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Methane emission from flooded rice fields under irrigated conditions

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Abstract In a study on CH_4 emission from flooded rice fields under irrigated conditions, fields planted with rice emitted more methane than unplanted fields. The CH_4 efflux in planted plots varied with the rice variety and growth stage and ranged from 4 to 26 mg $h^{-1}m^{-2}$. During the reproductive stage of the rice plants, CH_4 emission was high and the oxidation power of rice roots, in terms of α-naphthylamine oxidation, was very low. The CH_4 emission reached a maximum at midday and declined to minimum levels at midnight, irrespective of the rice variety. The peak CH_4 emission at midday was associated with higher solar radiation and higher soil/water temperature.

Key words Methane emission · Flooded rice field Varietal variation · Root oxidase activity · Diurnal variation

Introduction

Flooded rice paddies, an ecologically important and predominantly anaerobic ecosystem, are a major source of atmospheric CH_4 (Hogan et al. 1991; Neue 1993), a greenhouse gas implicated in global warming. More than two-thirds of world rice production is from tropical and subtropical regions. Based on data generated from rice-field measurements in Europe and the United States of America, and then extrapolated to Indian conditions, CH_4 emission from Indian rice fields contributed 37.8 Tg CH_4 $year^{-1}$ (Environmental Protection Agency 1990). However, actual field measurements made during 1989–1990 in selected rice-growing areas of India showed that CH_4 emissions amounted to 3 Tg $year^{-1}$ (Mitra 1992). In 1991, a national CH_4 campaign was organised in India by the National Physical Laboratory, New Delhi, in collaboration with more than 15 organizations, to collect data systematically on CH_4 emission from Indian rice fields under different agroclimatic conditions. The present study, conducted partly under this campaign, was concerned with field measurements of CH_4 in irrigated flooded rice fields at the Central Rice Research Institute, Cuttack, Orissa.

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Materials and methods

CH_4 emission from paddy fields was estimated during the wet cropping season (June–October) of 1991 under irrigated conditions. The soil was a Typic Haplaquept (deltaic alluvium) with a sandy, clay loam texture (25.9% clay, 21.6% silt, 52.5% sand; pH 6.2, cation exchange capacity 15 mEq 100 g^{-1}, 0.76% C, 0.09% total N, electrical conductivity 0.6 dS m^{-1}). The field was ploughed, puddled thoroughly to 15 cm in depth, and levelled. Rice plants (24-day-old seedlings) were transplanted at a spacing of 15×20 cm in two plots (6×4 m) for each variety, with two plots left unplanted. Urea (40 kg N ha^{-1}) was applied to all the plots, as 50% basal and two equal splits of 25% each at maximum tillering and panicle initiation. All the field plots were continuously flooded to a water depth of 10±2 cm during the entire period of crop growth. Rice varieties with different durations of growth, Annada (90 days), Ratna (120 days); IR-36 (125 days), and Gayatri (160 days), were used in this study.

Water depth and flux-chamber air temperatures were recorded with each set of emission measurements. Minimum and maximum temperatures of soil (3–4 cm below soil surface) and water (3–4 cm above soil surface) were continuously monitored in the fields. The pH of soil and water was monitored with a portable pH meter (Barnant Company, Illinois, USA) during each emission measurement. Daily maximum and minimum air temperatures, the barometric pressure, and daily precipitation were recorded by the weather station at the institute. Daily solar radiation was measured by a solarimeter (ATC Corporation, Tokyo, Japan).

CH_4 emission from the rice fields was monitored as described previously (Parashar et al. 1991). Aluminium bases (57 cm in length, 37 cm wide, and 10 cm in height, with a channel to accommodate perspex chambers) were installed manually at the measurement sites well in advance (at least 12 h before sampling). Six plant hills were enclosed inside the aluminium base. A perspex chamber (53×37×71 cm, length×width×height) was placed in the grooves of the aluminium base to cover the rice hills entrapped within the aluminium base. With the open end of the perspex chamber resting on the aluminium channel and water in the channel, the air inside the chamber was isolated from outside atmosphere and the system was air-tight. A battery-operated air-circulation pump (pulse pump with a flow rate of 1.5 liters min^{-1}, obtained from M/s Aerovironment Inc., Monrovia, Calif., USA) connected to polyethylene tubing was used to mix the air inside the chamber and to draw the air samples into Tedlar air-sampling bags (M/s Aerovironment Inc., USA) at fixed intervals of 0, 15, and 30 min (Parashar et al. 1991). Temperature fluctuations inside the perspex chamber during the sampling period were recorded using a thermometer fixed at the top of the perspex chamber.

Air samples were analysed for CH_4 in a Varian 3600 gas chromatograph equipped with a flame ionization detector and a molecular sieve of 5 Å. Column, injector, and detector temperatures were maintained at 80, 100, and 90 °C with a flow rate of high-purity Ar as the carrier gas at 30 ml min^{-1}. The gas chromatograph was calibrated before and after each set of measurements using 1 ppm CH_4 in N_2 obtained from M/s Mathesons, USA, as a primary standard, and 1.94, 4.4, and 10.9 ppm CH_4 in N_2 as secondary standards. Under these conditions, the retention time of CH_4 was 0.65 min and the minimum detectable limit was 0.5 ppm.

Root oxidase activity, as measured by the oxidation of α-naphthylamine, was assayed at different rice-growth stages following the method of Ota (1970). The rice plants were uprooted and washed several times in water. All operations were carried out with minimum exposure of roots to the atmosphere. The roots were washed in water, cut into 1-cm segments, and squeezed gently with Whatman filter paper no. 1 to remove excess moisture. One gram each of the root tips and root bases separately was incubated with 50 ml α-naphthylamine solution (20 μg ml^{-1}) in a 100 ml Erlenmeyer flask for 3 h on a shaker. One-milliliter aliquots of naphthylamine were treated before and after incubation with 1 ml each of sodium nitrite (100 μg ml^{-1}) solution and 1% sulfanilic acid. The color developed was read at 500 nm on a spectrophotometer after 30–60 min. The root pieces were subsequently dried at 60 °C in a hot-air oven and the dry weight was determined.

Results and discussion

Fields planted with rice emitted distinctly more CH_4 than unplanted fields under irrigated lowland conditions (Table 1). Thus, the CH_4 efflux was about 20 times higher in planted plots than in unplanted plots. However, the emission in planted plots varied from 4 to 26 mg CH_4 m^{-2} h^{-1} depending on the rice variety and growth stage. Of the three varieties used in this study, the maximum efflux was noticed in plots planted with Ratna followed by Annada and IR-36. The rice fields used in this study were subjected to puddling, a cultural practice used in transplanted rice cultivation. Puddling may decrease the downward percolation of water containing dissolved O_2 and hasten the anaerobiosis favorable for methanogenesis while decreasing the gas exchange between soil and atmosphere (Sharma and DeDatta 1985). While diffusing upwards CH_4 may get oxidized in the aerobic surface soil layer (Holzapfel-Pschorn et al. 1985). This would explain the low CH_4 emission from the unplanted flooded plots. However, presence of rice plant increased the emission of CH_4. There is evidence that the rice plant helps in transporting CH_4 trapped in deeper subsurface soil layers to the atmosphere (Nouchi et al. 1990).

Rice plants can transport molecular O_2 from the atmosphere through foliage to the root region. A positive O_2 flux in the root region and root oxidase activity can be used as an index of the oxidation status of the rice rhizosphere (Armstrong 1969). Since methanogenesis is a strictly anaerobic process and methanogens are inhibited by O_2 (Zeikus 1977), we measured the root oxidase activity (in terms of α-naphthylamine oxidation) in comparison with the CH_4 efflux in flooded rice fields.

α-Naphthylamine oxidase activity in rice roots was very pronounced during the early growth stages of the rice plants, but declined to negligible or undetectable levels at panicle initiation or heading stages (Table 2). Moreover, apical regions of the roots registered distinctly higher (fivefold or more) α-naphthylamine oxidase activity than the basal portions, especially during the vegetative phase. In later growth stages, α-naphthylamine oxidase activity declined to undetectable (Annada) or negligible (Ratna) levels, even in the apical region. The presence of some activity in the root-tip of the Ratna (120-day duration), and not Annada (90-day duration) rice plants at 70

Table 1 Time-course of CH_4 efflux from flooded rice paddy, values are means ± SD of four replicates. Figures in parentheses indicate days after transplantation for planted treatments (*ND* not determined)

Days after flooding	CH_4 efflux (mg m^{-2} h^{-1})						
	Unplanted	Planted					
		Annada		Ratna		IR-36	
22 (20)	1.09±0.02	16.99±2.49	1[a]	ND	1	7.41±2.25	1
32 (30)	0.89±0.1	10.04±1.10		26.59±1.38		11.22±3.24	
42 (40)	0.83±0.04	15.04±0.57	2	26.56±1.29		8.05±1.22	
52 (50)	2.93±0.10	14.07±1.14		11.39±1.84		9.18±0.96	
62 (60)	0.75±0.02	5.68±0.76	3	20.38±2.61	2	ND	2
77 (75)	ND	ND		10.83±5.07		9.72±1.50	
85 (83)	2.10±0.10	4.11±0.24		ND	3	6.09±0.92	3
97 (95)	ND	ND		7.07±2.97		ND	

[a] Growth stages: *1* maximum tillering, *2* Panicle initiation and flowering, *3* Grain filling and maturity

Table 2 α-Naphthylamine oxidase activity in rice roots. Values are means ± SD of two replicates

Varieties	Growth stage	Naphthylamine oxidized ($\mu g\ g^{-1}$ dry weight root h^{-1})	
		Root base	Root tip
Annada	Seedling (25 days)	929 ± 23	3385 ± 0
Ratna	Seedling (25 days)	970 ± 23	2669 ± 423
Annada	Panicle initiation 70 (days)	0	0
Ratna	Maximum tillering (70 days)	0	254 ± 80

days of growth may have been related to the longer duration of the former variety. Evidently, the rice rhizosphere is subjected to more intense reducing conditions during the reproductive phase, favoring the formation of CH_4. The emission of CH_4 was also considerable during the early growth stages of the rice plants, although root oxidase activity was high and total root biomass (1.03 g $hill^{-1}$ at tillering stage compared to 4.09 g $hill^{-1}$ at panicle initiation stage) was low. This may have been due to rapid anaerobic decomposition of soil organic matter immediately after soil submergence (Delwiche and Cicerone 1993) and subsequent transport of this CH_4.

The CH_4 emission from plots planted with Gayatri and Ratna rice plants reached the maximum around midday and declined to minimum levels at midnight (Fig. 1). The atmospheric emission of CH_4 is influenced by many factors, such as solar radiation, temperature, and pH (Lindau et al. 1993; Yagi and Minami 1993). In the present field study solar radiation and soil and water temperatures peaked between 12 noon and 2 p.m. The soil temperature increased from 28 °C at 6 a.m. to 30 °C at midday while the temperature of the standing water in the rice fields increased from 27 °C at 6 a.m. to 32 °C at midday. Diurnal variation in CH_4 emission has been strongly correlated with soil temperature (Sass et al. 1991). The pH of the standing water of the rice paddies increased from 7.0 at 6 a.m. to as high as 9.5 at 2 p.m. Possibly, peak CH_4 emissions at midday were favored by higher levels of solar radiation, soil temperature, and pH.

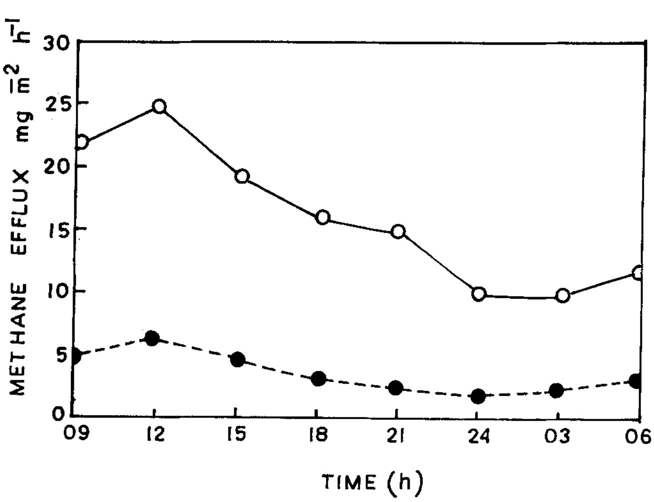

Fig. 1 Diurnal variation in CH_4 efflux in a flooded soil planted with two different rice varieties (Ratna ○——○; Gayatri ●- - -●)

The CH_4 efflux from continuously submerged rice fields in the present study was in the range 4–26 mg h^{-1} m^{-2}, which is equivalent to 0.7–4.7 $\times 10^9$ g ha^{-1} per cropping season (calculated for 75 days of continuous flooding). Of the 42 million ha under rice cultivation in India, only 16.4 million ha is irrigated. Of the remaining area under rain-fed conditions, 5.9 million ha is upland and 19.7 million ha is lowland. In rain-fed lowland areas, the rice fields are not always inundated. Thus, in rain-fed lowland areas, the CH_4 efflux over a rice cropping season may be less pronounced than in continuously submerged rice fields. Even under continuously submerged conditions, CH_4 emission from alluvial soil (organic C 0.76%), as used in the present study, is considerably lower than the predicted estimates of the United States Environmental Protection Agency (1990).

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