Methane Emission from Paddy Fields in Northeast Thailand

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Received Junuary 13, 1999

Abstract

Seasonal variations of CH_4 flux, soil Eh and soil temperature were measured in paddy fields at Khon Kaen and Surin for the major and the second rice*. The average values of the fluxes measured for the major rice at Khon Kaen and Surin were 19.8 and 13.3 mg m^{-2} h^{-1}, respectively, and for the second rice 15.1 and 15.4 mg m^{-2} h^{-1}, respectively. High CH_4 emission for the major rice at Khon Kaen was due to the high content of fresh organic matter, deep water depth and soil itself which has a low oxidizing capacity and low clay content. Moreover, the comparatively low CH_4 flux recorded during the 67-day period after flooding in the major rice at Surin was caused by the decomposition of the easily decomposable part of fresh organic matter before flooding.

The estimated seasonal emission rates of CH_4 for the major rice at Khon Kaen and Surin were 61.3 and 39.3 g m^{-2}, respectively, and for the second rice 34.8 and 44.4 g m^{-2}, respectively. Total CH_4 emission from Thai paddy fields was estimated to be 3.7 Tg $year^{-1}$ when the total paddy area was taken into consideration.

* Wet season rice cropping and dry season rice cropping are hereadter referred to as "major rice"and "second rice", respectively.

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Additional key words: fresh organic matter, global warming, methane flux, paddy soil, sandy loam soil

Introduction

To estimate the CH_4 flux in Thailand accurately, Yagi *et al.*[12] carried out measurements of CH_4 fluxes from rice paddy fields in the central plain of Thailand. They reported the presence of seasonal variations of CH_4 fluxes in Suphan Buri, Khlong Luang, and Chai Nat. The low emission rates of CH_4 at the latter two sites were attributed to the high concentration of sulfate in soil or the high soil Eh due to the lower abundance of the reducing capacity in relation to the oxidizing capacity of soil.

JIRCAS-DOA collaborative research was initiated in 1993. Katoh *et al.*[3] reported CH_4 flux from rice paddy fields at Bang Khen, Thailand. They observed a relatively low emission of CH_4 in the second rice in 1993 and 1994 with an average flux of 4.3 and 6.7 mg m^{-2} h^{-1}. The low emission rates of CH4 in the second rice were attributed to the very shallow water depth, whereas the average CH4 flux values in the second rice at Phrae and San Pa Thong were 15.8 and 8.8 mg m^{-2} h^{-1}, respectively[4]. Higher CH_4 emission from Phrae than that from San Pa Thong paddy fields was attributed to the high content of fresh organic matter and abundant water supply.

The northeastern region accounted for 56 and 12% of the total rice harvested area of Thailand in 1993 for the major and second rice, respectively. These data indicate that the northeastern region is an important area for the estimation of CH_4 emission from the paddy fields of Thailand.

In this paper, we report the results from the measurements performed in Khon Kaen and Surin paddy fields. We also tried to estimate the total CH_4 emission from paddy fields in Thailand based on a series of field measurements and the area of rice fields.

Experiments

1) Experimental sites and methods

Field measurements were performed at Khon Kaen and Surin Rice Experimental Stations of the Department of Agriculture. These two sites are located in the northeastern region of Thailand. Soil properties, analyzed by the methods which were described previously[12], are shown in Table 1. The soils of Khon Kaen and Surin are Roi Et soil with a

Table 1. Some properties of the paddy soil

	Khon Kaen	Surin
Series	Roi Et (Re)	Roi Et (Re)
Taxonomy	Aeric Paleaquults	Aeric Paleaquults
Texture	sandy loam	sandy loam
pH (air-dried soil)	5.8	4.5
pH (flooded soil)	6.8	6.6
Total C (g kg^{-1})	0.53	0.49
Total N (g kg^{-1})	0.02	0.03
Available N (μg N g^{-1})*	37	35
Free Fe_2O_3 (g kg^{-1})	0.1	0.8
ER Mn (μg g^{-1})**	37	34
SO_4^{2-} (μg S mL^{-1})	trace (<1)	trace (<1)

*Easily reducible manganese.

sandy loam texture and are classified as Aeric Paleaquults. Roi Et soil covers 30% of the paddy area and accounts for the largest distribution of paddy fields in Thailand. This soil is extremely low in clay content, total carbon and total nitrogen contents and plant nutrients.

The field was irrigated prior to transplanting and surface paddy water was maintained at depth ranging between 0 and 20 cm until the maturation stage of rice plants. Rice varieties used, duration of the flooding period and dates of flooding, transplanting, drainage and harvest are listed in Table 2. Rice plants (*Oryza sativa*) were cultivated according to the conventional method. After the harvest of the previous crop, the roots, weeds and approximately half of the aboveground biomass of rice plants were plowed back into the paddy fields. In the Khon Kaen paddy field, organic matter was incorporated into the soil once a few days before flooding, while twice before flooding in the Surin paddy field. The rate of mineral fertilizer applied (basal fertilizer and topdressing) and rice yields are shown in Table 3.

2) Sampling and determination of CH_4 emision, soil temperature and redox potential (Eh)

The closed chamber method was used for gas sampling from paddy fields as described by Yagi and Minami[10, 11]. Methane concentration was measured by gas chromatography (GC/FID). Soil temperature and soil redox potential (Eh) were measured by the methods described in a previous paper[12]. Eleven and thirteen measurements were performed during the cultivation period for the 1993 major rice (August to November) at Khon Kaen and Surin, respectively. Eleven and fifteen measurements were performed for the 1994 second rice (January to May) at Khon Kaen and Surin, respectively. All the measurements were performed in duplicate in the morning (8:00-11:00).

Table 2. Cultivation practices and rice variety

Site	Year	Rice cultivation	Flooding	Trans-planting	Drainage	Harvest	Floofing period (days)	Rice variety '
Surin								
	1994	Major	25 Jun	1 Aug	31 Oct	16 Nov	129	KDML105
	1995	Second	17 Jan	10 Feb	24 May	31 May	127	RD23
Khon Kaen								
	1994	Major	27 Jun	19 Jul	10 Nov	23 Nov	137	RD23
	1995	Second	18 Jan	19 Jan	21 Apr	28 Apr	93	RD23

Table 3. Fertilizer and rice yield

Site	Year	Rice cultivation	Basal fertilizer ($kg\ ha^{-1}$) N	P_2O_5	K_2O	Topdressing N ($kg\ ha^{-1}$)	Rice yield ($Kg\ ha^{-1}$)
Khon Kaen							
	1994	Major	40	40	20	20	3410
	1995	Second	40	40	20	20	Not recorded
Surin							
	1994	Major	20	20	20	19	3940
	1995	Second	25	25	12.5	0	3270

Results and Discussion

1) Methane emission from Khon Kaen paddy field

Seasonal variations of CH_4 flux, soil Eh and soil temperature in a paddy field for the major rice at Khon Kaen are shown in Fig. 1. Methane flux ranged from 14.1 to 29.4 mg m^{-2} h^{-1}, with an average value of 19.8 mg m^{-2} h^{-1}. Soil temperature measured at a depth of 5 cm ranged from 23 to 30℃, with an average value of 27.7℃. Soil Eh measured at a depth of 5 cm ranged from -209 to -266 mV, with an average value of -243 mV.

Seasonal variations of CH_4 flux, soil Eh and soil temperature in a paddy field for the second rice at Khon Kaen are shown in Fig. 2. Methane flux ranged from 0.3 to 22.6 mg m^{-2} h^{-1}, with an average value of 15.1 mg m^{-2} h^{-1}. Soil temperature measured at a depth of 5 cm ranged from 22 to 30℃, with an average value of 27.1℃. Soil Eh measured at a depth of 5 cm ranged from -15 to -280 mV, with an average value of -246 mV.

In the Khon Kaen paddy field, plant debris and weeds were incorporated into the field a few days before flooding. The high content of these fresh organic materials in the Khon Kaen paddy field led to a large CH_4 flux at the early stage of rice cultivation. The enhancement of the CH_4 flux by the application of organic matter was also reported by many researchers[2, 5, 8, 10]. Large flux of CH_4 from the Khon Kaen paddy field was maintained until the water was drained. At the early stage of rice cultivation, spontaneous gas evolution may be the dominant pathway of CH_4 from soil to the atmosphere because the aerenchyma of rice plants was not sufficiently developed[4)].

The ratio of the terminal carbon products of organic matter decomposition in anaerobic soil, namely, CO_2 to CH_4, depends on the ratio of the total oxidizing (electron-accepting) capacity to reducing (electron-donating) capacity of the paddy soil. The main chemical species for the oxidizing and reducing capacities in paddy soil are ferric iron (Fe^{3+}) and readily decomposable organic matter, respectively[7)]. The soil characteristics listed in Table 1 show that the soil at Khon Kaen, contained a small amount of free ferric iron and a large amount of available nitrogen, the latter being commonly used as an index of readily decomposable organic matter in soil. Our results suggest that the high CH_4 emission rates from Khon Kaen paddy fields are also due to the large reducing capacity compared to the oxidizing capacity.

2) Methane emission from Surin paddy field

Seasonal variations of CH_4 flux, soil Eh and soil temperature in the paddy field for the major rice at Surin are shown in Fig. 3. Methane flux ranged from 0 to 28.2 mg m^{-2} h^{-1}, with an average value of 13.3 mg m^{-2} h^{-1}. Soil temperature measured at a depth of 5 cm ranged from 23 to 31℃, with an average value of 28℃. Soil Eh measured at a depth of 5 cm ranged from -55 to -344 mV, with an average value of -166 mV.

Seasonal variations of CH_4 flux, soil Eh and soil temperature from a paddy field for the second rice at Surin are shown in Fig. 4. Methane flux ranged from 2.3 to 27.0 mg m^{-2} h^{-1}, with an average value of 15.4 mg m^{-2} h^{-1}. Soil temperature measured at a depth of 5 cm ranged from 19 to 30℃, with an average value of 26.1℃. Soil Eh measured at a depth of 5 cm ranged from 117 to -226 mV, with an average value of -132 mV.

Methane flux from 0 to 67 days after flooding was below 10 mg m^{-2} h^{-1} for the major rice, except for one site at 60 days after flooding. Soil Eh was always higher than -200 mV during this period. The seasonal pattern of CH_4 emission from the Surin paddy field was quite different from that from the Khon Kaen paddy field. A similar tendency was observed for both CH_4 flux and soil Eh in the second rice. This difference may be ascribed to the difference in the organic matter treatment prior to field flooding. Rice stubbles and weeds present on the fields were incorporated twice in the Surin field, while they were incorporated a few days before flooding in the Khon Kaen field. These organic materials in the Surin field are likely to be decomposed more efficiently under aerobic conditions than those in the Khon Kaen field.

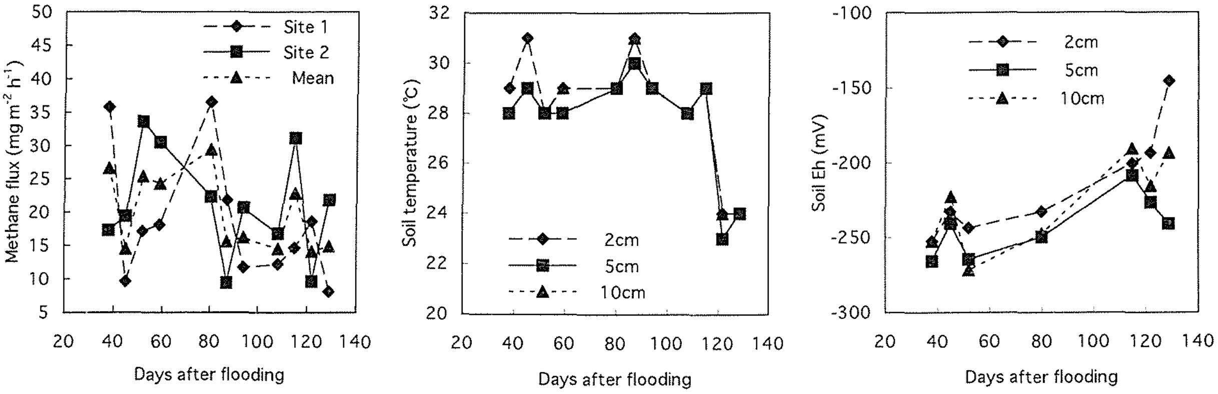

Fig. 1 Methane flux, soil temperature and soil Eh in Khon Kaen paddy field (1994 major rice)

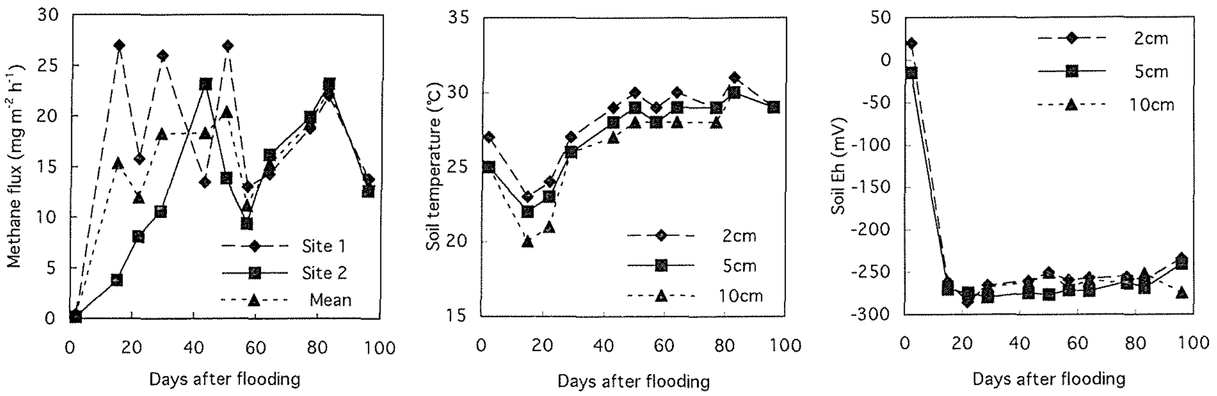

Fig. 2 Methane flux, soil temperature and soil Eh in Khon Kaen paddy field (1995 second rice)

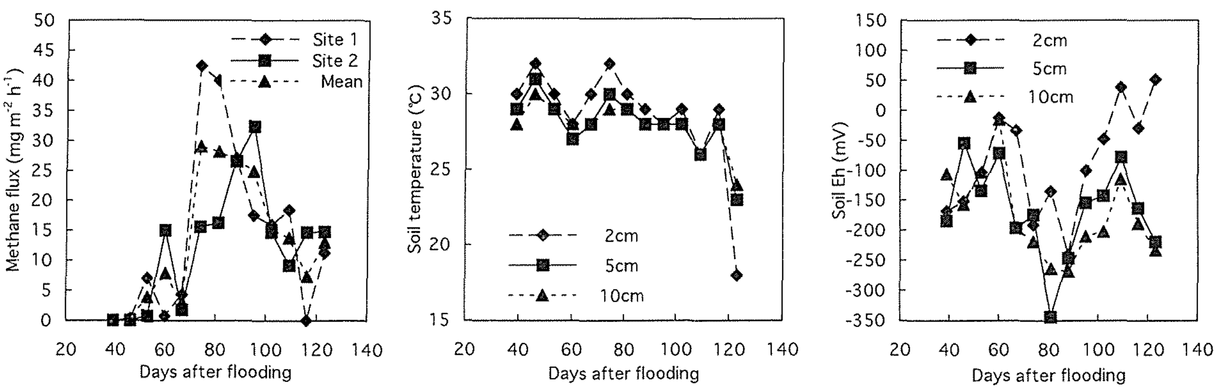

Fig. 3 Methane flux, soil temperature and soil Eh in Surin paddy field (1994 major rice)

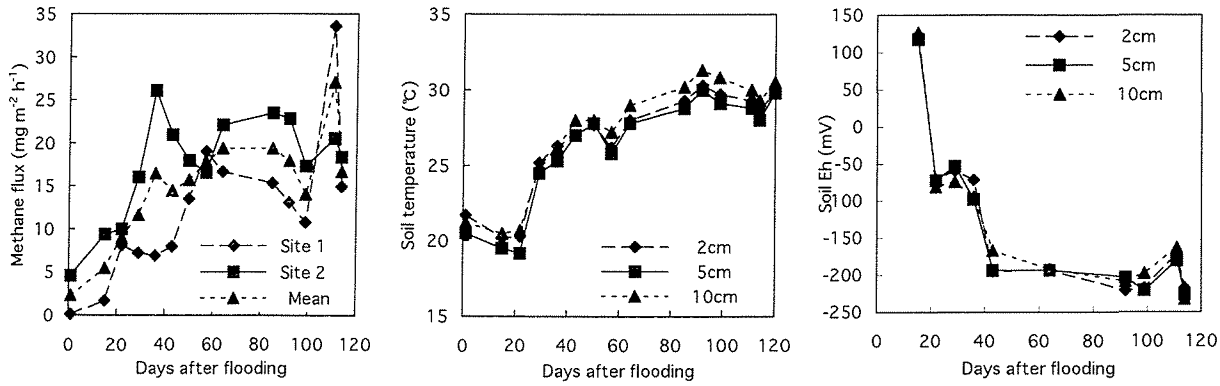

Fig. 4 Methane flux, soil temperature and soil Eh in Surin paddy field (1995 second rice)

Thus the longer duration of the incorporation period of organic matter before flooding may account for the low CH_4 emission in the Surin paddy field. Such a practice which promotes aerobic decomposition of fresh organic matter before flooding is one of the most effective and practical options to mitigate CH_4 emission from paddy fields as suggested by many researchers[6, 9, 13]. Another possible explanation would be the difference in the free iron content between the two paddy soils. The higher content of free iron in the Surin soil possibly required a longer period of time to develop strictly anaerobic conditions in soil, which in turn caused the longer initial stage with low CH_4 flux after the soil was flooded.

3) Estimation of seasonal CH_4 emission

The flux data, estimated seasonal emission rates of CH_4 and yield of rice grain from Khon Kaen and Surin paddy fields are summarized in Table 4. The seasonal emission rates were estimated by multiplying the averaged flux and duration of the flooding period. The estimated seasonal emission rates at Khon Kaen and Surin for the major rice were 61.3 and 39.3 g m^{-2} and for the second rice 34.8 and 44.4 g m^{-2}, respectively. The high emission rate of CH_4 for the major rice at Khon Kaen was attributed to the longer duration of the flooding period and high CH_4 flux values.

4) Estimation of total CH_4 emission rates from paddy fields in Thailand

Table 5 shows the duration of the flooding periods, average CH_4 flux and estimated seasonal emission rates. Seasonal emission rate was calculated by using the following equation;

Estimated seasonal emission (g m^{-2} flooding period^{-1})

= CH_4 Flux (mg m^{-2} h^{-1}) x flooding period (days) x 24(h) x 1000

Since the average seasonal emission rates for the major and second rice in Thailand were 41.8 and 26.9 g m^{-2} flooding period^{-1}, respectively and the paddy area of the major and second rice in 1991 was 83 x 10^9 m^2 and 7 x 10^9 m^2, respectively[1], the estimated seasonal emission rates for the major and second rice were 3.5 and 0.2 tera gram season-1, respectively. Therefore, the total CH_4 emission rates from Thai rice fields were 3.7 tera gram year-1. However, this estimated seasonal emission may possibly be overestimated because all the flux measurements were performed in experimental fields under controlled irrigation and higher rates of fertilization which resulted in a higher plant biomass as well as higher grain yield than in the farmers' fields. Large input of fresh organic matter into the experimental fields may possibly lead to a higher emission rate of CH_4 than the average value of that in farmers' fields. A long history of large organic matter input may increase the labile pool of

Table 4. Seasonal emission of CH_4 from thai paddy fields

Site	Year	Rice cultivation	Flooding period (day)	CH_4 flux ($mg\ m^{-2}\ hr^{-1}$)	Estimated seasonal emission ($g\ m^{-2}\ seaseon^{-1}$)
Khon Kaen					
	1994	Major	129	19.8	61.3
	1995	Second	96	15.1	34.8
Surin					
	1994	Major	123	13.3	39.3
	1995	Second	120	15.4	44.4

Table 5. Seasonal emission retes of methane from Thai paddy fields

Site	Year	Rice cultivation		Flooding period (day)	CH_4 flux ($mg\ m^{-2}\ hr^{-1}$)	Estimated emission Second	seasonal ($g\ m^{-2} seaseon^{-1}$) Major
Khon kaen							
	1991	Major	*1	97	16.4		50.8
	1991	Second	*1	109	19.4	38.2	
Khlong Lugang							
	1991	Second	*1	83	3.1	6.1	
Chai Net							
	1991	Major	*1	94	1.1		2.5
Bang Khen							
	1992	Major	*2	106	21.8		55.5
	1992	Second	*2	120	4.3	12.4	
	1994	Second		118	6.7	19.0	
Phitsanulok							
	1992	Major	*3	98	7.4		17.4
	1993	Second	*3	113	6.6	17.9	
San Pa Thong							
	1993	Major	*3	103	16.1		39.8
	1994	Second	*3	101	8.8	21.3	
Phtae							
	1993	Major	*3	128	22.2		68.2
	1994	Second	*3	127	15.9	48.5	
Khon Kaen							
	1994	Major	*3	129	19.8		61.3
	1995	Second	*3	96	15.1	34.8	
Surin							
	1994	Major	*3	123	13.3		39.3
	1995	Second	*3	120	15.4	44.4	
		Mean				26.9	41.8

*1 Yagi et al. (1994).
*2 Katoh et al. (1999a)
*3 Katoh et al. (1999b)

soil organic matter which also increases CH_4 emission. Detailed studies on organic matter dynamics in farmers' fields and its influence on CH_4 emission should be carried out to verify this assumption.

Conclusion

For Thailand which is a major rice-exporting country, it is essential that rice production be maintained at a comparatively high level. To achieve this objective, agricultural practices such as flooding of the rice fields, incorporation of organic materials into soils to preserve the soil fertility, etc. are likely to be applied. However, such practices have been found to lead an increase in the emission rates of methane which plays a major role in global warming. Therefore, the mitigation of methane emission should be actively promoted through the implementation of measures compatible with sustainable production of rice, including water management through intermittent drainage of flooded paddy fields; reduction of the amount of labile organic matter in soils through the composting of fresh organic matter; selection of rice variety associated with lower rates of methane emission as other cultural practices[13].

Acknowledgments.

We thank Kunnika Naklang of Surin Rice Experiment Station and Miss Somjit Khonthasuvon of Khon Kaen Rice Experiment Station and the staff of the Department of Agriculture for their assistance in the field experiments. We also thank the editorial secretary for their useful advice on editing the draft and correcting English.

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東北タイにおける水田からのメタン発生

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摘　要

東北タイのKhon KaenおよびSurinの水田圃場において，雨季作および乾季作での水稲栽培期間中のメタンフラックス，土壌Eh，および地温の季節変動の測定を行った。雨季作栽培期間中のメタンフラックスの平均値は，Khon KaenおよびSurinで，それぞれ，19.8および13.3 mg m^{-2} h^{-1}であり，乾季作栽培期間中のそれらは，それぞれ，15.1 および15.4 mg m^{-2} h^{-1}であった。雨季作における，両水田のフラックスの違いは，土壌の新鮮有機物含量，田面水位，および酸化容量や粘土含量など土壌の理化学生の違いによると考察された。特に，Surinの雨季作における，湛水後67日間の低いフラックスは，湛水前に新鮮有機物の易分解性画分の多くが分解されたためと考えられた。

季節変動の測定より見積もられた栽培期間全体のメタン発生量は，雨季作において，Khon KaenおよびSurinで，それぞれ，61.3および39.3 g m^{-2}であり，乾季作では，それぞれ，34.8および44.4 g m^{-2}であった。本プロジェクトにおける一連の調査結果から，タイ全体の水田からのメタン発生量は3.7 Tg $year^{-1}$であると見積もられた。

キーワード：新鮮有機物，地球温暖化，メタンフラックス，水田土壌，砂壌土

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