Spatial-temporal variabilities of N_2O emission from *Acacia mangium* soils

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Abstract
We compared spatial structures of N_2O fluxes in an *Acacia mangium* plantation stand in Sumatra, Indonesia between drier (August) and wetter (March) season. A 60 × 100 m plot was divided into 10 × 10 m grids. The N_2O fluxes and soil properties were measured at 77 grid points of 10 m intervals in the plot. Spatial structures of the gas fluxes and soil properties were identified using geostatistical analysis. The mean of N_2O fluxes in a wetter season was significantly higher than that in a drier season. N_2O fluxes had a strong spatial dependence with a range of about 18 m in both the drier and wetter season. The spatial structure of N_2O fluxes in a wetter season was mainly governed by that of water-filled pore space (WFPS), while that in a drier season possibly depended on the spatial patterns of soil resource distribution. Our results indicate that we should consider factors controlling spatial structures of N_2O fluxes separately between the drier and wetter season, though the geostatistical parameters were comparable between the seasons.

Key Words
Leguminous tree, fast wood plantation, nitrous oxide, seasonal change, spatial structure, Indonesia.

Introduction
Nitrous oxide (N_2O) is a major greenhouse gas in the atmosphere and significantly contributes to global warming according to the latest data (IPCC 2007). Tropical rain forest soils have been identified as an important source of N_2O (Keller *et al.* 1986). Industrial plantations of fast-growing tree species, in particular leguminous tree plantations, have been widely introduced into tropical Asia (FAO 2001). However, presence of leguminous and other nitrogen (N)-fixing trees in forests may enhance N_2O emission from the soils, because they produce N rich litter through symbiotic N fixation, leading to high soil N availability and soil N cycling (Erickson *et al.* 2001). In the fast-growing leguminous tree plantations in tropical Asia, their soils have been demonstrated to be a significant source of N_2O as well (Arai *et al.* 2008; Konda *et al.* 2008). Therefore, it is necessary to elucidate the N_2O emissions and underlying mechanisms involved in the emission in fast-growing leguminous tree plantations, in order to estimate the accurate magnitude of mitigating global warming by the plantations, and to develop management options to mitigate N_2O emissions as well. Soil surface N_2O fluxes show large seasonal (Kiese *et al.* 2003) and spatial variability (Folorunso and Rolston 1984), and these are serious problems in precisely estimating the source and sink strength of N_2O in tropical rain forest ecosystems. It is essential to understand the seasonal and spatial variations of these gas fluxes to conduct accurate quantitative evaluations of these gas emissions in the leguminous tree plantation soils. Our objectives were (1) to evaluate the seasonal and spatial variation in N_2O fluxes in the fast-growing leguminous tree plantation, and (2) to clarify the major factors controlling the variation of these fluxes from the relationship between the gas fluxes and soil properties.

Methods
Site description
The field measurements were done in an *A. mangium* plantation area (3°52’40’’S, 103°58’40’’E) in South Sumatra, Indonesia, in August 2005 and March 2006. The mean annual temperature and precipitation from 1991 to 2002 were 27.3°C and 2,750 mm, respectively (Hardjono *et al.* 2005). Although there are no distinctly pronounced dry and wet seasons, the period from June to September is relatively dry (average monthly precipitation < 150 mm (Hardjono *et al.* 2005)). This study was conducted once during the drier and wetter season, respectively. The topography is undulating and the soils are Acrisols, derived from Tertiary sedimentary rock. A 60 × 100-m plot was established in an *A. mangium* plantation. The 60 × 100-m plot was divided into 10 × 10-m grids, and gas and soil samples were collected once at each grid point (n=77) on 8 August 2005 and on 3 March 2006.

Gas sampling and analysis
We measured N_2O and CO_2 fluxes using the static chamber method (Arai *et al.* 2008). Polypropylene chambers (22.2 cm upper diameter, 18.7 cm lower diameter, 12.0 cm high) were inserted into the soil to a depth of 2 cm 1 day before sampling. The chamber diameter at the soil surface was 19.4 cm. After sealing the chambers with lids containing a sampling port and an air bag to equilibrate the inside pressure to atmospheric pressure, we took 40-mL gas samples with a syringe after 0, 15, and 30 min. The gas samples were ejected into previously evacuated 30-mL glass vials with butyl rubber stoppers. These glass vials were analysed in the laboratory for the concentrations of N_2O and CO_2 using gas chromatographs (GC-14B, Shimadzu Co. Ltd., Kyoto, Japan) equipped with an electron capture detector and a thermal conductivity detector, respectively. We calculated the gas flux by linear regression because the increase in gas concentration in the chamber during this sampling period appeared linear.

Soil sampling and analysis
After gas sampling, we collected all litters from 0.059 m^2 area near the chambers and separated them into fresh (L layer) and decayed (FH layer) litter. The dry weights of the L and FH layer were determined on an oven-dry basis (105 °C, 24 h). After litter sampling, we took top 10 cm mineral soil using two 200-mL (5.1 cm diameter, 10 cm height) sampling cylinders in a drier season and one 200-mL soil cylinder in a wetter season. One cylinder soil sample (200 mL) of drier season was used for analyses of bulk density, expressed in an oven-dry basis (105 °C, 24 h). We used the bulk density in the drier season as well for the wetter season. The 200ml soil samples in each season were homogenized and stored in a refrigerator at 4 °C. Gravimetric moisture was determined after drying soil subsamples at 105 °C for 24 h. We calculated water-filled pore space (WFPS) of soil using gravimetric moisture, bulk density and particle density (2.58 Mg/m^3) determined by a pycnometer. Ammonium (NH_4^+) and nitrate (NO_3^-) nitrogen were extracted with tenfold 2M KCl for 5 g samples by shaking for 1 h within 3 d of sampling. The filtrate was stored in a freezer, and determined for NH_4-N and NO_3-N concentrations using a flow-injection analyzer (AQUA LAB Co., Ltd., Tokyo, Japan). Soil pH (H_2O) was measured using a glass electrode for a suspension of 10 g soil and 25 mL distilled water.

Results and discussion

Averaged N_2O fluxes of 77 chambers showed a pronounced seasonal difference with significantly higher rates in the wetter season, 1.85 (±1.18) mg $N/m^2/d$, than in the drier season, 0.55 (±0.42) mg $N/m^2/d$ (Table 1). Seasonal patterns of N_2O fluxes often can be explained by soil moisture (Kiese *et al.* 2003), decomposition rates of litter (Werner *et al.* 2007) and diffusion restriction of inorganic N (Davidson *et al.* 1993). In our study, the mean of WFPS was higher in the wetter season than in the drier season. In the wetter season, L layer accumulated in the drier season was almost disappeared, and FH layer amounts and CO_2 fluxes increased significantly than in the drier season (Table 1) .This may indicate that higher supply of

Table 1. Statistical and geostatisitical data of gas fluxes and soil parameters in the drier and wetter seasons. Values followed by different uppercase letters are significantly different between seasons (*P* < 0.05). †Bulk density was measured once in the drier season. ‡Spatial structures were not apparent.

Property	Season	Mean	SD	Range	Q value
N_2O flux (mg N m^2/d)	Dry	0.55^A	0.42	18.0	0.81
	Wet	1.85^B	1.18	17.4	0.97
CO_2 flux (g $C/m^2/d$)	Dry	2.73^A	0.66	-‡	-‡
	Wet	4.29^B	0.91	-‡	-‡
Bulk density† (Mg/m^3)	Dry	0.75	0.08	21.7	0.99
	Wet	-	-	-	-
WFPS (%)	Dry	55.5^A	8.0	-‡	-‡
	Wet	66.3^B	1.0	17.1	0.94
Soil pH (H_2O)	Dry	4.88^A	0.40	70^+	0.56
	Wet	5.03^B	0.37	63.2	0.50
L amount (kg/m^2)	Dry	0.27	0.09	-‡	-‡
	Wet	0.02	0.03	-‡	-‡
FH amount (kg/m^2)	Dry	0.78^A	0.38	25.2	0.87
	Wet	1.13^B	0.31	-‡	-‡
Soil NH_4-N (mg/kg)	Dry	29.4^A	3.2	33.7	0.55
	Wet	68.7^B	2.8	-‡	-‡
Soil NO_3-N (mg/kg)	Dry	20.6^A	7.7	-‡	-‡
	Wet	8.7^B	4.2	-‡	-‡

available carbon and nitrogen to soil microbes through accelerated litter decomposition in the wetter season. In the *A. mangium* soils during the wetter season, high water content and supply of available carbon and nitrogen into the soils can promote microbial activities, resulting in the enhancement of N_2O emissions.

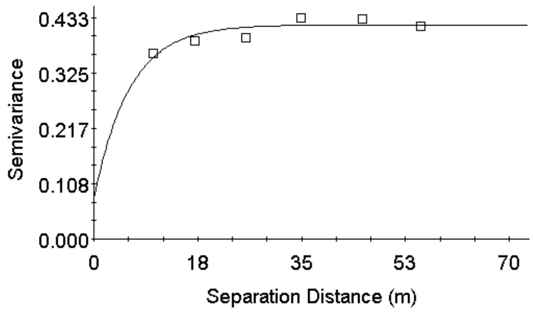

Figure 1. The Semivariogram of N_2O fluxes in the drier season.

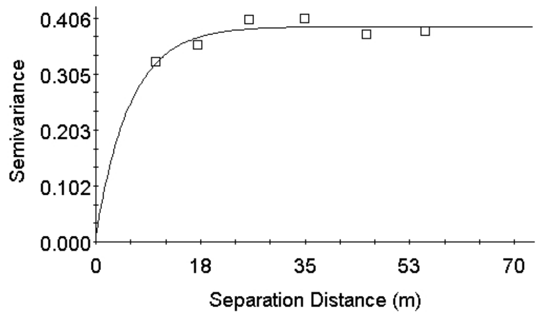

Figure 2. The Semivariogram of N_2O fluxes in the wetter season.

N_2O fluxes had strong spatial dependence with a range of about 18 m in both the drier and wetter season (Table 1, Figure 1, 2), indicating that the degree and limit of spatial dependence at sampling scale (Gorres *et al.* 1997; Yanai *et al.* 2003) were comparable between the seasons. The N_2O fluxes significantly correlated with litter amounts (R=0.335, $P<0.01$) and CO_2 fluxes (R=0.416, $P<0.01$) in the drier season, while they significantly did with WFPS (R=0.391, $P<0.01$) in the wetter season. Because FH layer of *A. mangium* plantation was not a direct source of N_2O in a drier season according to a litter removal experiment in the same plantation soils (Konda *et al.* unpublished data), the accumulated litter layer may function as a substantial soil resource for increasing N_2O fluxes during the drier season. We estimate that the spatial pattern of N_2O fluxes in the drier season was mainly controlled by the spatial distribution of fresh resource supplied from the litter layer to the soils, while anaerobic conditions in the soils could play an important role for the spatial pattern in a wetter season due to the enhancement of denitrification rates and also N_2O emission rate.

Conclusion

The spatial structure of N_2O fluxes in the wetter season mainly depended on that of WFPS, while in the drier season it possibly depended on fresh resource supply from the litter layer to the soils. We should consider factors controlling spatial structures of N_2O fluxes separately between the drier and wetter season, though the geostatistical parameters were comparable between the seasons.

References

Arai S, Ishizuka S, Ohta S, Ansori S, Tokuchi N, Tanaka N, Hardjono A (2008) Potential N_2O emissions from leguminous tree plantation soils in the humid tropics. *Global Biogeochemical Cycles* **22**, GB2028.

Davidson EA, Matson PA, Vitousek PM, Riley R, Dunkin K, Garciamendez G, Maass JM (1993) Processes Regulating Soil Emissions of NO and N_2O in a Seasonally Dry Tropical Forest. *Ecology* **74**, 130-139.

Erickson H, Keller M, Davidson EA (2001) Nitrogen oxide fluxes and nitrogen cycling during postagricultural succession and forest fertilization in the humid tropics. *Ecosystems* **4**, 67-84.

FAO (2001) 'Global Forest Resources Assessment 2000' (Food and Agriculture Organization of the United Nations: Rome).

Folorunso OA, Rolston DE (1984) Spatial Variability of Field-Measured Denitrification Gas Fluxes. *Soil Science Society of America Journal* **48**, 1214-1219.

Gorres JH, Dichiaro MJ, Lyons JB, Amador JA (1997) Spatial and temporal patterns of soil biological activity in a forest and an old field. *Soil Biology and Biochemistry* **30**, 219-230.

IPCC (2007) Climate change 2007: The physical science basis. Contribution of Working Group I. In 'Fourth Assessment Report of the Intergovernmental Panel on Climate Change'. (Eds S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor, HL Miller). (Cambridge University Press, New York).

Keller M, Kaplan WA, Wofsy SC (1986) Emissions of N_2O, CH_4 and CO_2 from Tropical Forest Soils.

Journal of Geophysical Research-Atmospheres **91**, 1791-1802.

Kiese R, Hewett B, Graham A, Butterbach-Bahl K (2003) Seasonal variability of N_2O emissions and CH_4 uptake by tropical rainforest soils of Queensland, Australia. *Global Biogeochemical Cycles* **17**, 1043.

Konda R, Ohta S, Ishizuka S, Arai S, Ansori S, Tanaka N, Hardjono A (2008) Spatial structures of N_2O, CO_2, and CH_4 fluxes from *Acacia mangium* plantation soils during a relatively dry season in Indonesia. *Soil Biology and Biochemistry* **40**, 3021-3030.

Werner C, Kiese R, Butterbach-Bahl K (2007) Soil-atmosphere exchange of N_2O, CH_4, and CO_2 and controlling environmental factors for tropical rain forest sites in western Kenya. *Journal of Geophysical Research-Atmospheres* **112**, D03308.

Yanai J, Sawamoto T, Oe T, Kusa K, Yamakawa K, Sakamoto K, Naganawa T, Inubushi K, Hatano R, Kosaki T (2003) Spatial variability of nitrous oxide emissions and their soil-related determining factors in an agricultural field. *Journal of Environmental Quality* **32**, 1965-1977.

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