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Nitrous oxide and methane emissions from soil–plant systems

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Abstract

The closed chamber method was used to measure the N_2O and CH_4 emissions from rice, maize, soybean and spring wheat fields in Northeast China. Rice field almost did not emit or deposit N_2O in total during flooding period, whereas N_2O was substantially emitted during non-flooding period. The annual emission amount of N_2O was 1.70 kg N_2O ha^{-1}, but that in flooding period was only 0.04 kg N_2O ha^{-1}. Daily average and seasonal total CH_4 emission in rice field were 0.07 and 7.40 g CH_4m^{-2}, respectively. A trade-off between N_2O and CH_4 emissions from rice field was found. The growth of Azolla in rice field greatly stimulated both N_2O and CH_4 emissions. Total N_2O emissions (270 days) from maize and soybean fields were 7.10 and 3.12 kg N_2O ha^{-1}, respectively. The sink function of the uplands monitored as the atmospheric CH_4 was not significant.

Introduction

Nitrous oxide (N_2O) and methane (CH_4) are two important greenhouse gases playing an important role in the photochemical reactions of the troposphere and stratosphere and in the global warming.

N_2O is 300 (mass basis) times more radiatively active than CO_2, and CH_4 is 15 times more effective than CO_2 (mass basis) at absorbing infrared radiation (Rodhe, 1990).

Estimated annual increases of atmospheric N_2O and CH_4 are 3.7 Tg N and 40 Tg C, respectively (Duxbury et al., 1993), and 70-90% of which is of biogenic origin (Bouwman, 1990).

Current global budget for N_2O is unbalanced–unknown sources totaling 6.5 Tg N y^{-1} (Robertson, 1993). It is suggested that either the known source strength has been underestimated or that certain globally significant sources have not been identified.

In the past years, N_2O and CH_4 emissions from rice, maize, spring wheat and soybean fields in Northeast China and N_2O emission by plants have been measured. Some results are presented in this paper.

Materials and methods

N_2O and CH_4 fluxes have been measured (weekly or less) at Shenyang Experimental Station of Ecology since 1992. Some characteristics of the experimental site are given in Table 1.

The experimental rice field was divided into 4 blocks receiving the following different fertilization treatments: 1) no fertilization (A); 2) Urea (374 kg urea ha^{-1}) alone (B); 3) B + manure (37.5 T ha^{-1}) (C); and 4) C + Azolla (D). Urea was applied 3 times: the first time (134 kg ha^{-1}) applied as basal fertilizer in late May, the second (134 kg ha^{-1}) and third (107 kg ha^{-1}) top-dressed in late June and mid-August, respectively. Manure was applied as basal. Azolla inoculum (156 g m^{-2}) was spread to the treatment D in late June without harvest over the growing season. The treatment C represented the fertilization level of local farmers. The rice fields were flooded by 5-10 cm water layer during the entire growing season (late May–mid-September)

Maize field was fertilized at sowing (300 kg urea.ha^{-1}) and stamening (450 kg urea.ha^{-1}) times.

Wheat field was fertilized in mid-March (150 kg urea ha^{-1}) and mid-May (450 kg urea ha^{-1}), respectively.

Table 1. Characteristics of the experimental site

Latitude & longitude	41°32'N, 123°23'E
Annual temperature	7.0–8.0 °C (with a maximum 39.3 °C and minimum -33.1 °C)
Annual precipitation	570–680 mm
Cropping system	single harvest y^{-1}
soil	meadow brown soil
pH	6.4
Organic matter ($g.kg^{-1}$)	16.17
Total N ($g.kg^{-1}$)	0.76
CEC cmol (+) kg^{-1}	17.9

A small amount of urea (77 kg urea.ha^{-1}) as starting N was applied to soybean field at sowing time (early May).

The closed chamber (0.8 x 0.8 x 1.0m^3) technique was used for flux measurements. Gas samples were taken after 40 min. incubation from the chambers by syringes and analyzed by gas chromatography.

Plant materials used for testing N_2O emission were either cultivated aseptically in laboratory or collected from fields.

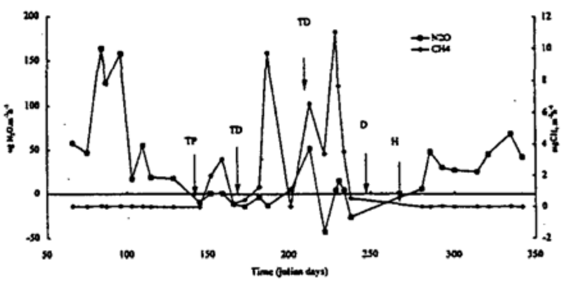

Figure 1. Seasonal variation of N_2O and CH_4 emission from rice field (treatment C). (TP: Transplanting; TD: Top Dressing; D: Drainage; H: Harvest.)

Results and discussion

N_2O and CH_4 emissions from rice field

N_2O emission

The measurement of N_2O emission from rice field has not yet been conducted widely and systematically as compared with CH_4. In Northeast China, the rice plant was transplanted in late May and harvested in early October. Rice field flooded by 5-10 cm water layer during the growing season (late May–mid-September), and drainaged for harvest in mid-September. The measurements of N_2O emissions showed that although the N_2O fluxes differed from year to year, the emission patterns did not change much (Fig. 1). Two peaks of N_2O emission were observed over the year. The first (biggest) peak occurs before transplanting (late May) which might result from N_2O produced and accumulated in soil by nitrification and denitrification processes during winter and early spring. The flooding for transplanting decreases soil Eh and results in N_2O reduction to N_2, and thus decreases N_2O flux. Rice field almost did not emit or deposit N_2O in total during flooding period. However, N_2O was substantially emitted when rice field was drainaged for harvest. N_2O fluxes from normally managed rice field (treatment C) were in the range of -39~164 $ugN_2O\ m^{-2}h^{-1}$ over the year. The amount of annual emission is 1.70 kg $N_2O\ ha^{-1}$, while that in flooding period was only about 0.04 kg $N_2O\ ha^{-1}$. Therefore, monitoring N_2O emission in non-flooding period is much more important for estimating annual total N_2O emission from rice field.

CH_4 emission

Rice is a major crop and cultivated widely in China. Flooded rice fields are an important source of CH_4 emission on global scale. Measurements of CH_4 emission from rice fields have been done at different locations of the world (Sass, 1994).

Three peaks of CH_4 emissions were observed during the growing season (Fig. 1). The first peak occurs soon after transplanting, the second during the vigorous growing phase of rice plant (before and after flowering stage), and the third during filling and maturing stage.

The seasonal variation pattern of CH_4 emission from rice fields in Northeast China was similar to that observed in southern rice paddies in China by Wang et al. (1994), but their emission rates were lower. The difference in CH_4 emission flux between northern and southern rice field in China reflects the difference in their soil properties. Daily average and seasonal total CH_4 emissions (110 days) from rice field in Northeast China were 0.07 and 7.40 g CH_4 m^{-2}, respectively. CH_4 rarely emitted or deposited during non-flooding period (Fig. 1.).

Interrelation between N_2O and CH_4 emissions

It has been known that the redox potentials in soil where N_2O and CH_4 are produced are quite different. Smith et al. (1993) showed that the critical redox potential of a flooded rice soil at which N_2O is produced is +250 to +300 mV over a range of soil pH conditions. Wang et al. (1993) reported that the critical soil Eh for initiation of CH_4 production is approximately -140 to -160 mV. Flooded rice fields provide essential conditions for N_2O, and especially CH_4 productions.

N_2O and CH_4 emissions from rice fields have been measured separately in most of experiments conducted so far. Therefore, it is difficult to reveal the interrelation between the two gas emissions. We have been monitoring the N_2O and CH_4 emissions from rice fields simultaneously and systematically since 1992. The results as shown in Fig. 1 indicated that: 1) rice field substantially emitted N_2O, but rarely emitted CH_4 during non-flooding period; and 2) during flooding period, however, rice field almost did not emit or deposit N_2O in total, but emitted CH_4 in large quantity. This clearly suggests a trade-off between N_2O and CH_4 emissions in rice field. Bronson et al. (1993) reported that additions of organic amendments stimulated CH_4 emissions, but resulted in lower N_2O fluxes in a rainfed fallow-irrigated rice system. As N_2O is a more effective greenhouse gas than CH_4, especially on the long-term basis (Shine et al., 1990), this interrelation should be considered when management strategies for CH_4 mitigation are proposed.

Influences of Azolla and fertilization on N_2O and CH_4 emissions

Azolla has been used by Chinese farmers for centuries as a green manure to improve the nitrogen balance in rice field and as green fodder of livestock, poultry and fish (Liu & Zheng, 1992). The results showed that the growth of Azolla in rice field greatly stimulated both N_2O and CH_4 emissions (Figs. 2–3). The laboratory experiments (unpublished data) suggested that this stimulation was likely due to the exudation of Azolla root and decomposition of dead Azolla, but not due to

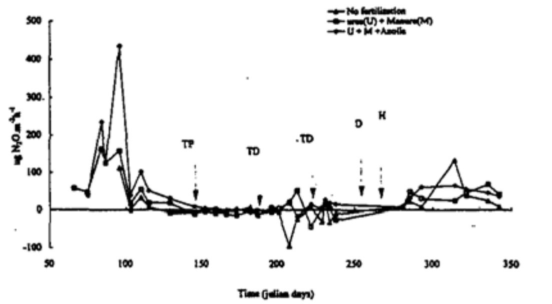

Figure 2. Effect of Azolla and fertilization on N_2O emission from rice field. (TP: Transplanting; TD: Top Dressing; D: Drainage; H: Harvest.)

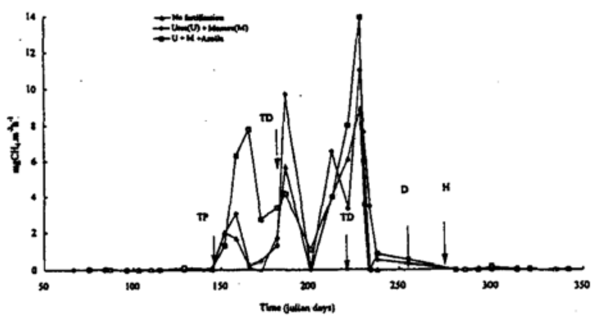

Figure 3. Effect of Azolla and fertilization on CH_4 emission from rice field. (TP: Transplanting; TD: Top Dressing; D: Drainage; H: Harvest.)

Azolla transportation of N_2O and CH_4 in soil as rice plant did.

Reports on the influence of chemical fertilizer application on CH_4 production and emission were inconsistent (Lindau et al., 1994). Our results showed that applying urea + manure increased N_2O and CH_4 emissions (Figs. 2–3). Improving plant growth and enhancing root growth through fertilization may also increase CH_4 emission. The application of urea and manure provides the substrates for producing N_2O and CH_4, and thus increases their fluxes.

N_2O and CH_4 emissions from maize, spring wheat and soybean fields

Maize, wheat and soybean are also staple crops in China. Northeast China is the main production area of these crops. Little information on N_2O and CH_4 emissions from these fields is available so far. In Table 2 are summarized some results on emission measurements conducted at Shenyang since 1992.

As the soil was frozen to a considerable depth, the measurements had to be stopped during the period of

Table 2. N_2O Fluxes from different agricultural ecosystems

Field	Flux ($\mu g\ N_2O\ m^{-2}\ h^{-1}$) Range	Average	Total emission ($kg\ N_2O\ ha^{-1}$)
Maize	-11.86∼557.24	121.77	7.10 (273 days)
Soybean	-20.28∼217.55	42.50	3.12 (273 days)
Spring wheat	-9.47∼46.51	14.29	0.31 (40 days)

Table 3. N_2O emission rate of maize seedlings under different N and P supply and illumination (ug $N_2O.g^{-1}dw.h^{-1}$)

Treatment		CK	N	P	NP
sunlight	low fertilization[a]	0.051	0.126	0.040	0.104
outdoor	high fertilization[b]	0.050	0.580	0.044	0.052
scattered	low fertilization	0.275	0.638	0.215	0.521
light indoor	high fertilization	0.282	5.186	0.221	5.107

a: 0.02g N kg^{-1} sand, 0.005 g P kg^{-1} sand; *b*: 0.2g N kg^{-1} sand, 0.05g P kg^{-1} sand.

Table 4. Photosynthesis and N_2O emission from soybean (S) and hippophae (H)

	(lx)	CO_2 concentration (ppm) 360 S	360 H	465 S	465 H	600 S	600 H
Photosynthesis	0	-1.60	2.14	-0.65	-1.90	-0.37	0.36
($mgCO_2.dm^{-2}h^{-1}$)	3000	1.62	0.57	2.58	1.43	4.27	2.14
	10000	5.18	2.26	7.85	3.14	12.76	3.74
	30000	7.20	6.41	11.36	12.47	15.91	13.54
N_2O emission	0	5.88	-9.54	-11.76	-16.92	-4.2	-0.18
($ngN_2O.dm^{-1}.h^{-1}$)	3000	24.48	-14.04	0.12	-18.6	-3.84	-4.08
	10000	15.12	-10.92	13.8	-23.4	12.9	-1.98
	30000	-7.68	-11.76	-17.34	-19.32	-4.56	-2.46

early December to early March. The maize field emitted much more N_2O than another two. Considering the value of 2.45 kg N_2O-N $ha^{-1}y^{-1}$ emitted from unfertilized maize field, N_2O-N emitted from fertilized maize field accounted for 0.61% of N fertilizer. 3.12 kg N_2O-N $ha^{-1}y^{-1}$ was emitted from the soybean field, including natural emission, emission from N fixed by soybean crop and emission associated with urea fertilizer applied as starting N. The flux in spring wheat field was close to that in winter wheat field in Northern China Plain (Su et al., 1992).

Agricultural soils can be sinks for atmospheric CH_4 in aerated soils (Bouwman, 1990). Nitrogen fertilizer, especially NH_4^+-based fertilizers, have recently been reported to strongly repress CH_4 consumption in forest (Steudler et al., 1989) and prairie (Mosier et al., 1991) soils. The results obtained from this study suggest that the sink function of the fields monitored as the atmospheric CH_4 is not significant. A long N fertilization might have suppressed CH_4 consumption to the low levels in this study. Because all of these cropping systems are of a significant source of N_2O and a weak sink of CH_4 in the atmosphere, strategies for reducing N_2O emission should be emphasized.

N_2O emission from plant

Dean & Harper (1986) showed that leaves of soybean formed N_2O and NO during an assay for nitrate reductase. Mosier et al. (1990) pointed out that rice plants increase the flux of N_2O+N_2 from the soil to the atmosphere through their conduit transport. However, no records of the N_2O emission from plant are reported. Chen et al. (1990, 1992) firstly reported that plant per se emitted N_2O under normal conditions and that the N_2O emission rates were related to plant species and their growing stages.

The pot experiments further revealed that supplying N fertilizer significantly enhanced N_2O emission under the conditions of phosphorus deficiency and weaker illumination, but phosphorus supply and stronger illumination could markedly reduce the N_2O emission from maize seedings (Tab. 3, Chen et al., 1995).

It was also found that the variation of illumination and CO_2 concentration had a significant influence on the N_2O emission rates from plants, even alterated the plant as a source or a sink of N_2O. The N_2O emission from plant was not directly correlated to plant photosysthesis activity (Tab. 4).

Considering that plant directly and indirectly influences N_2O and CH_4 emissions, plant as an important component should be enclosed whenever possible, when measuring the flux by using chamber technique.

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