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Emission and Production of Methane in the Paddy Fields of Japan

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Abstract

Rates and variations of methane (CH_4) emission and production in the paddy fields in Japan were analized. CH_4 emission from paddy fields showed strong seasonal variations, depending on soil Eh, water management, and mineral fertilizer applied. The emission rate widely varied with soil types during the cultivation period. Annual emission rates from paddy fields composed of Peat soil, Gley soil, and Andosols are estimated at 44.8, 8.0-27.0, and 0.6-12.6 g-CH_4/m^2, respectively. Application of rice straw with rates of 6-9 t/ha increased the CH_4 emission rates by 1.8- to 3.5-fold. The CH_4 production rates of paddy soils measured under the laboratory incubation experiments also showed seasonal variations, which were well correlated with the CH_4 emission rates measured in the paddy fields. These results indicate that the seasonal variations of CH_4 emission from paddy fields to the atmosphere are mainly brought about by the variation of CH_4 production in paddy soils. However, the ratio of the production rates to the emission rates varied among soils, suggesting that physical and chemical properties of soils play a significant role for production and emission of CH_4 in the paddy fields.

Discipline: Agricultural environment
Additional key words: greenhouse effect, methane flux, methanogenesis, organic matter, paddy soil

Introduction

The concentration of atmospheric methane (CH_4) has been increasing at a rate of about 1% per year in recent years. CH_4 has strong influence on the atmospheric chemistry. Because of its infrared absorption spectrum, CH_4 is an important greenhouse gas in the climate system. The rapid increase could therefore be of significant environmental consequence[4].

Most of the atmospheric CH_4 is produced by the bacterial activities in extremely anaerobic ecosystems. It is of a general view that among the wide variety of sources, paddy fields may be an important source of atmospheric CH_4, taking into account the recent increase in their total areas in the world[2]. There are, however, a number of uncertainties in estimating CH_4 emission rates from paddy fields[1]. More information should be accumulated to adequately assess CH_4 production and emission in the paddy fields.

From the above viewpoint, a study on emission and production of CH_4 in the paddy fields has been conducted in Japan since 1988. This report attempts to review the results of the study, including (1) field measurements of CH_4 emission, and (2) a relationship between the observed CH_4 emission under the field condition and the CH_4 production in the soils under a laboratory condition.

Experimental methods

1) Field measurements

Emission rates (fluxes) of CH_4 from paddy fields were measured during the cultivation period at four different sites in the central region of Japan, i.e. Ryugasaki, Kawachi, Mito and Tsukuba. Some soil properties of these sites are listed in Table 1. Successive application of organic matter, such as rice straw and its compost, has been performed at the three sites, for more than 10 years, where the experimental fields for each consist of non-nitrogen, mineral, compost, and rice straw plots. Organic matter was applied at a rate of 12 t/ha to the compost plots, and 6–9 t/ha to the rice straw plots in addition to the mineral fertilizers.

A closed chamber method was used for the measurements of the CH_4 flux from the paddy fields[3,6]. The metal chambers (28.5 cm in diameter, 16.7, 66.0, or 102.0 cm in height) and the sampling system is illustrated in Fig. 1. The CH_4 flux was determined by measuring the temporal increase of the CH_4 concentration of the air within the chamber during the period of 10 min. The air within the chamber was collected in a Tedlar bag (poly-vinyl fluoride bag) and the concentration of CH_4 was determined by a gas chromatograph equipped with flame ionization detector (Shimadzu GC-12A).

2) *Laboratory incubation experiments*

Paddy soil was collected several times during the cultivation period using a stainless core sampler for the measurements of CH_4 production rates in the

Table 1. Soil properties of the paddy fields under study

	Site			
	Ryugasaki[a)]	Kawachi[b)]	Mito[a)]	Tsukuba[a)]
Soil	Gley soil	Peat soil	Humic Andosol	Light-colored Andosol
Texture	SCL	CL	L	L
Percolation rate (mm/day)	10	10	30	30
pH	5.9	5.6	6.5	5.9
Total C (%)	1.4	3.4	6.0	2.2
Total N (%)	0.13	0.26	0.40	0.21
C/N	10	13	15	10
RMC (μgC/g 28 days)[c)]	78.9	232.9	38.3	19.4

a): Data of mineral fertilizer plot, b): Data of rice straw plot,
c): Contents of readily mineralizable carbon.

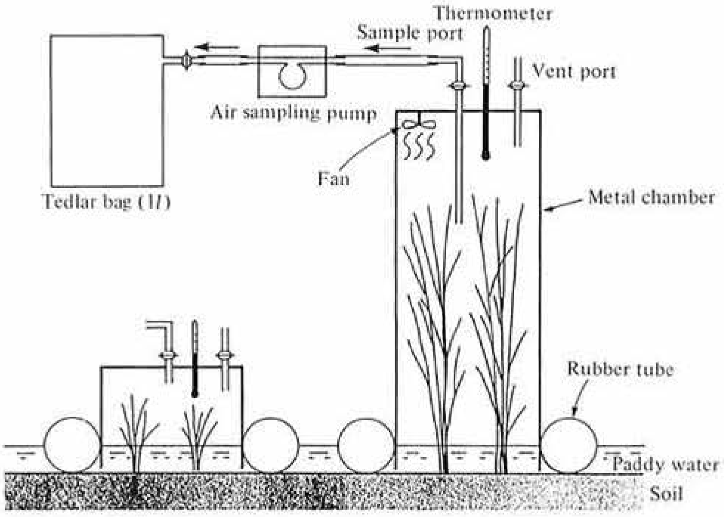

Fig. 1. Schematic illustration of the chambers and the sampling system used for the measurements of the CH_4 flux from paddy fields

soil. After the soil sample was transported at $< 5°C$ to the laboratory, the core was subdivided, and 10–15 g in fresh weight of the soil sample with a depth of 3–8 cm was transferred to a 50 m*l* Erlenmyer flask. The flask was stoppered with a butyl rubber septum, and the atmosphere in the flask was replaced either with H_2–CO_2–N_2 (10:20:70) or with N_2. The flasks were then incubated at 25°C for scheduled periods, and a change of the CH_4 concentraton in the head space was determined by a gas chromatography.

Results and discussions

1) CH_4 emission from paddy fields[6,7]

Seasonal variations of the CH_4 fluxes from the paddy fields in Ryugasaki are shown in Fig. 2, along with the daily mean temperature of soil and air, soil Eh, and the agricultural practices. A strong seasonal variation of CH_4 fluxes from paddy fields was observed during the cultivation period. The CH_4 emission began to increase in accordance with the decrease of the soil Eh in nearly a month after

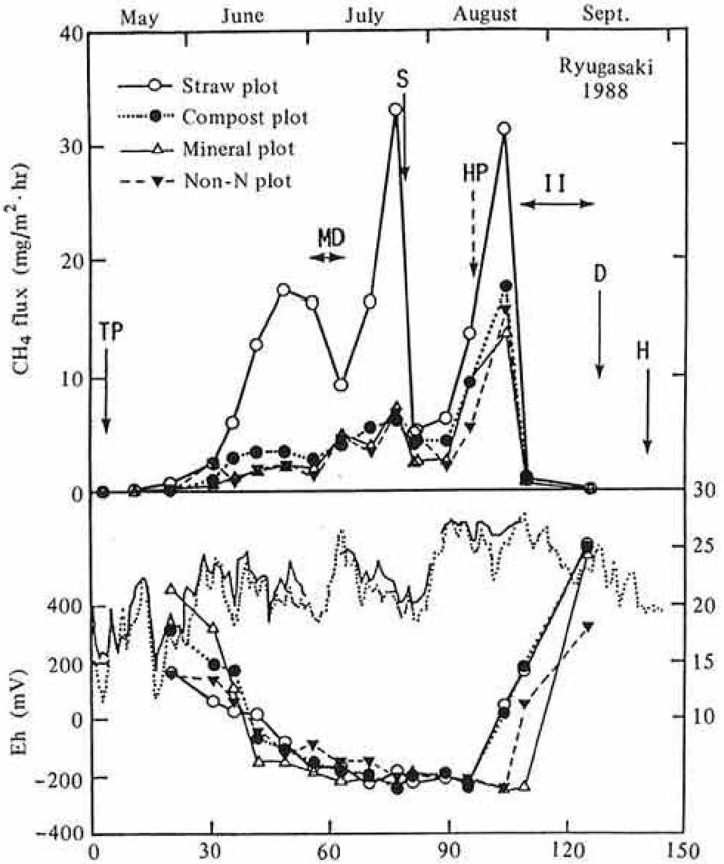

Fig. 2. Seasonal variations of CH_4 flux, daily mean temperature of soil (solid line) and air (dotted line), and soil Eh in the Ryugasaki paddy field

The soil temperature and the Eh at 5 cm depth.

TP: Transplanting, MD: Mid-summer drainage, S: Supplementary application of mineral fertilizer, II: Intermittent irrigation, D: Drainage, H: Harvest, HP: Heading period of rice plants.

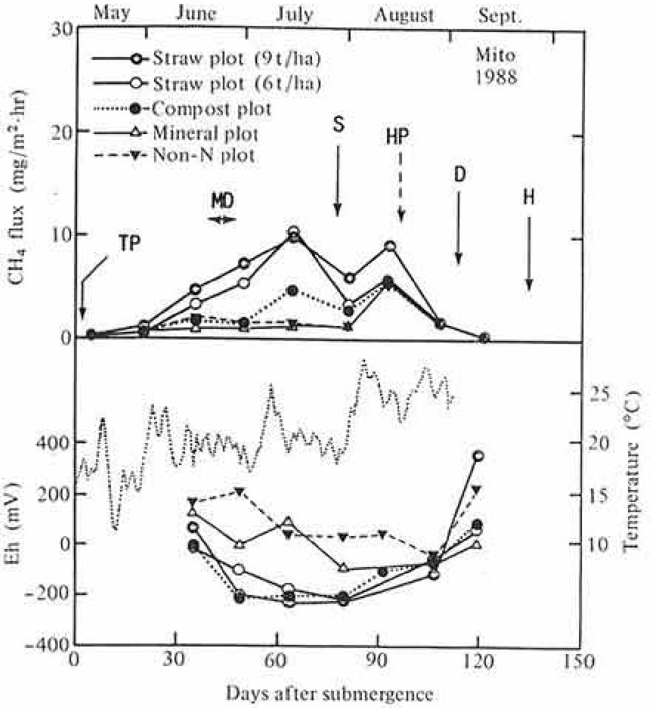

Fig. 3. Seasonal variations of CH_4 flux, daily mean air temperature, and soil Eh in the Mito paddy field
The soil Eh at 15 cm depth.
Arrows: Refer to the notes in Fig. 2.

submergence. Then the fluxes increased as the developing growth of rice plants, though considerable depressions were observed during the period of mid-summer drainage and shortly after the supplementary application of mineral fertilizers, i.e. top dressing. The fluxes rapidly dropped after the paddy field was intermittently drained by interruption of the continuous irrigation at the end of August.

The CH_4 flux from a rice straw plot was much greater than that from the other plots throughout the submerging period. The application of compost prepared from rice straw did not appreciably enhance the CH_4 flux. The differences in the magnitude and the variation of the CH_4 fluxes between the mineral and the non-nitrogen plots were negligible.

Fig. 3 shows the results obtained from various plots of the paddy field in Mito. The trends of the seasonal variations of the CH_4 fluxes and the effects of organic matter application almost corresponded to those observed in Ryugasaki. In addition, the CH_4 flux from the paddy fields increased with the greater amount of rice straw applied. The fluxes in Mito were appreciably smaller as compared to those in Ryugasaki. This is probably due to the relatively higher soil Eh in the Mito paddy field.

In Kawachi, the pattern of seasonal variation of the CH_4 flux was very similar to that observed in Ryugasaki (Fig. 4A). The fluxes were, however, much greater than those from the other sites studied. The CH_4 fluxes observed in Tsukuba remained considerably low throughout the cultivation period.

From the integration of the observed seasonal variations of the CH_4 fluxes, annual emission rates of CH_4 from the individual plots were calculated. The results are listed in Table 2, including also the average and the maximum values of the observed fluxes.

Emission rates of CH_4 greatly varied among the soil types and the organic matters applied. Annual emission rates of CH_4 from the rice straw plots were 44.8, 27.0, 9.8, and 1.1 g/m² per year in the paddies of Peat soil, Gley soil, Humic Andosol, and Light-colored Andosol, respectively. The highest flux was

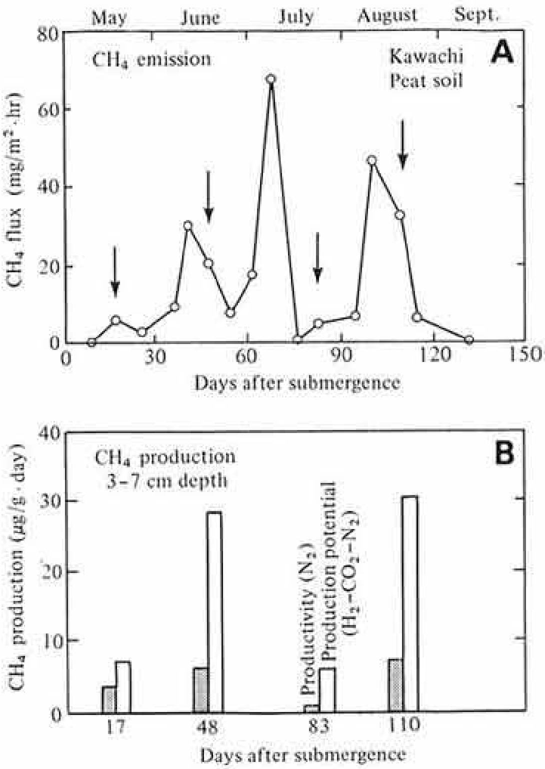

Fig. 4. Seasonal variations of CH_4 flux (A) from and CH_4 production (B) in the Kawachi paddy field The arrows in the figure A indicate the dates of soil sampling for the measurements of CH_4 production.

observed in the paddy field consisting of Peat soil, followed by the Gley soil field. Since the management of irrigation and other cultivation practices in Kawachi were almost the same as those in Ryugasaki, it is very likely that the difference in the CH_4 fluxes at these two sites was caused by the difference in organic matter contents in the soils. The CH_4 fluxes from Andosols were significantly lower.

The application of rice straw to the paddy fields significantly increased the CH_4 emission from paddy fields. Annual emission rates of CH_4 from the plots that had received 6–9 t/ha of rice straw in addition to the mineral fertilizers increased to higher levels approximately 1.8- to 3.5-fold as compared with the mineral fertilizer plots. The annual emission rates of CH_4 from individual plots were positively correlated with the contents of readily mineralizable carbon in paddy soils collected before submergence.

2) *CH_4 production in paddy soils*[7]

Fig. 5 shows temporal changes of CH_4 production in the Ryugasaki paddy soils (collected on June 17, 1988) incubated under H_2–CO_2–N_2 (10:20:70) atmosphere at 25°C. An incubation temperature of 25°C corresponds to a suitable soil temperature observed in the paddy fields of Japan in the summer season. Under that temperature condition, a rapid production of CH_4 was observed during the first 3

Table 2. Methane flux during the cultivation period and annual emission rates from individual plots of paddy fields

Site	Plot	Flux Ave. (mg/m²·hr)	Flux Max. (mg/m²·hr)	Annual emission rate (g/m²·yr)
Ryugasaki	Non-nitrogen	2.8	15.3	8.0
	Mineral	2.9	13.3	8.2
	Compost (12 t/ha)[a]	3.8	17.3	10.5
	Rice straw (6 t/ha)[a]	9.6	32.6	27.0
Kawachi	Rice straw (6 t/ha)[a]	16.3	67.2	44.8
Mito	Non-nitrogen	1.4	5.1	4.1
	Mineral	1.2	5.7	3.6
	Compost (12 t/ha)[a]	1.9	5.7	5.9
	Rice straw (6 t/ha)[a]	3.2	10.2	9.8
	Rice straw (9 t/ha)[a]	4.1	8.9	12.6
Tsukuba	Mineral	0.2	0.5	0.6
	Rice straw (6 t/ha)[a]	0.4	0.7	1.1

a): Organic matter was applied in addition to the mineral fertilizer.

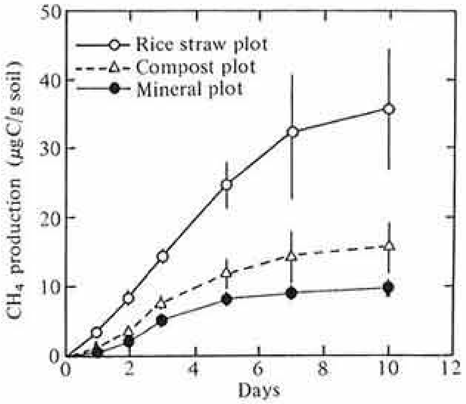

Fig. 5. CH$_4$ production in the Ryugasaki paddy soils
The soil samples were collected on June 17, 1988 and incubated under H_2-CO_2-N_2 (10:20:70) atmosphere at 25°C.
Bars indicate the deviation between duplicated treatments.

Table 3. Correlation coefficients among CH$_4$ flux, CH$_4$ production potential (MPP), and CH$_4$ productivity (MP)

	Site (Soil)		
	Ryugasaki (Gley soil)	Mito (Andosols)	Kawachi (Peat soil)
Number of data	16	20	4
	— Correlation coefficient (r) —		
MPP-flux	0.88***	0.87***	0.96*
MP-flux	0.91***	0.77***	0.91
MPP-MP	0.88***	0.95***	0.87

*, **, *** 5, 1, 0.1% confidence level, respectively.

days. The production rate in this period is defined as CH$_4$ production potential (MPP). The MPP indicates a potential activity of CH$_4$ production in paddy soils incubated in the presence of the additional substrates, H_2 and CO_2, for methanogenesis. In the case of incubation under N_2 atmosphere, the production rates of CH$_4$ were almost linearly increased during the period of 28 days. This rate is defined as CH$_4$ productivity (MP). The MP indicates an indigenous activity of CH$_4$ production in the respective paddy soils.

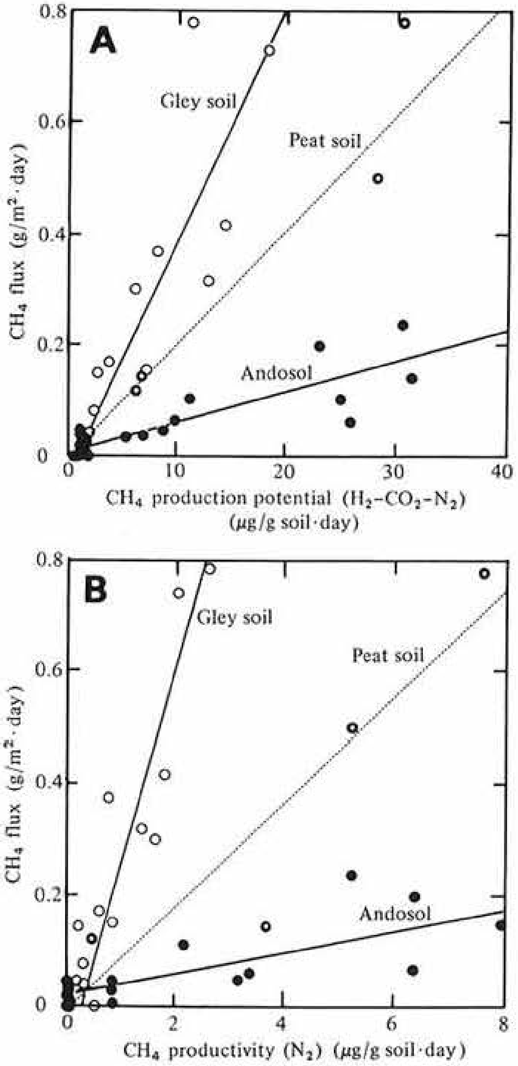

Fig. 6. Relationships between the CH$_4$ production in and the CH$_4$ emission from paddy fields of Gley soil (Ryugasaki), Peat soil (Kawachi), and Andosols (Mito)

The MPP of paddy soils collected from the rice straw plots was always higher than that from the compost and the mineral fertilizer plots, as shown in Fig. 5. The MPP also showed strong seasonal variations, corresponding closely to the seasonal variations of CH$_4$ fluxes measured in the paddy fields. An example of Kawachi Peat soil is shown in Fig. 4. The soil samples were collected at 17, 48, 83 and 110 days after submergence. The seasonal changes of the MPP and the MP were very close to those of the CH$_4$ flux.

In Fig. 6, the MPPs and the MPs of paddy soils of Ryugasaki Gley soil, Kawachi Peat soil, and Mito Andosols are plotted against the CH$_4$ fluxes measured at the same day when the soil samples were colleced. In the individual sites, the MPPs and the MPs are well correlated with the CH_4 fluxes (Table 3). The results indicate that there is a close relation between the CH_4 production in and the emission from paddy fields. And they suggest that the seasonal variations of CH_4 emission from paddy fields to the atmosphere be mainly caused by the variations of CH_4 production in paddy soils. However, the gradient of the regression lines widely varied among the soils. The high ratio of the emission rates to the production rates in Ryugasaki Gley soil indicates that the environment in the soil is much more favorable for CH_4 production than the other soils. In the Mito Andosols, however, the production seems to be suppressed. The relatively higher redox potential in the Andosols due to rapid percolation possibly contributes to the lower CH_4 emission.

Conclusions

Following are the results of the field measurements and the laboratory incubation experiments pertaining to the emission and production of CH_4 from the paddy fields located in the central part of Japan: (1) emission rates of CH_4 from paddy fields were fluctuated with varying soil types, organic matter applications, and agricultural practices; (2) seasonal variations of CH_4 emission from the paddy fields were related to the variations of CH_4 production in the paddy soils; and (3) the ratio of the emission rates to the production rates varied among the soils, suggesting that physical and chemicial properties of soil have a significant effect on production and emission from paddy fields.

In estimating a global contribution of rice cultivation to the atmospheric increase in CH_4, a great number of detailed field data of CH_4 emission, especially in tropical Asia, would be required. However, it is very difficult to take continuous flux measurements at many sites simultaneously, because they are laborious work. From this viewpoint, information on the CH_4 production of paddy soils under laboratory experiments would help effectively provide useful indications on the emission rates of CH_4 from paddy fields.

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