B-51.2.6 The budget of emission/absorption of CH_4 and N_2O in Japanese forest soils

Contact person Haruo Tsuruta,
National Institute of Agro-Environmental Sciences,
3-1-1 Kannon-dai, Tsukuba 305-8604, Japan
Tel: +81-(0)298-38-8276 Fax: +81-(0)298-38-8199
E-mail: tsuruta@niaes.affrc.go.jp

Total budget for FY1998 4,500,000 yen

Abstract

To estimate the variety of CH_4 uptake rates by the soil in a forest, 18 stainless chambers were set for flux measurement. Nine were set on upper part of a slope, and the other nine were set on lower part of the slope. The mean flux of CH_4 in 18 chambers was –3.08±0.72 and -3.20±0.74 $mgCH_4m^{-2}d^{-1}$ in June and July, respectively. The result indicates that the use of only three chambers in one sampling location is enough to estimate the mean flux in a forest floor, and we recommend to set six chambers (three on upper part of a slope and three on lower part of the slope) for more precise estimation of CH_4 flux. A three-year measurement of CH_4 flux was conducted in a natural deciduous forest in Ibaraki between Mar. 1995 and Nov. 1997. The mean flux was 4.9 and 2.5 $mgCH_4m^{-2}d^{-1}$ near a ridge and on an upper part of a valley, respectively. The CH_4 flux showed a seasonal variation, higher in summer and lower in winter. The inter-annual variation of the CH_4 uptake rate between 1995 and 1997 was small at both sites. The mean flux near a ridge was relatively larger than literature values ever given for temperate ecosystems.

The first intensive research on N_2O emission in Asian forests has been conducted in a suburb of Tokyo City since 1998. A clear seasonal variation of N_2O flux was observed in all of three locations along the slope of a deciduous forest, in which the N_2O fluxes were correlated well with the soil temperature (r^2 = 0.66 - 0.82). Throughout a year, the N_2O emission at more humid bottom location was twice as much as in other locations. On the basis of these observations, an annual N_2O emission rate was calculated as 0.56 kg N ha^{-1}. This value is considerably higher in comparison with literature values ever given for temperate ecosystems, suggesting a crucial importance of 'nitrogen-saturation' as a factor controlling N_2O emission from forests in Japan.

Key Words nitrous oxide(N_2O), methane(CH4), forests, natural soils, Monsoon Asia

1. Introduction

Studies for the global cycle of atmospheric N_2O and CH_4 that have started since the end of 1980's, have shown that natural terrestrial ecosystems are of fundamental importance. The N_2O emission from natural soils, for example, is now estimated as 6 Tg yr^{-1}, which corresponds to 40% of the total natural and anthropogenic sources (IPCC, 1994). The quantitative role of natural terrestrial ecosystems, however, has not been fully evaluated yet. A revised estimate with higher precision is necessary to clarify the global inventory of atmospheric N_2O and CH_4. Especially, the quantitative role of temperate natural soils has considerable uncertainties, leaving wide ranges in the estimation of annual N_2O and CH_4 fluxes.

The flux data in temperate forests has been reported in quite limited regions: only North America and Europe. No data are available for greenhouse-gas fluxes in Asian forests under Monsoon climate, which is distinctively different in precipitation and soil properties from these districts. Thus, the first research has started in this study to evaluate of N_2O and CH_4 fluxes in Asian ecosystems.

2. Research Objective

The objective of the present study is, 1) to collect the preliminary data on N_2O and CH_4 fluxes in Asian ecosystems through a systematic research performed in Japanese forests, and 2) to accumulate the data which could help to develop an efficient method to investigate these gas fluxes, with a special emphasis on their horizontal variations in association with highly heterogeneous feature of Japanese forests.

3. Materials and method

(1) Methane

To estimate the variety of CH_4 uptake rates of the soil in a forest, 18 stainless chambers (40cm diameter, 15cm height) were set for flux measurement in a deciduous forest in Hokkaido Research Center of Forestry and Forest Product Research Institute. Nine chambers were set on upper part of a slope, and the other chambers were set on lower part of the slope. Three-year filed measurement of CH_4 flux was conducted in a natural deciduous forest (Ogawa Research Forest) in Ibaraki between Mar. 1995 and Nov. 1997. Three chambers were set in each two sampling sites, near a ridge and upper part of a valley slope.

(2) Nitrous oxide

The flux measurement of N_2O emission was carried out by using a closed chamber technique in a suburb of Tokyo City. The research site is a deciduous forest with a dominant tree of oak. Bamboo bushes dominate the understory vegetation. The soil in this site is a volcanic ash soil named 'Kanto loam'. Employing a small watershed (a total area of 0.52ha) as a research unit, three sampling locations were selected along the landscape: ridge part, steep slope part and valley part. N_2O emission was measured by using closed chambers installed on the forest floor. Triplicate measurements of N_2O flux were made at each site twice a month from spring to winter in 1998. The high NO_3^- concentration in streams around this area, more than 70 μM, indicates a 'nitrogen-saturated' situation. A NO_3^- leaching from this area is evaluated well comparable to that for highly nitrogen saturated forests in Europe and North America.

4. Results and Discussion

(1) Methane

The CH_4 flux in Hokkaido in June 1998 was -3.32±0.82 $mgCH_4m^{-2}d^{-1}$ on the upper part of the slope, and 3.09±0.68 $mgCH_4m^{-2}d^{-1}$ on the lower part of the slope, respectively. In July 1998, the flux was -3.46±0.51 on the upper part of the slope, and -2.70±0.72 $mgCH_4m^{-2}d^{-1}$ on the lower part of the slope, respectively. There was no significant difference in the CH_4 flux between upper part and lower part of the slope in June, while significantly different in July. The mean flux of CH_4 in 18 chambers was -3.08±0.72 $mgCH_4m^{-2}d^{-1}$ in June and -3.20±0.74 $mgCH_4m^{-2}d^{-1}$ in July, respectively. The standard deviation of CH_4 flux in 18 chambers was small (0.23), enough to estimate the flux in a forest by using

only three chambers. To estimate the mean flux more precisely, it is recommended that each three chambers will be prepared both on a upper part and lower part of a slope in a forest .

In Ogawa Research Forest, the CH_4 fluxes near the ridge were always larger than the CH_4 flux on an upper part of a valley (Fig.1). The mean flux of three years was -4.9 $mgCH_4m^{-2}d^{-1}$ near a ridge and -2.5 $mgCH_4m^{-2}d^{-1}$ on an upper part of a valley, respectively. The CH_4 uptake rate showed a seasonal variation, higher in summer and lower in winter. The inter-annual variation between 1995 and 1997 was small at both sites. The mean flux near a ridge was relatively larger than literature values ever given for temperate ecosystems (Tab. 1).

(2) Nitrous oxide

In all of three locations, N_2O fluxes showed a similar seasonal variation with a mid-summer maximum (Fig. 2). The fluxes were well accounted for by the seasonal variations of soil temperature with their correlation coefficient (r^2) of 0.66 - 0.81, indicating that temperature was the principal factor regulating the N_2O emission.

N_2O emission at the bottom location was about twice as much as ones at the other locations. Constantly lower soil water tensions observed at the bottom, indicate more humid condition, which favors microbial N_2O production in the forest floor. The emission rate and its seasonal change were quite similar between the ridge and the slope locations.

The estimate of annual N_2O emission rate from the present forest site was calculated from a combination of a record of soil temperature in this site and a linear regression between N_2O flux and soil temperature. The overall intensity of N_2O emission from the research area was calculated as 0.56 kg N ha^{-1} yr^{-1}. Though the bottom location emitted a large quantity of N_2O more than 1 kg N ha^{-1} yr^{-1}, it contributed little to the overall emission due to its small areal coverage.

The annual N_2O emission rate was comparatively larger than literature values ever observed for most temperate forests except the data from Germany (Tab. 2). From our previous studies, the present forest site has been suggested to be in a situation of nitrogen saturation represented by elevated nitrate concentrations in neighboring forest streamwaters as high as 100 uM. The results thus suggest that it is very important to consider the magnitude of 'nitrogen saturation' to evaluate N_2O emission from Japanese forests.

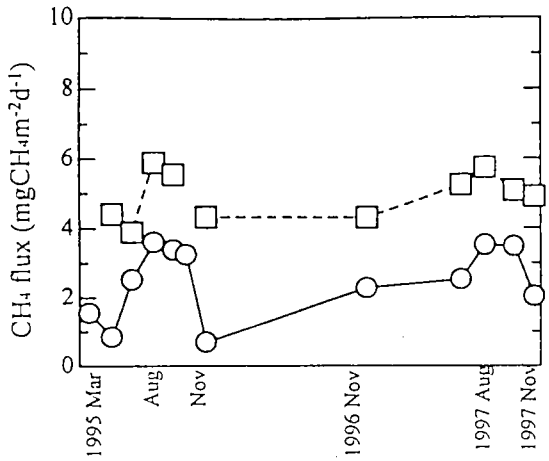

Fig. 1 Measurement of CH_4 flux in Ogawa Research Forest (Ibaraki Pref., Japan)

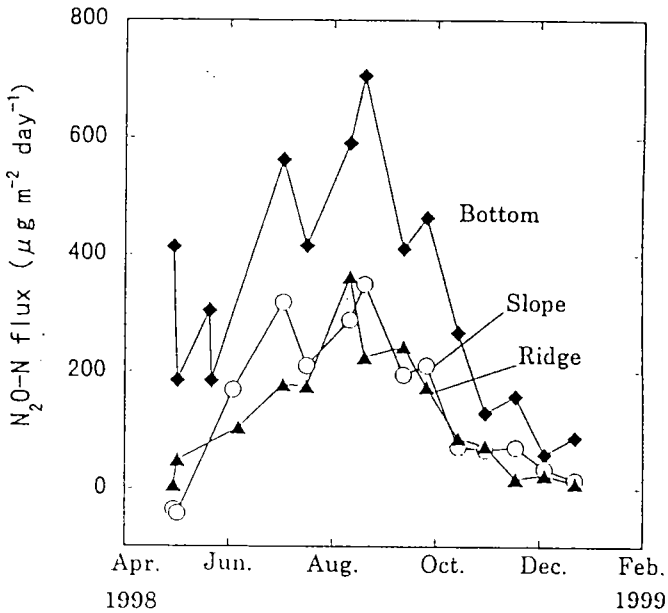

Fig. 2 Seasonal variation of N_2O flux at three locations in a forest (near Hachiohji, a suburb of Tokyo)

Table 1 CH_4 uptake rate measured in forest soils in the world

region	country	vegetation	uptake rate ($mgCH_4m^{-2}d^{-1}$)		Reference
			range (seasonal)	average (annual)	
North America	U.S.A.	*Pinus*	3.2~4.2**	3.5*	Steudler *et al.*, 1989
		Quercus, Acer	3.5~5.3**	4.2*	Steudler *et al.*, 1989
	U.S.A.	*Tsuga, Pinus, Prunus etc.*	0~2.8	1.65	Crill, 1991
	U.S.A.	*Populus*	0.55***	ND	Whalen *et al.*, 1992
		Betula	0.22***	ND	Whalen *et al.*, 1992
		Picea	0.62 & 0.55***	ND	Whalen *et al.*, 1992
	Canada	*Picea, Ledum, Betula*	ND	0.27~1.57	Adamsen & King, 1993
		Pinus, Quercus	ND	2.7	Adamsen & King, 1993
	U.S.A.	spruce and fir	0.64~2.6*	0.64~1.7*	Castro *et al.*, 1993
	U.S.A.	*Pinus*	3.2~7.0*	ND	Castro *et al.*, 1994
	U.S.A.	*Pinus*	0~7.4	2.9	Castro *et al.*, 1995
		hardwood	0.8~6.4	4.5	Castro *et al.*, 1995
	U.S.A.	*Quercus*	2.1~7**	3.8~5.4	Goldman *et al.*, 1995
Central America	Costa Rica	*Laetia, Pentaclethra*	0.3~2.3**	1.20~1.26	Keller & Reiners, 1994
Europe	Germany	?	0~1.8*	0.49*	Koschorreck & Conrad, 1993
		deciduous forest	0~5.9*,**	2.2*	Born *et al.*, 1990
		spruce forest	ND	0.25*	Born *et al.*, 1990
	Scotland	*Acer, Fraxinus*	0.19~3.30	1.4	Dobbie *et al.*, 1996a
	Denmark	*Fagus, Picea etc*	0.27~1.06	0.7	Dobbie *et al.*, 1996a
	Poland	birch, alder, oak, pine, etc.	0.84~1.23***	1.0	Dobbie *et al.*, 1996a
	U.K.	*Acer, Fraxinus, Fagus*	2.19~2.97	ND	Dobbie & Smith, 1996b
	Denmark	*Picea, Quercus*	ND	0.64~1.7*	Priemé & Christensen, 1997
Asia	Japan	*Quercus, Fagus, Acer*	0.69~3.60	2.49	this study
	Japan	*Quercus, Fagus, Acer*	3.89~5.88	4.93	this study

* adjust the unit (recalculated) ** the value read from graphs *** value measured only once

Table 2 Annual N_2O emission rate measured in temperate forests

Vegetation	Country	N_2O $kgN\ ha^{-1}\ yr^{-1}$	References
·Pine	USA	0.010	Bowden et al. (1990)
·Hardwood	USA	0.017	Bowden et al. (1990)
·spruce-fir	USA	0.02-0.08	Castro et al. (1993)
·Douglas-fir	USA	0.03-0.09	Matson et al. (1992)
·Spruce	Austria	0.081	Henrich & Haselwandter (1997)
·Spruce	Sweden	0-0.16	Klemedtsson et al. (1997)
·Hardwood	USA	0.23	Bowen et al. (1993)
·Beech	Germany	5.6	Brumme & Beese (1992)
		0.1 - 2	IPCC (1994)*
·Oak	**Japan**	**0.56**	**This study**

*calculated from the data of IPCC (1994) divided by an area of temperate forest ($10 \times 10^{12}\ m^2$).

References

Adamsen, A. P. S., and King, G. M. (1993) Methane consumption in temperate and subarctic forest soils: rates, vertical zonation and responses to water and nitrogen. *Applied Environmental Microbiology* **59(2)**, 485-490

Born, M., Dörr, H. and Levin, I. (1990) Methane consumption in aerated soils of the temperate zone. *Tellus* **42B**, 2-8

Bowden, R. D., P. A. Steudler, and J. M. Melillo (1990) Annual nitrous oxide fluxes from temperate forest soils in the Northeastern United States. *J. Geophys. Res.* **95 D9**. 13997-14005.

Bowden, R. D., M. S. Castro, J. M. Melillo and P. A. Steudler and J. D. Aber (1993) Fluxes of greenhouse gases between soils and the atmosphere in a temperate forest following a simulated burricane blowdown. *Biogeochemstry* **21** 61-71.

Brumme, R. and F. Beese (1992) Effects of liming and nitrogen fertilization on emissions of CO_2 and N_2O from a temperate forest. *J. Geophys. Res.* **97D12** 12851-12858.

Castro, M. S., Steudler, P. A., Melillo, J. M., Aber, J. D. and Millham, S. (1993) Exchange of N_2O and CH_4 between the atmosphere and soils in spruce-fir forests in the northeastern United States. *Biogeochemistry* **18**, 119-135

Castro, M. S., Melillo, J. M., Steudler, P. A. and Chapman, J. W. (1994) Soil moisture as a predictor of methane uptake by temperate forest soils. *Canadian Journal of Forest Research* **24**, 1805-1810

Castro, M. S., Steudler, P. A. and Melillo, J. M. (1995) Factors controlling atmospheric methane consumption by forest soils. *Global Biogeochemical Cycles* **9**, 1-10

Crill, P. M. (1991) Seasonal patterns of methane uptake and carbon dioxide release by a temperate woodland soil. *Global Biogeochemical Cycles* **5**, 319-334

Dobbie, K. E., Smith, K. A., Prieme, A., Christensen, S., Degorska, A. and Orlanski, P. (1996a) Effect of land use on the rate of methane uptake by surface soils in northern Europe. *Atmospheric Environment* **30**, 1005-1011

Dobbie, K. E. and Smith, K. A. (1996b) Comparison of CH4 oxidation rates in woodland, arable and set aside soils. *Soil Biology & Biochemistry* **28**, 1357-1365

Goldman, M. B., Groffman, P. M., Pouyat, R. V., McDonnell, M. J. and Pickett, S. T. A. (1995) CH_4 uptake and N availability in forest soils along an urban to rural gradient. *Soil Biology & Biochemistry* **27**, 281-286

IPCC (1995) Climate Change 1994, Cambridge University Press.

Keller, M. and Reiners, W. A. (1994) Soil-atmospheric exchange of nitrous oxide, nitric oxide, and methane under secondary succession of pasture to forest in the Atlantic lowlands of Costa Rica. *Global Biogeochemical Cycles* **8**, 399-409

Klemedtsson, L., A. K. Klemedtsson, F. Moldan and P. Weslien (1997) Nitrous oxide emission from Swedish forest soils in relation to liming and simulated increased N-deposition. *Biol. Fertil. Soils* **25**, 290-295.

Koschorreck, M. and Conrad, R. (1993) Oxidation of atmospheric methane in oil: measurements in the field, in soil cores and in soil samples. *Global Biogeochemical Cycles* 7, 109-121

Matson, P. A., S. T. Gower, C. Volkmann, C. Billow, and C. C. Grier (1992) Soil nitrogen cycling and nitrous oxide flux in a Rocky Mountain Douglas-fir forest: effects of fertilization, irrigation and carbon addition. *Biogeochemistry* **18**, 101-117.

Priemé, A. and Christensen, S. (1997) Seasonal and spatial variation of methane oxidation in a Danish spruce forest. *Soil Biology & Biochemistry* **29**, 1165-1172

Steudler, P. A., Bowden, R. D., Melillo, J. M. and Aber, J. D. (1989) Influence of nitrogen fertilization on methane uptake in temperate forest soils. *Nature* **341**, 314-316

Whalen, S. C., Reeburgh, W. S. and Barber, V. A. (1992) Oxidation of methane in boreal forest soils: a comparison of seven measures. *Biogeochemistry* **16**, 181-211