Effects of phosphorus addition on N_2O emission in an *Acacia mangium* plantation with and without root exclusion

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Abstract
Effects of phosphorus (P) fertilization on N_2O emissions in an *Acacia mangium* plantation were compared among C-plot (control), T-plot (trenched), P-plot (P added), and TP-plot (both trenched and P added) for 106 days in the wet season. N_2O emissions from P-plot were significantly smaller than that of C-plot, and are attributed to accelerated root absorption of N. In contrast, N_2O emissions from TP-plot were not significantly smaller and rather seemed to be larger than that of T-plot. We concluded that P application suppress N_2O emissions from *Acacia mangium* plantations, possibly because P addition accelerates root absorption of N.

Key Words
Nitrous oxide, humid Tropics, P limitation, fast-growing wood plantation.

Introduction
It is well known that nitrous oxide (N_2O) is an important greenhouse gas following CO_2 and CH_4 (IPCC, 2007). Soils are major sources for N_2O, which is a byproduct or intermediate product of microbial nitrification and denitrification (Bremer *et al.*1997; Davidson *et al.* 2000; Wrage *et al.* 2001).
Tropical forests are important sources of N_2O (Matson and Vitousek 1990). Several studies have demonstrated that *Acacia mangium* was a non-negligible emission source of N_2O (Dick *et al.* 2006; Arai *et al*. 2008; Konda *et al.* 2008) because of Acacia's high N-fixing ability as a leguminous tree.
Hall and Matson (1999) suggested that poor soil P availability, which is common in tropics (Vitousek *et al.* 1993, Cleveland *et al.* 2002), causes higher emissions of N_2O by demonstrating that nitrogen (N) fertilizer inputs to the P-limited ecosystems generated 10-100 times greater N_2O fluxes than the same treatment to the N-limited ecosystems. Their report suggests that the removal of P limitation may lead to suppression of N_2O and NO_2 loss. Here we tested the hypothesis that the removal of P limitation suppresses N_2O emission from *Acacia mangium* plantations. We used trench method to investigate the effects of P fertilization on N_2O emission both in vegetation-existing condition and non-vegetation-existing condition in an *Acacia mangium* plantation.

Materials and methods
Plot setting
The experiment site is located at an *Acacia mangium* plantation in South Sumatra Province, Indonesia (3°47.394' E, 103°55.236' S). This region is humid tropical rain forest with an annual precipitation of 2000~3000 mm and a mean annual temperature of 27.3°C (Hardjono *et al.* 2005). The period from April to September is a relatively dry season and from October to May is wetter season, although there is no clear distinction. The soils in the area are Acrisols with Tertiary sedimentary rock as the parent material.
A 6-year-old *Acacia mangium* stand, where trees were planted 3 m interval, was selected for the experiment. The experimental design included four treatments, C-plot (control), T-plot (trenched), P-plot (P added), and TP-plot (both trenched and P added). Plots of 9 m×9 m were established randomly in 6 replications for every treatment. In T-plots and TP-plots, we established 1 m×1 m subplots and made vertical cuts along the boundaries down to 0.5 m below the ground surface (approximately the bottom of the root zone) at the beginning of September 2008. Pieces of polyethylene board were inserted into the vertical cuts to inhibit root re-growth. Soils were refilled into the trench to minimize disturbance as little as possible. Seedlings and herbaceous vegetation in T-plots and TP-plots were removed by hand when necessary. At the beginning of November, TSP (Triple Super Phosphate) was applied to each P-plot and TP-plot by hand at the rate of 200 kg/P/ha/yr.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Gas flux measurement
From the end of November to the beginning of March, N_2O emissions were measured 6 times (3-day before and 4-, 7-, 15-, 29-, and 106-days after P addition) with a static chamber method (Ishizuka *et al.* 2002), using PVC chambers (20 cm diameter, 15 cm height). We chose this period because N_2O emissions were reported to be larger in the wetter season (Arai *et al.* 2008). Forty-ml gas samples at 0, 15, and 30 min were taken into 30-ml glass vacuum vials with butyl rubber lids. N_2O concentration was analyzed using a gas chromatograph (GC-14B, SHIMADZU, Kyoto, Japan) equipped with an electron capture detector. We calculated N_2O emission rates using a linear regression slope, using data at 0, 15, and 30 min, because the increase in gas concentration appeared linear. The cumulative gas emissions were estimated using the linear trapezoidal method.

Soil sampling and analysis
At each gas sampling day, soils were also sampled from 0-5 cm depth. We collected a single soil core within 1 m radius of each chamber using 100 mL cylinder. Soil water content was immediately measured using a portion of the sample. WFPS was calculated as follows:

$$\text{WFPS} = (\text{Gravimetric water content}) \times (\text{Bulk density/Porosity}) \times 100, \qquad (1)$$

where Porosity = 1 − (Bulk density/Particle density). Soil pH (H_2O) was measured using moist soils. Ten g soil and distilled water were mixed to 1 : 2.5 ratio, and pH was measured after shaking 30 min.

Data analysis
The level of significance was examined by ANOVA followed by Tukey's multiple comparison tests after confirming the normality of data by the Kolmogorov-Smirnov test. Each statistical analysis was performed using SPSS version 10.0 (SPSS Inc., Chicago, USA).

Results and discussion
The values of pH did not change during experiment period. N_2O emissions from P-plot were significantly smaller than that of C-plot (Figure 1). In contrast, N_2O emissions from TP-plot were not significantly smaller and rather seemed to be larger than that of T-plot (Figure1), showing that P application suppressed N_2O emissions only if vegetation existed. Figure 2 shows the relationship between N_2O emission rate and WFPS at 4-, 7-, 15-, 29-, and 106-days after the start of experiment. N_2O emissions seemed to be smaller in P-plot than C-plot in a similar WFPS condition, while there were no such trends for TP-plot and T-plot.
Earlier studies suggest that P addition to P-limited soils reduces N_2O emissions by removing the P limitation on microbial N immobilization and decreasing N for nitrification and denitrification processes. Sundareshwar *et al.* (2003) showed that P addition to swampy ecosystem reduced the denitrification rate and N_2O emissions. In our study, however, such a mechanism did not operate, for P addition to T-plot did not suppress N_2O emissions significantly.

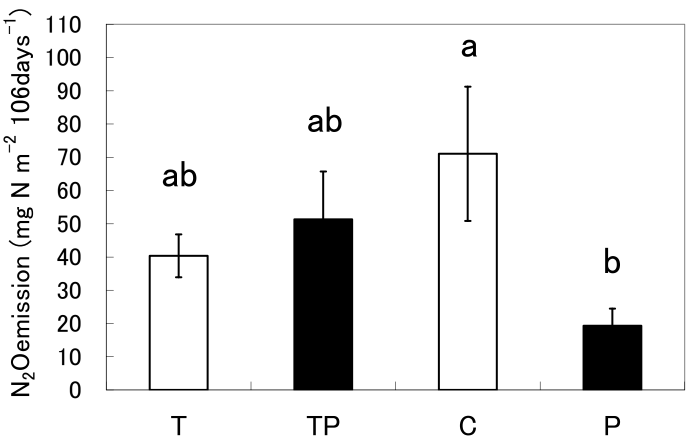

Figure 1. The cumulative N_2O emissions from each subplot. The same letters are not significantly different using ANOVA followed by Tukey's multiple comparison tests (P < 0.05).

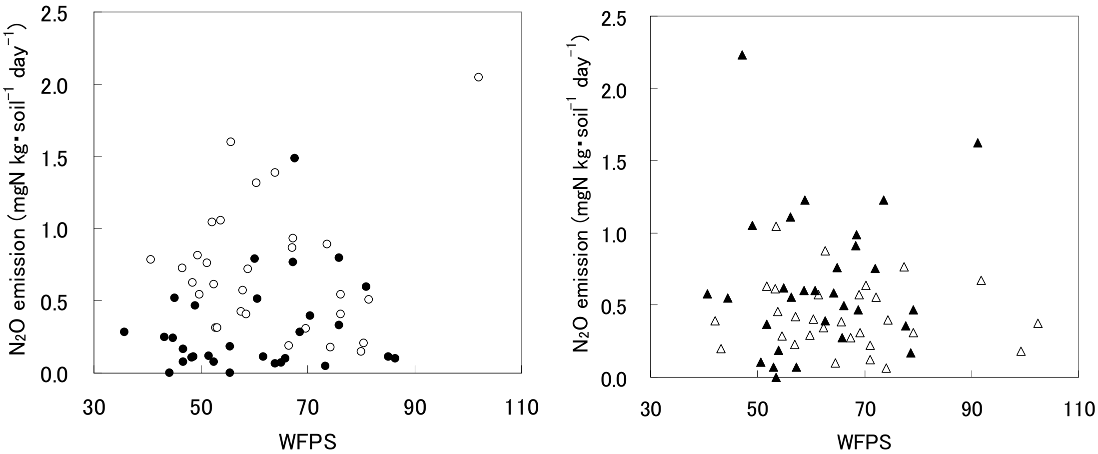

Figure 2. Relationship between N_2O flux and WFPS at 4, 7, 15, 29, and 106 days after the start of experiment. Open and closed circles represent C-plots and P-plots, respectively, and open and closed triangles represent T-plots and TP-plots, respectively.

Meanwhile, P addition significantly decreased N_2O emissions from the plot without trenching, probably because P addition accelerated root absorption of N. Vegetation is presumably the main competitor of nitrifying and denitrifying microbes because plant growth is dependent on N availability as well as N_2O emission (Aerts *et al.* 1995). Although it has been recognized in various forest ecosystems that microorganisms are stronger competitors for inorganic N than plants, (Johanson, 1992; Kaye and Hart, 1997), some studies have that particular plant species to be the stronger competitor (Silvan *et al.* 2005). Probably *Acacia mangium* is also stronger competitor for inorganic N than nitrifying and denitrifying microbes, thereby the P addition released P limitation of *Acacia mangium* and increased N uptake and suppressed N_2O emissions.

Conclusion

This study showed that P application should suppress N_2O emissions from the *Acacia mangium* plantation, possibly because P addition accelerates root absorption of N. P application to the *Acacia mangium* plantation might be an effective global warming mitigation option by suppressing N_2O emissions

References

Aerts R, van Logtestijn R, van Staalduinen M, Toet S (1995) Nitrogen supply effects on productivity and potential leaf litter decay of Carex species from peatlands differing in nutrient limitation. *Oecologia* **104**, 447-453.

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.

Bremner JM (1997) Sources of nitrous oxide in soils. *Nutrient Cycling in Agroecosystems* **49**, 7-16.

Cleveland CC, Townsend AR., Schmidt SK., (2002) Phosphorus limitation of microbial processes in moist tropical forests: Evidence from short-term laboratory incubations and field studies. *Ecosystems* **5**, 680-691.

Davidson EA, Keller M, Erickson HE, Verchot LV, Veldkamp E (2000) Testing a conceptual model of soil emissions of nitrous and nitric oxides. *Bioscience* **50**, 667-680.

Dick J, Skiba U, Munro R, Deans D (2006) Effect of N-fixing and non-N-fixing trees and crops on NO and N_2O emissions from Senegalese soils. *Journal of Biogeography* **33**, 416-423.

Hall SJ, Matson PA (1999) Nitrogen oxide emissions after nitrogen additions in tropical forests. *Nature* **400**, 152-155.

Hardjono A, Ishibashi N, Matsumura N, Taniguchi I, Heriyanto NM, Ando K (2005) The management aspects of industrial plantation in south Sumatra - A case of PT. MUSI HUTAN PERSADA -. Carbon Fixing Forest Management Project (FORDA & JICA). (Bogor: Indonesia).

IPCC (2007) Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Cambridge University Press: New York).

Ishizuka S, Tsuruta H, Murdiyarso D (2002) An intensive field study on CO_2, CH_4, and N_2O emission from soils at four land-use types in Sumatra, Indonesia. *Global Biogeochemical Cycles* **16**, 1049.

Johnson, DW (1992) Nitrogen retention in forest soils. *Journal of Environmental Quality* **21**, 1-12.
Kaye JP, Hart SC (1997) Competition for nitrogen between plants and soil microorganisms. *Trends in Ecology and Evolution* **12**, 139-143.
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.
Matson PA, Vitousek PM (1990) Ecosystem approach to a global nitrous oxide budget. *BioScience* **40**, 667-672.
Silvan N, Tuittila E-S, Kitunen V, Vasander H, Laine J (2005) Nitrate uptake by *Eriophorum vaginatum* controls N2O production in a restored peatland. Soil Biology and *Biochemistry* **37**, 519-526.
Sundareshwar PV, Morris JT, Koepfler EK, Fornwalt B (2003) Phosphorus limitation of coastal ecosystem processes. *Science* **299**, 563-565.
Vitousek PM, Walker LR, Whiteaker LD, Matson PA (1993) Nutrient limitations to plant growth during primary succession in Hawaii Volcanoes National Park. *Biogeochemistry* **23**, 197-215.
Wrage N, Velthof GL, van Beusichem ML, Oenema O (2001) Role of nitrifier denitrification in the production of nitrous oxide. *Soil Biology and Biochemistry* **33**, 1723-1732.