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SHORT COMMUNICATION

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Nitrous oxide and methane transport through rice plants

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Abstract The separate closed chamber technique was used to study the potential of rice plants for transporting N_2O and CH_4 produced in soil to the atmosphere. The results indicate that N_2O produced in soil can be conducted to the atmosphere via rice plants similarly to CH_4 transport. More than 80% of both N_2O and CH_4 was emitted through rice plants. The rest was emitted through the soil/water/atmosphere interface by ebullition and diffusion. Nitrate addition increased the total N_2O emission rate substantially but decreased the total CH_4 emission. Nitrate addition did not change the CH_4 emission ratio through rice plants, but lowered the percentage of N_2O emission through rice plants. The results suggest that rice plants serve not only as a conduit for most of the CH_4 leaving the soil but also for the N_2O produced in the soil.

Key words Methane · Nitrous oxide · Greenhouse gases · Flooded rice soil

Introduction

Growing awareness of global warming and ozone destruction has led to an increased emphasis on the study of greenhouse gases such as CO_2, CH_4, N_2O and CFCs. Of these, CH_4 and N_2O are two important trace gases with radiative activities and are next only to CO_2 in their contribution to global warming.

Three processes including ebullition, molecular diffusion and lacunae transport by plants through aerenchyma have been recognized as regulating the flux of CH_4 from paddy fields into the atmosphere (Wang et al. 1994). Of the three pathways, aerenchyma transport is considered the most important when rice plants are involved in the ecosystem. Rice plants develop an intercellular gas space system – aerenchyma, which provides the roots with O_2. This gas space system also enables the transport of other gases, including CH_4 and CO_2 from the soil/sediment to the atmosphere. The transport of CH_4 via rice plants has been well documented by many authors (Cicerone and Shetter 1983; Seiler et al. 1984; Inubushi et al. 1990; Bouwman 1990). Most of the knowledge on the issue of gas transport by plants has obtained with CH_4. Few studies of N_2O emission through aquatic plants have been conducted. Mosier et al. (1990) and Bhadrachalam et al. (1992) found the fluxes of N gases from the soil were greater when rice plants were enclosed in the system. This suggests that N_2O produced in the flooded soil system may also be transported through rice plants. To test this hypothesis, we applied the separate closed chamber method to quantify the amounts of N_2O, in comparison with CH_4, emitted from plants and soil separately.

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Materials and methods

The experiment was conducted in Shenyang Experimental Station of Ecology, Chinese Academy of Sciences (41°32′N, 122°23′E). The soil used was a meadow brown paddy soil (silt loam) with an organic matter content 16.17 g kg^{-1}, total N 0.76 g kg^{-1} and pH 6.4, respectively. Three rice plants including whole roots at the booting stage were dug out from the field with soil and transplanted into growth chambers maintained with 5 cm standing water. The separate closed chamber used in this study is shown in Fig. 1. It consists of two gas collection chambers for gas emission from shoot and soil separately. The PVC soil container was 14 cm in diameter and 25 cm in height. It was filled with soil and standing water up to 20 cm and the remaining 5 cm was left for collection of gases emitted from soil. The gas possibly emitted from the 10-cm base part of sheaths was included in the emission from soil/water in this experiment. The top cover chamber was made of transparent Plexiglas and was 40 cm in height. The two chambers were separated by two pieces of half-circle PVC plates which had a center hole (about 0.5 cm in diameter) to allow the penetration of rice plants. The rice plant was carefully sealed with silicon sealant to prevent gas leaks between the two chambers. Rubber stoppers were installed at the top of the upper chamber and at the side of the lower chamber to allow gas sampling. Methane measurement was

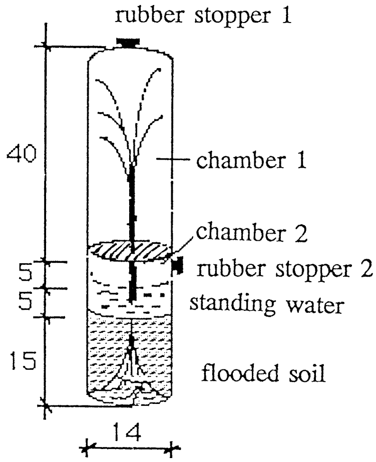

Fig. 1 Schematic diagram of the closed chamber system method (units are centimeters)

Table 1 Percentage of CH_4 and N_2O emission through rice plants and the soil/water interface

Treatment	CH_4		N_2O	
	Plant	Soil/water	Plant	Soil/water
Control	83.8 (17.0)	16.3 (4.0)	85.7 (13.2)	14.3 (2.8)
N-amended	83.0 (10.2)	17.0 (4.4)	74.6 (9.0)	24.5 (4.7)

Data in parentheses are standard deviations ($n=3$)

taken 1 week after re-transplanting to allow the rice plants to adopt to the new growth environment. For each measurement, the top chamber was placed of the top of the container and sealed with silicone sealant for 24 h. Gas samples in the headspace of both chambers were taken every 4 h by syringe and transferred into a 15-ml Vacutainer immediately.

The effect of nitrate N application on N_2O emission followed the same sampling procedure. One hundred milligrams KNO_3-N solution was added to the water phase after CH_4 measurement. Two days later, the chambers were sealed again and the gas collection procedure was repeated.

Both CH_4 and N_2O concentrations in the Vacutainers were analyzed by gas chromatography. For CH_4 analysis, an SP-2305E GC (Gas chromatography) equipped with FID (Flame ionization detector) was used; detector, oven and injector temperatures were 170, 140 and 100 °C, respectively. A Shimadzu GC-14A equipped with ECD (Electron capture detector) was used for N_2O analysis; detector, oven and injector temperatures were 300, 60 and 100 °C, respectively.

Results and discussion

As shown in Table 1 and Fig. 2, our results for CH_4 agreed well with published data (Schütz et al. 1989; Holzapfel-Pschorn et al. 1985; Sass et al. 1990). Most of the CH_4 produced in the soil was emitted through the rice plant, representing 84% of the total flux. The remaining 16% was emitted through the soil/water interface, although this percentage might be even smaller because the gas possibly emitted from the 10-cm base part of the sheaths was included in the emission from soil/water in this experiment. The ratio was not affected by the decrease in total emission caused by nitrate amendment.

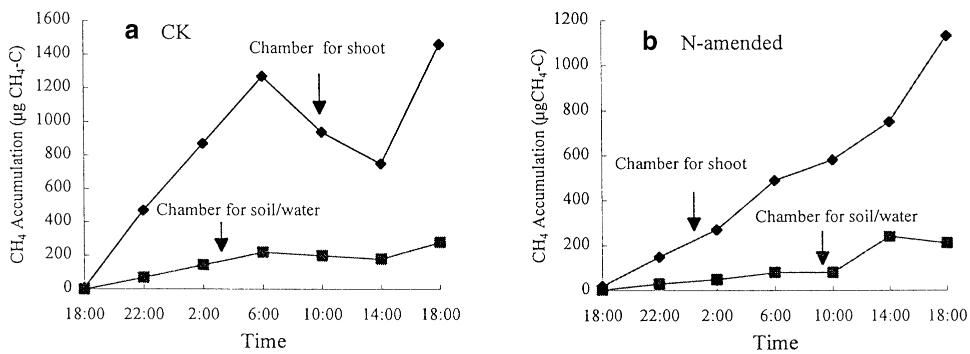

Fig. 2 a, b Emission of CH_4 through rice plants and the soil/water interface in a diurnal measurement (illustrated by the amount of CH_4 cumulated in the chambers as a function of time). **a** Control, **b** N-amended

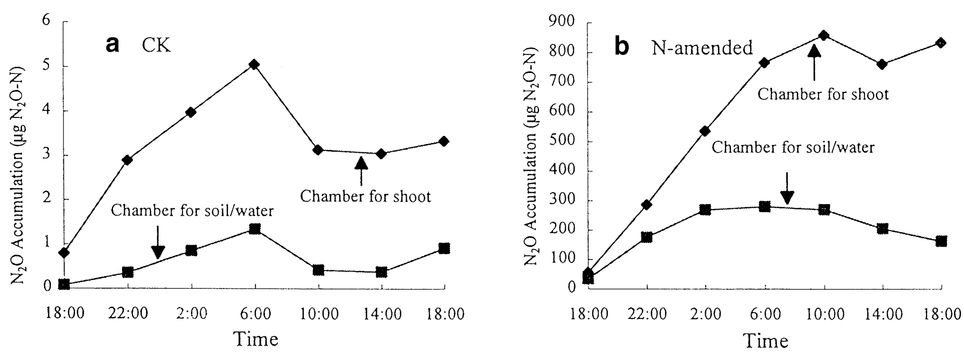

Fig. 3 a, b Emission of N_2O through rice plants and the soil/water interface in a diurnal measurement (illustrated by the amount of CH_4 cumulated in the chambers as a function of time). **a** Control, **b** N-amended

Most of the N_2O produced in the soil was also emitted through the rice plant. A similar emission pattern to that for CH_4 is shown in Fig. 3. The decrease in cumulated N_2O might suggest re-solubilization of this water-soluble gas. Emissions from the soil/water/atmosphere interface only contribute a minor part of the total flux of both gases. Long-term flooded paddy field usually shows low denitrification activities due to the limitation of available nitrate. The processes of denitrification and N_2O emission were greatly stimulated by nitrate addition in our study. Nitrate-amended treatment increased the N_2O emission substantially 2 days after KNO_3 addition. However, nitrate-N decreased the percentage of N_2O emission through rice plants from 86% in the control to 75%.

Gas transport is a physical process. Therefore, N_2O produced in the soil could possibly escape in the same pathway as CH_4. However, N_2O is a more water soluble gas with a solubility in water about 20 times that of CH_4 (0.675 and 0.033 g l^{-1} H_2O at 20 °C, respectively). This water may act as a carrier of N_2O, and emission through diffusion might be enhanced for N_2O. In addition, in combination with the physiological movement of water, such as transpiration, N_2O may be emitted to the atmosphere through the rice plants. The opportunities for emission of N_2O through ebullition should be smaller than for CH_4 due to the high solubility of this gas. Further study needs to be conducted to confirm this observation.

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References

Bhadrachalam A, Chakravorti SP, Banerjee NK, Mohanty SK, Mosier AR (1992) Denitrification in intermittently flooded rice fields and N-gas transport through rice plants. Ecoll Bull (Copenhagen) 42:183–187

Bouwman AF (1990) Soils and the greenhouse effect. John Wiley and Sons, New York, pp 1–21

Cicerone RJ, Shetter JD (1983) Seasonal variation of methane flux from a California rice paddy. J Geophy Res 88:11022–11024

Holzapfel-Pschorn H, Conrad R, Seiler W (1985) Production, oxidation and emission of methane in rice paddies. FEMS Microbial Ecol 31:343–351

Inubushi K, Umebayashi M, Wada H (1990) Methane emission from paddy fields. In: Transactions, 14th International Congress of Soil Science, Kyoto vol. 2:249–254

Mosier AR, Mohanty SK, Bhadrachalam A, Chakravorti SP (1990) Influence of rice plants on the evolution of N_2 and N_2O from the soil to the atmosphere. Mitteilgn Dtsch Bodenk Gesellsch 60:115–120

Sass RL, Fisher FM, Harcombe PA, Turner FT (1990) Methane production and emission in a Texas agricultural wetland. Global Biogeochem Cycles 4:47–68

Schütz H, Holzapfel-Pschorn A, Conrad R, Rennenberg H, Seiler W (1989) A 3-year continuous record on the influence of daytime, season, and fertilizer treatment on methane emission rates from an Italian rice paddy. J Geophys Res 94:16405–16416

Seiler W, Holzapfel-Pschorn A, Conrad R, Scharffe D (1984) Emission of methane from rice paddies. J Atmosph Chem 1:241–268

Wang ZP, Crozier CR, Kludze HK, Patrick WH Jr (1995) Soil characteristics affecting methane production and emission in flooded rice fields. In: Peng S, Ingram KT, Neue HU, Ziska LH (eds) Climate change and rice. Springer, Berlin Heidelberg New York, pp 80–90