B-16.1.1 Studies on Development of Reduction Techniques for Methane and Nitrous Oxide Emissions from Agricultural Fields

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Abstract (1) Survey of organic matter management in local paddy fields in Thailand showed that biomass of weeds grown during fallow period was important for methane(CH_4)emission during cultivation period as well as that of residual rice straw. The organic matter application experiment in lysimeter paddy fields indicated that the treatment of rice straw and stubbles at harvest had a significant effect on CH_4 emission from paddy fields in next cultivation period. (2) A laboratory experiment showed that the temperature around the root greatly affected the CH_4 transport process in rice plants. And the gas entrapped in the soil could enter into the rice body directly from the part of the stem near the base which is beneath the soil surface due to gas pressure in the gas phase resulting from the pressure exerted by the standing water. (3) The nitrous oxide(N_2O) emission rates from maize upland fields with fertiliser application at four experimental sites in the wet seasons of Thailand were in a range of 0.08-0.44 % of the total application rate of nitrogen to the fields. The N_2O emission ratio in the tropics of Thailand was nearly equal to that in Japan located in the temperate zone.
(4) The N_2O emission rates from rice paddy fields during a cultivation period in three experiment stations(Fengqiu, Nanjing, and Yingtan) in China were in a range of 1.7-472 mgN m^{-2} h^{-1}. The flux of N_2O was greatly enhanced after the final water drainage, while CH_4 stopped to emit, and the total emission rates of N_2O and CH_4 were negatively correlated. Hence, the emission of CH_4 and N_2O was in the same relationship of "trade-off" as in Japan.

Key Words Methane(CH_4), Rice Paddy Fields, Nitrous Oxide(N_2O), Fertilized Upland Fields, Reduction Technique for Emission

1. Introduction

Agricultural ecosystem is one of the major sources of greenhouse gases such as methane(CH_4) and nitrous oxide(N_2O). Rice paddy fields emit CH_4, and upland fields with the application of fertiliser emit N_2O. The emission rates of these sources to the atmosphere are estimated to be 12% and 20% of the total emission rate, respectively. The previous study performed during 1990-1994, revealed that the major factors controlling CH_4 emission were soil chemical/physical properties, water management, organic matter applications. On the basis of these new findings, the reduction techniques for CH_4

emission and the modeling of CH_4 transport through rice plants should be developed. On the contrary, the field research on the N_2O emission from agro-ecosystems in Asian countries has recently started except Japan, under the collaborative study with National Institute of Agro-Environmental Sciences.

Research Objectives

2.1 Development of reduction techniques for methane emission from rice paddy fields

Options that mitigate CH_4 emission from paddy fields have been tested and evaluated their efficiency and possibility of adoption to local rice farming[1]. These studies suggested that altering organic matter management and selection of rice cultivars are promising candidates for adopting paddy fields in tropical Asian countries. In this study, we tested the possibilities of mitigating CH_4 emission from paddy fields by these two options as well as surveying organic matter treatment of local farmers in tropical Asia.

2.2 Methane transport through rice plants

It is widely accepted that there are three pathways of CH_4 emission from rice paddy to the atmosphere: molecular diffusion at soil-water interfaces, ebullition of gas bubbles and plant-mediated transport. Many researchers have documented that the major pathway of the three is plant mediated transport. In this study, we tried to clarify the effects of temperature on the rate of CH_4 transport from the root zone to the atmosphere using hydroponically grown rice plants. In addition, we tried to reveal, using the laboratory experiments and observations in the field, how the entrapped gas in the soil affects the CH_4 transport through the rice body.

2.3 Emission of nitrous oxide from upland fields in Thailand

There are few data concerning N_2O emission from natural and cultivated soils tropical zone, especially in tropical Asia. It is critical to determine N_2O emission from land use system in this important geographical region. The objective of the work is to clarify N_2O emission from fertilized upland field in Thailand.

2.4 Emission of nitrous oxide from rice paddy fields in China

No research was performed on the emission of N_2O from rice paddy fields in China, although rice paddy fields have been identified as one of the sources of atmospheric N_2O by a field measurement in Japan[2]. In order to estimate the N_2O emission rate from rice paddy fields in China, a field measurement of the N_2O flux from rice paddy fields has been started since 1994, under the collaborative study on the greenhouse gas emission from agricultural fields between Japan and China.

3 Development of reduction techniques for methane emission from rice paddy fields

3.1 Method

(1) Survey of organic matter management was carried out at local paddy fields in Thailand. Rice yields and amounts of residual organic matter, including rice straw and weed, were determined at harvest of main rice (November to December) and at the beginning of next cultivation (June).

(2) Effect of organic matter treatment on CH_4 emission from paddy fields was studied in lysimeter paddy plots. Three different organic matter treatment; 1) applying 600 g/m^2 of rice straw (straw plot), 2) removing rice straw (control plot), and 3) removing rice straw and stubbles (removed plot), at the harvest of previous rice season was tested. Flux of CO_2 was measured by a manual chamber method during fallow period. Flux of CH_4 was measured by an automated chamber system during rice cultivation period.

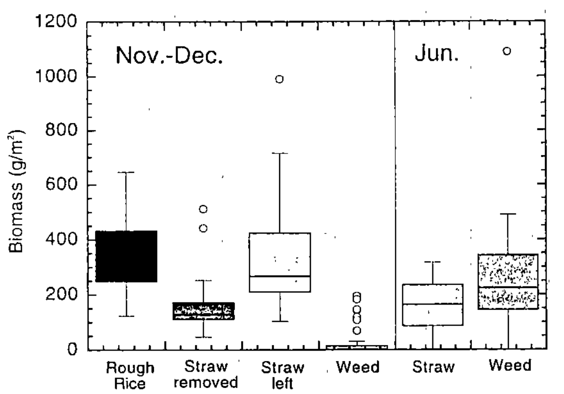

Fig.1 Amount of organic matter collected from paddy fields in Thailand

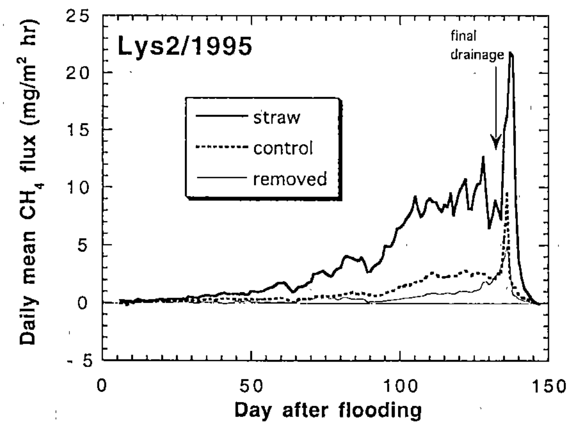

Fig. 2 Effect of organic matter treatment on CH_4 emission from a rice paddy field

(3) Effect of rice cultivars on CH_4 emission from paddy fields was studied by planting two different cultivars in lysimeter paddy plots. Two cultivars were selected according to different degree of aerenchyma development.

3.2 Results and discussion

(1) Rough rice yield at 43 study sites of local paddy fields in Thailand was 334±125 g/m². Aboveground biomasses of rice straw and weeds collected at 34 undisturbed fields out of 43 study sites at the beginning of next cultivation were 152±98 and 253±184 g/m². These results showed that biomass of weeds grown during fallow period was important for CH_4 emission during cultivation period as well as that of residual rice straw (Fig. 1). There was a positive correlation between rough rice yield and aboveground biomasses of rice straw and weeds at the beginning of next cultivation.

(2) Fluxes of CO_2 during fallow period from different organic matter treatment, straw, control, and removed plots, were 191, 147, and 112 gC/m², respectively. Whereas, fluxes of CH_4 during cultivation period were 10.1, 2.63, and 1.28 gC/m², respectively (Fig. 2). These results indicated that the treatment of rice straw and stubbles at harvest had a significant effect on CH_4 emission from paddy fields in the next cultivation period.

(3) The average flux of CH_4 from paddy plots planted Aichi-asahi in three replication was larger than that planted Norin-22 in the early stage of cultivation. Total emission rates during cultivation period were 43.8±16.8 and 33.8±3.5 g/m², respectively, which had no statistical significance at P=0.05 level. Further studies will be needed to clarify the effect of rice cultivar on CH_4 emission from paddy fields.

4.Methane transport through rice plants

4.1 Method

(1) Methane emission rates from the top of the rice plants whose roots were soaked in a solution with a high methane concentration were measured using a flow-through chamber method with the top or root of the rice plants being kept at various temperatures. The CH_4 emission rates and CH_4 concentrations in solution were analyzed using a diffusion model which assumes that the CH_4 emission from a rice paddy is driven by molecular diffusion through rice plants by a concentration gradient.

(2) To clarify the effect of the gas phase below ground on the CH_4 emission rate through rice plants, we partly exposed the root and stem base of hydroponically grown rice to a high concentration of CH_4 gas at various gas pressures, and immersed the rest of the roots in a solution with a high CH_4 concentration.

The CH_4 emission rate was measured from the top of the rice plant using a flow-through chamber method.

4.2 Results and discussion

(1) In the experiment where the temperature around the root was changed, the conductance for CH_4 transport was typically 2.0-2.2 times larger when the solution temperature was changed from 15℃ to 30℃ (Fig. 3). When air temperature surrounding the top of the rice plant was changed, the change in conductance was much less. These results suggest that the temperature around the root greatly affects the CH_4 transport process in rice plants, and that the process of passing through the root is important in determining the rate of CH_4 transport through rice plants[3].

(2) The CH_4 emission rate drastically increased with a small increase in gas pressure in the gas phase at the root and stem base zone, with about a 3 times larger emission rate being observed with 10 x 10^{-3} atm of extra pressure (corresponding to 10 cm of standing water in rice paddy) compared to no extra pressure (Fig. 4). However, when alginate was applied to the stem near the base to prevent contact with the gas phase, the CH_4 emission rate did not increase with increasing gas pressure (Fig. 4). On the other hand, from observations in the rice paddy, it was found that the gas is entrapped near the surface (e.g., at a depth of 1 cm) and the gas entrapped in the soil would come into direct contact with a part of the stem near the base of the rice plant. Thus, the gas entrapped in the soil could enter into the rice body directly from the part of the stem near the base which is beneath the soil surface due to gas pressure in the gas phase resulting from the pressure exerted by the standing water[4]. Hence, this mechanism involving the entrapped gas could play an important role in CH_4 emission from rice paddy by affecting the plant-mediated CH_4 transport as well as ebullition of gas bubbles.

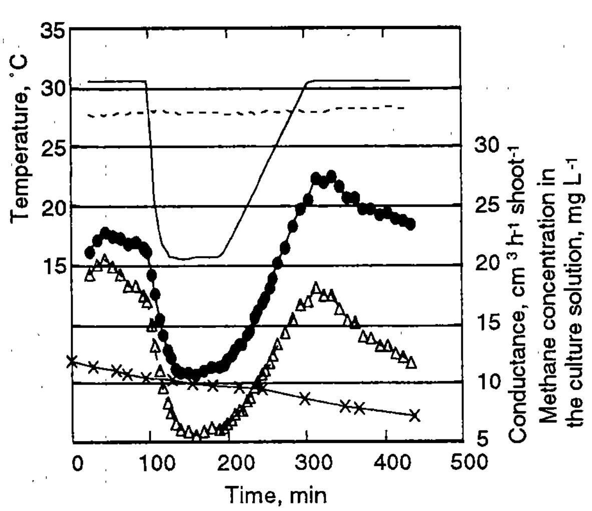

Fig. 3 Time courses of the solution temperature(—), the air temperature in chamber(- -), the CH_4 concentration in solution(×), the CH_4 emission rate from the top of the rice plant(△) and the conductance of CH_4 transport in rice plants(●).

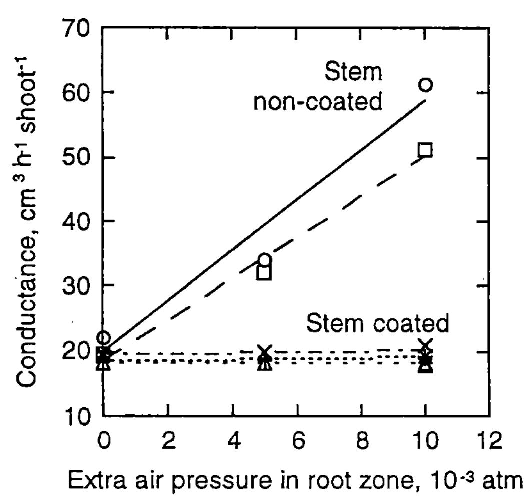

Fig.4 Effect of gas pressure in the rice root and stem base zone on the conductance in the rice body for CH_4 transport, with or without coating the stem near the base with alginate (i.e., with or without exposing a part of the stem near the base to a high concentration of CH_4 gas).

Table 1 Nitrous oxide emission from upland fields in Thailand

	region	Soil	days	+N plot N_2O emission N_2O-Nmg/m^2	-N plot N_2O emission N_2O-Nmg/m^2	(+N--N) emission Fertilizer—N a* (%)	b**
Khon Kaen	N. E	Oxic Paleustults	106	28.9	10.9	0.12	0.24
Chiang Mai	north	Typic Ochraqalfs	78	19.6	11.9	0.08	0.16
Nakhon Sawan	central	Typic Calciustalfs	106	40.3	10.0	0.25	0.48
Phra Putthabat	central	Oxic Paleustults	110	35.1	12.2	0.19	0.37

* : calculated under the assumption that the N_2O emission from the soils between ridges is not different between +N and -N plots

** : calculated under the assumption that the N_2O emission from the soils between ridges is as same as the N_2O emission from the ridges

5. Emission of nitrous oxide from upland fields in Thailand

5.1 Method

Nitrous oxide emission from upland soils was measured through one year with closed chamber method at four experimental sites in Thailand. Two sites are located in the central part of Thailand and another two sites are located in the north eastern and north part. Two treatments, one was applied with nitrogen fertilizer and the other was not applied were set in triplicate at each experimental sites. Maize was cultivated in the experimental plots according to conventional method of each district. During the crop season, air in the chamber was sampled eleven to fourteen times. During the dry season, the air was sampled every month.

5.2 Results and discussion

The N_2O flux increased just after fertilizer application at three experimental fields except for Khon Kaen. The NO_3^-concentration in the soils also increased after fertilization. It seems that the increased N_2O flux and NO_3^- concentration were derived from the application of nitrogen fertilizer by nitrification. The average measured N_2O flux from unfertilized plots through crop season was 4.16±1.52μ gN_2O-N / m^2 hr, 5.05±1.65μ gN_2O-N / m^{2}hr, 5.25±1.68μ gN_2O-N / m^{2}hr, 6.74±2.95μ gN_2O-N / m^{2}hr, at Nakhon Sawan, Phra Phutthabat, Khon Kaen and Chiang Mai, respectively. We estimated that N_2O emission from nitrogen fertilized field was 0.22-0.44 %, 0.19-0.38 %, 0.12-0.24 % and 0.08-0.15% of the N applied at Nakhon Sawan, Phra Phutthabat, Khon Kaen and Chiang Mai, respectively(Table 1). These values were calculated from the difference of emitted N_2O between fertilized and unfertilized plots after fertilizer application[5]. Compared to the values estimated in the temperate zone by another researchers[6, 7], these estimated nitrogen loss as N_2O are not significantly different. Our results showed that N_2O emission rate to applied nitrogen was not significantly different between the Tropical Zone and the Temperate Zone.

6. Emission of nitrous oxide from rice paddy fields in China

6.1 Method

During a rice cultivation period in 1994, the N_2O flux was measured in rice paddy fields in Nanjing, Yingtan, and Fengqiu of China, by closed chamber method. In Nanjing, an intensive field measurement was carried out in the experimental farm of Jiangsu Academy of Agricultural Sciences to study the effect of nitrogen fertilizer from and an application rate on N_2O emission. The four plots were treated where urea and ammonium sulphate were applied at the application rates of 100 and 300 kgN ha^{-1}, respectively. The controlled plot was set with non-nitrogen fertilizer. In Yingtan, the N_2O flux measurement was performed in a farmer's field near the Red Soil Ecological Experimental Station in Chinese Academy of Sciences. The three plots were located in the top , middle and bottom position of a slope with the same fertilizer application rate of urea(122 kgN ha^{-1}). In Fengqiu, the experimental field was set in Fengqiu Agro-Ecological Experimental Station, Chinese Academy of Sciences, constructing of the three plots with the sandy, loamy and clayey soils. Pig manure of 5t ha^{-1} and $(NH_4)HCO_3$ of 130kgN ha^{-1} were applied as the basal and Urea of 270 kgN ha^{-1} was topdressed.

6.2 Results and discussion

(1) The N_2O flux from three rice paddy fields was greatly enhanced after the final water drainage and the alternative of irrigation, while CH_4 emission stopped to emit(Fig. 5). The relationship between N_2O and CH_4 emissions in China was the same as measured in Japan[2].

(2) The N_2O emission rates in the cultivation period was in a range of 1.7-472 mgN m^{-2} h^{-1} among three rice paddy fields. The major factors controlling N_2O emission were water regime and soil texture in the

(3) The flux of N_2O was higher from sandy soils than in the other two soils in Fengqiu.. It strongly suggests that soil texture is one of the major factors controlling the N_2O emission from paddy fields.

(4) In Nanjing, the N_2O emission rate was higher from the rice paddy plot with the application of ammonium sulphate than from the plot with urea application at the total application rate of 300kgN ha^{-1}. It also increased three or five times with the increase in the total application rate of 100 kgN ha^{-1} to 300 kgN ha^{-1} in the rice paddy fields. The emission ratio of N_2O-N into the atmosphere to the total amount of nitrogen applied to the paddy fields was in a range of 0.038-0.28 %. The CH_4 emission rate in the cultivation period was lower in the plots with the application of nitrogen fertiliser than in the controlled

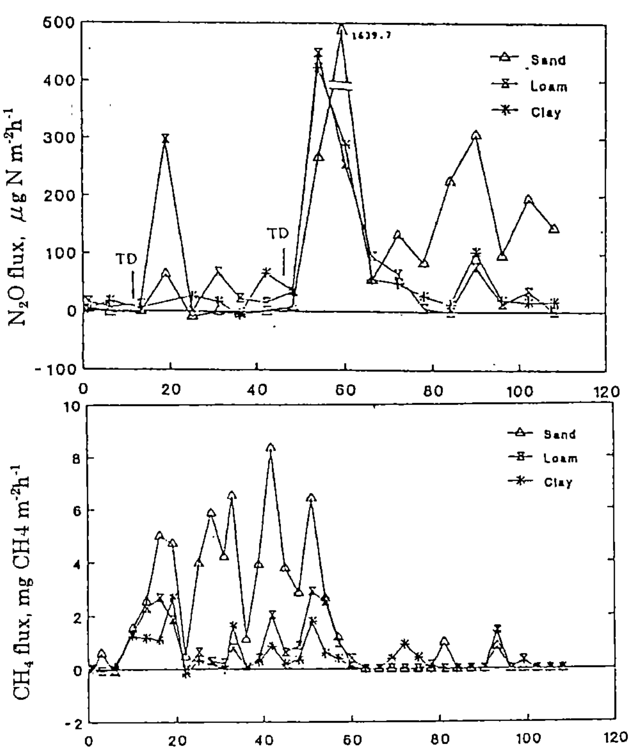

Fig. 5 The fluxes of N_2O(upper figure) and CH_4 (lower figure) from paddy field in Fengqiu

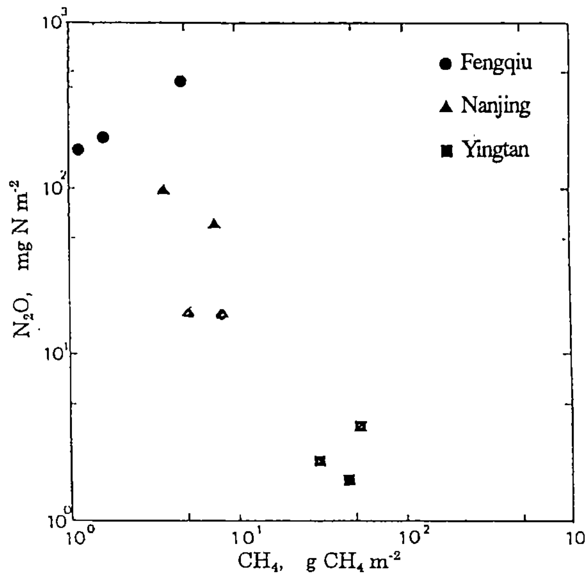

Fig. 6 Relationship between the CH_4 and N_2O emission rates from three rice paddy fields

plot with non-nitrogen, in contrast with the N_2O emission rate[9].

(5) The flux measurements in three rice paddy fields clearly showed that the total N_2O emission rate was higher in the plots where the total CH_4 emission rate was lower, and vice versa (Fig. 6). Hence, the emission of N_2O and CH_4 from the rice paddy fields was in a relationship of "trade-off", as measured in Japan.

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