2O flux and ΔSO_4^{2-} concentration (rainy−dry).

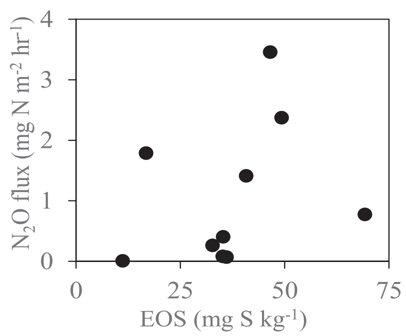

Fig. 5: Relationship between easily oxidizable sulfur (EOS) and soil N_2O flux in rainy season.

Existence of crop or vegetables on study field and these species did not influence soil N_2O flux in our study. Klemedtsson *et al*. (2005) showed that soil N_2O emission from boreal peat soil increased with decreasing of peat C:N ratio of below 25. Higher peat C:N ratio in our study sites ranging from 34.4 to 57.5 may not be useful as an indicator for explaining spatial distribution of soil N_2O flux. Positive correlation between soil N_2O and CO_2 fluxes suggested N_2O production was significantly influenced by CO_2 production induced by peat decomposition (Fig. 3a), though soil CO_2 flux included root respiration. Fertilizer N did not significantly affect soil N_2O emission in this study which agreed with Toma *et al*. (2011). A significant positive correlation between soil N_2O flux and soil NO_3^- concentration was found in this study, indicating that soil N_2O emission from upland soil in tropical peatland was probably resulted from mineral N release by peat decomposition followed by nitrification and denitrification in rainy season. However, no correlation between soil N_2O flux and soil NH_4^+ concentration was observed showing that nitrification was not the main process of N_2O production. Large soil N_2O emission might be due to field management practices, which influence peat decomposition.

Increasing in soil N_2O flux with decreasing soil CH_4 flux showed N_2O could be reduced to nitrogen (N_2) under the reduced condition in which CH_4 was produced. As N_2O has higher potential for global warming than CH_4, to establish environmental condition suitable for CH_4 production rather than N_2O production may be one of the strategies for reducing impact of global warming in upland field on tropical peatland. This strategy might be also effective for reducing C release by aerobic decomposition of peat.

On the sulfur-denitrification process, autotrophic sulfur-denitrification bacteria uses elemental sulfur and NO_3^- as an electron donor and accepter, respectively, without requirement of organic matter as C source (Sahinkaya and Kilic 2014). Under the sulfur-denitrification process, therefore, SO_4^{2-} is produced by oxidation of elemental sulfur. Significant positive correlation between soil N_2O flux and soil SO_4^{2-} concentration in our study can indicate N_2O production by the process of sulfur-denitrification. Furthermore, significant positive relationship between ΔN_2O flux and ΔSO_4^{2-} concentration possibly showed that higher potential of sulfur oxidation closely linked to higher N_2O production potential in rainy season, though type of fertilizer applied to the study field should be determined. However, no correlation between N_2O flux in rainy season and EOS showed more specific type of sulfur, such as SO_4^{2-} bounded to ionized metals, might be origin of sulfate in peat soil, since EOS measured in this study included sulfur in hydrogen peroxide decomposable organic matter in peat. Hasegawa and Hanaki (2001) showed that soil NO_3^- concentration and the ratio of soil NO_3^- concentration reduction and N_2O production rates were decreased by addition of S^0 or FeS to soil by column experiment. This indicates that sulfur application enhanced both denitrification and N_2O reduction. Hasegawa and Hanaki (2001) also showed that sulfide produced under the reduced condition possibly inhibited N_2O reduction, showing that N_2O can be greatly produced under the sulfide rich condition in soil due to the acceleration of denitrification process and inhibition of N_2O reduction on that process. Therefore, investigation on the relationship between soil N_2O flux and soil sulfide concentration and existence of sulfur-denitrifies in our study sites are needed to verify above hypothesis. Source of the sulfide should also need to be determined in the future study. If there is significant correlation between soil N_2O flux and soil sulfide concentration in rainy season, source of the sulfide should also be determined in the future study.

CONCLUSION

Spatial variation of soil N_2O flux did not depend on topography, while soil N_2O flux potentially influenced by season, quality of peat and land management practice which influence the peat decomposition. In our study site, sulfur-denitrification may potentially contribute to large amount of N_2O emission. Understanding on these mechanisms can help to establish good strategy for mitigating N_2O emission from upland field established on tropical peatland.

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