N_2O emission in *Acacia mangium* stands with different ages, in Sumatra, Indonesia

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Abstract
We compared N_2O emissions at various-aged acacia plantation forests for 1 year in Sumatra, Indonesia. Three areas were prepared for this experiment, in each of which three acacia forests (1, 3, and 5 year-old, respectively) and one secondary forest were selected. The N_2O emission was high from November to March (rainy season) and low from May to November (relatively drier season). The average of N_2O emission was higher in the order of 1 year old acacia > 3 year old acacia > 5 years old acacia > secondary forest. Although our results suggest that plantations of leguminous trees possibly cause increased N_2O emission from soils, the emission may fluctuate along with the age of the stand due to the control of nitrogen availability for microorganisms in the soil.

Key Words
Leguminous tree plantation, nitrous oxide, fast-growing wood plantation, humid tropical forest, global warming, nitrogen availability.

Introduction
Nitrous oxide (N_2O) is a strong greenhouse gas with a global warming potential 296 times as high as that of CO_2. N_2O emission from wet tropical forest is the largest natural ecosystem source of N_2O and is estimated to be 3.0 Tg N/y (Prather *et al.* 2001). Acacia is one of the most important leguminous trees for industrial plantations because of its fast growth and tolerance to acidic and nutrient-poor environments. These plantations are favoured in Asia, where 96% of the total global plantation area is located (FAO 2001). Recently, Arai *et al.* (2008) suggested that these acacia plantation soil is a possible "new" emission source of N_2O due to its nitrogen fixation ability. In their report, the N_2O emission had been enhanced 8 times higher compared to the control of secondary forest. But the experiment was carried out only at 7-year-old acacia forest, in which the growth rate of acacia gradually decreases from the period showing the highest growth rate (around 5 years old). However, the demand for nitrogen resource to the plant should change and the excess nitrogen available for microorganisms to stimulate N_2O emission from soils might also fluctuate with age. It is hypothesized that the stand age of acacia plantation, controlling nitrogen availability for microorganism in the soil, will affect N_2O emission rate. In this study, we are to clarify the stand-age effect to N_2O emission in acacia plantation forest. This result will contribute to the precise evaluation in the N_2O emission in a whole rotation period of such leguminous plantation.

Methods
Site description
Field measurements were carried out in humid tropical forests in Muara Enim, South Sumatra Province, Indonesia (3°30′–4°05′S, 103°50′–104°10′E). Annual rainfall is 2750 mm and the annual average temperature is 27.3°C from 1991 to 2002 in Subanjeriji and Benakat (Arai *et al.* 2008). Although there is no apparent dry seasons, the rainfall is less from May to September. The soils are Acrisols derived from Tertiary sedimentary rocks. Three areas (Sodong, Gemawang, and Banding Anyar) were selected for flux measurements. In each area, we selected four types of forest, i.e., 1-year-old (SD1, GM1 and BA1), 3-year-old (SD3, GM3 and BA3), and 5-year-old (SD5, GM5 and BA5) acacia plantations, respectively, and secondary forest (SN, MB and AU). The soil texture was clay or sandy clay.

Flux measurements
N_2O flux measurements were carried out using a static chamber method (Arai *et al.* 2008). Gas sampling was performed every 45 days from September 2007 to August 2008. Six replicate chambers made of PVC tubes

0.207 m in diameter and 0.15 m in length were inserted into the soil on one day before sampling day. After sealing the chambers with lids, which had sampling ports and air bags to equilibrate the inside pressure to atmospheric pressure, we took 40-mL gas samples using a syringe after 0, 15, and 30 min. We compressed the gas samples into 30-mL glass vials with butyl rubber stoppers that had been evacuated beforehand in the laboratory. The temperature inside the chamber and in the soil at a depth of 5 cm was measured using a temperature sensor. The glass vials were brought to the laboratory, and N_2O concentrations were analysed using a gas chromatograph (Shimadzu GC-14B) with an electron capture detector. We calculated fluxes using the slope of a linear regression, substituting the data at 0, 15, and 30 min elapsed time.

Soil sampling and analysis

Soil samples for chemical and biochemical analysis were taken from 0–5 cm depth, in September and December in 2007 and March and June in 2008. In each plot, a composite soil sample was obtained by mixing six 200-mL samples taken approximately 2 m from each chamber using three 100-mL cylinders (5.1 cm in diameter and 5 cm in height). These soils were passed through a 2-mm-mesh sieve and stored at 4°C. Soil pH (H_2O) was measured using a glass electrode with a well-mixed solution of 10 g soil and 25 mL deionized water. Total carbon and nitrogen contents were determined using an NC analyzer (JM1000CN, J-SCIENCE LAB Co., Ltd., Kyoto, Japan) for air-dried samples. Inorganic ammonium (NH_4^+-N) and nitrate (NO_3^--N) were extracted by shaking a mixture of 5 g fresh soil and 50 mL 2M KCl for 1 h within 1 day of sampling. Ammonium and nitrate concentrations in the extracted solution were determined using a flow-injection analyzer (AQUA LAB Co., Ltd., Tokyo, Japan). Bulk density was determined using six core samples in each site collected in September 2008. We also took soil samples every 45 days at depths of 0–5 cm to measure soil water content.

Results and discussion

The average soil pH ranged from 4.4 to 5.0 (Table 1). The average ammonium and nitrate contents in the soil were the highest in 1-year-old acacia plantation and the lowest in secondary forest. This suggests that the excess nitrogen, not absorbed by plant, is abundant in 1-year-old acacia forest.

Table 1. Statistics of soil properties in each stand age and secondary forest

Vegetation type	pH (H_2O)		Bulk Density Mg/m^3		C mg/g		N mg/g		NH_4-N µgN/g		NO_3-N µgN/g	
	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.
acacia 1yr	4.46	0.17	0.99	0.12	0.38	0.05	0.026	0.003	20.4	10.4	20.8	5.4
acacia 3yr	4.62	0.22	0.88	0.15	0.46	0.09	0.031	0.005	9.7	6.5	6.1	4.0
acacia 5yr	4.66	0.11	0.93	0.01	0.37	0.05	0.027	0.003	10.4	0.1	5.5	0.7
Secondary	4.94	0.51	0.86	0.12	0.38	0.04	0.027	0.001	8.8	5.5	3.6	1.5

The N_2O flux was high in the wet season and low in the drier season (Figure 1). The exceptionally high flux in drier season on June was due to the heavy rain just before the sampling day. The order of average N_2O flux was: 1 year old acacia > 3 year old acacia > 5 years old acacia > secondary forest.

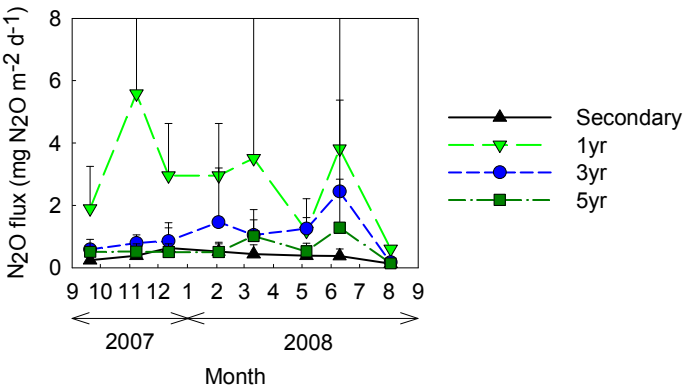

Figure 1. The seasonal fluctuation in N_2O flux in each forest. The vertical bar means the standard deviation in three site.

The N_2O flux highly correlated with nitrate content in the soil (R^2=0.9558), indicating that the nitrogen availability for microorganisms is the key role for N_2O emission from soils. Because the nitrogen availability for microorganisms might be trade-off between plant uptake rates of nitrogen, the differences in N_2O emission rate in the different-aged acacia forests might reflect the difference in plant uptake rates of nitrogen.

Conclusion

The N_2O flux in acacia forests differed among the sites with different age. This indicates that the evaluation of N_2O emission in these land-use have to account the whole rotation cycle of these plantation. This result will contribute to the precise evaluation in the N_2O emission in such leguminous plantation at temporally and spatially expanded scales.

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