Biol Fertil Soils (1997) 25:285–289

ORIGINAL PAPER

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Methane emission from two Indian soils planted with different rice cultivars

Received: July 7, 1996

Abstract In a greenhouse study, methane emissions were measured from two diverse Indian rice-growing soils planted to five rice cultivars under similar water regimes, fertilizer applications and environmental conditions. Significant variations were observed in methane emitted from soils growing different cultivars. Total methane emission varied between 8.04 and 20.92 g m^{-2} from IARI soil (Inceptisol) and between 1.47 and 10.91 g m^{-2} from Raipur soil (Vertisol) planted to rice. In all the cultivars, emissions from IARI soil were higher than from Raipur soil. The first methane flux peak was noticed during the reproductive phase and the second peak coincided with the grain-ripening stage of the rice cultivars.

Key words Methane emission · Wetland soils · Greenhouse gases · Inceptisol · Vertisol · Rice · *Oryza sativa*

Introduction

Wetland rice fields are considered to be the major biogenic source of methane. Rice plants play an important role in the emission of methane to the atmosphere by acting as a conduit for the transfer of methane from soil to the atmosphere. Root exudates and root mass undergoing senescence form an important source of carbon for methane production (Ghosh et al. 1994). It is plausible that the amount of methane transferred through different rice cultivars will vary due to variations in their morphological characteristics. Also differences in the amount and nature of root exudates produced by different rice cultivars are likely to influence the amount of methane generated as the root exudates serve as carbon source for soil microorganisms including methanogens (Raimbault et al. 1977). The magnitude of methane emission from rice paddies is also influenced by soil type (Neue and Roger 1993; Minami 1994). Development and adoption of rice cultivars transporting a lesser amount of methane is the most attractive mitigation option because of the relative ease of its adoption at the farmers' level. The investigation was therefore designed to obtain information on the characterization and quantification of methane emission from two Indian soils planted with five different rice cultivars.

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Materials and methods

Experimental set-up

The experiment was conducted during the wet season (July to November) of 1994 in the greenhouse of the Indian Agricultural Research Institute (IARI), New Delhi. The surface soils (0–15 cm depth) were collected from the Research farms of IARI, Delhi and Indira Gandhi Agricultural University, Raipur (Madhya Pradesh). Both soils were air dried, ground to pass through a 0.1-cm mesh sieve and 4 kg of each soil was added to glazed pots 25 cm in height and 15 cm in diameter.

The soils were inundated with tap water and stirred to simulate puddling and allowed to stand for 24 h prior to transplanting with rice cultivars. Twenty-day-old rice seedlings (three seedlings per hill) were transplanted in each pot in a completely randomized design with three replications. Three pots containing each soil were left unplanted and kept as controls. Each pot received N (90 mg N kg^{-1} soil) as urea in two split doses (half of which was applied as a basal dose 1 day before transplanting and the remaining half applied 40 days after transplanting). Each pot also received P (40 mg P_2O_5 kg^{-1} soil as single superphosphate), K (40 mg K_2O kg^{-1} soil as muriate of potash) and 10 mg Zn kg^{-1} soil using zinc sulphate as basal dose. A water layer of 5 cm was maintained in all the pots throughout the growth period. Five rice varieties, namely Pusa-33, Pusa-169 and Pusa Basmati-1 (all from Indian Agricultural Research Institute, Delhi), Kranti and Shyamla (from Raipur, Madhya Pradesh), were planted. These varieties differed in growth characteristics and maturity period.

Soil analysis

The IARI farm soil was well-drained old alluvium (Inceptisol) and was classified as a member of the coarse sandy loam, non-acidic, mixed hypothermic family of the type Ustochrept. The other soil was a Vertisol with clay loam texture. The soil samples of the experimen-

Table 1 Physicochemical characteristics of the soils

	IARI (Inceptisol)	Raipur (Vertisol)
pH (1:2.5 w/v H_2O)	7.8	8.0
Organic carbon (%)	0.32	0.50
Available N (kg ha^{-1})	210	204
Available P (kg ha^{-1})	8.7	8.1
Available K (kg ha^{-1})	140	460
DTPA extractable		
Fe (mg kg^{-1})	4.1	5.6
Cu (mg kg^{-1})	1.5	1.3
Mn (mg kg^{-1})	11.9	9.0
Texture	Sandy loam	Clay
Sand (%)	70.4	27.1
Silt (%)	11.0	13.8
Clay (%)	18.6	59.1

Table 2 Total methane emission and dry matter production from five rice cultivars grown on two soils. In parentheses is the growth duration of the crop

Cultivar	Flooding period (days)	Methane (g m^{-2})		Dry matter (g pot^{-1})	
		IARI	Raipur	IARI	Raipur
Pusa-33	91 (100–110)	20.92	3.37	39	26
Pusa-169	107 (125)	16.25	2.75	36	23
Pusa-Basmati-1	120 (135)	14.46	10.91	31	24
Shyamla	120 (135)	8.31	1.47	22	17
Kranti	107 (125)	8.04	1.53	34	22
Uncropped	120	3.14	0.37	–	–

tal set up were analysed by standard methods of analysis. The organic carbon in the soil was determined by the wet digestion method outlined by Walkley and Black (1934). Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija 1956). Olsen's method (Olsen et al. 1954) was followed for the estimation of available phosphorus. Available potassium was estimated by flame photometer (Hanway and Heidel 1952). The diethylenetriaminopentoacetic acid (DTPA) method was adopted for the estimation of Fe, Mn and Cu (Lindsay and Norvell 1978). The soil texture was determined by the hydrometer method (Bouyoucas 1962). The physicochemical characteristics of the soils are given in Table 1.

Methane emission measurements

Methane emission measurements were undertaken from each pot from day 1 after transplanting the seedlings up to 120 days after transplanting (DAT) i.e. 5 days before harvest. Gas samples were collected once a day between 1100 and 1200 hours at intervals of 3–4 days using the closed chamber technique described by Hutchinson and Mosier (1981). The closed chambers (10×10 cm, 60 cm in height) were made of acrylic (Perspex) sheet and the joints were sealed with silicone grease to make them leak proof. The acrylic chambers were placed over the aluminium jackets (10×10×10 cm, with a water channel 1 cm wide to accommodate the acrylic chambers) preinserted into the soil to a depth of 5 cm in each pot well in advance (1 day before sampling) to ensure a minimum disturbance to the soil at the time of gas collection in the chambers. The water seal surrounding the acrylic chamber in the channel made the system airtight. Gas samples from each pot were drawn at 0-, 10- and 20-min intervals after installation of the chamber using an airtight syringe (capacity 20 ml). Immediately thereafter, a slightly higher sample volume of gas (about 15 ml) was transferred to a pre-evacuated Vacutainer (capacity 12.5 ml) closed with an airtight rubber stopper by hypodermic needle (26 gauge) to maintain a higher pressure than the atmosphere to avoid contamination or dilution of the collected sample. Mixing of the gas inside the chamber was achieved during sampling by drawing air out of the chamber headspace into a syringe and releasing it back into the chamber (8–10 times) before the final sample was withdrawn. The samples were analysed by gas chromatograph (HP 5890 Series II) fitted with flame ionization detector (FID) and Porapak N column (stainless steel column, 180 cm long and 0.31 cm outside diameter). Column, detector and injector temperatures were maintained at 70, 130 and 130 °C, respectively. Nitrogen was used as the carrier gas, hydrogen as the fuel gas and zero air as the supporting gas with flow rates of 20, 30 and 250 ml min^{-1}, respectively. Using a gastight disposable syringe (Dispovan), a 5-ml gas sample containing methane was introduced into the gas chromatograph fitted with a fixed volume sample loop (1 ml). The retention time of methane was 1.9–2.2 min. The concentration of methane in a sample was determined by calculating from the standard curve obtained by injecting standard gas mixtures containing the known concentration of methane under the same set of conditions. The GC was calibrated periodically using gas mixtures having methane concentrations from 2 to 150 µl l^{-1} prepared from 0.5% methane in nitrogen standard by static dilution technique. The column was periodically heated to 250 °C for 15–20 min to remove possible contamination of the associated gases such as water vapour, CO_2, and other hydrocarbons which reduce the activity of the column due to their adsorption at 70–80 °C. The flux measurement was then calculated by using the equation:

$$[\{(C_t - C_o) \times AH\}/A \times t] \text{ ml m}^{-2} \text{ h}^{-1} \quad (1)$$

or

$$[\{(C_t - C_o) \times AH\}/A \times t] \times 16/22.4 \text{ mg m}^{-2} \text{ h}^{-1} \quad (2)$$

where C_t = concentration of methane at time t, C_o = concentration of methane at time o, t = time interval, A = area of the gas chamber and H = height of the headspace.

Redox potential (*Eh*) and pH measurements

The redox potential (*Eh*) was measured on the day of gas sampling using a battery-operated pH cum millivoltmeter (Century CP 901). The glass electrode was replaced by a platinum microelectrode specially prepared in the laboratory. The platinum tip was inserted into each pot under investigation at the root zone (5 cm depth) throughout the growing season whereas the reference electrode (calomel) was placed at the surface only to maintain electrical contact (Ponnamperuma 1972). Sufficient time (8–10 min) was given for the millivolt reading to become stabilized before recording it. The pH of the submerged soil was measured using a portable pH meter (Systronics Griph 'D' pH Meter Model 327). All analyses were done in triplicate and the means were taken as representative values for methane flux, *Eh* and pH.

Results

The data on methane emission flux from different cultivars and the variation in soil redox potential (*Eh*) in two soils are shown in Fig. 1. Variations in the methane emissions from two soils growing in different rice cultivars were observed. Two maximum methane flux peaks were recorded from cropped soils (Fig. 1). During the early period of plant growth soon after transplanting methane was emitted at a lower rate and was nearly the same as observed in uncropped soil.

The methane emissions during the early growth period varied in the range 0.01–4.58 mg m^{-2} h^{-1} (IARI soil) and 0.01–1.22 mg m^{-2} h^{-1} (Raipur soil). Methane emission in-

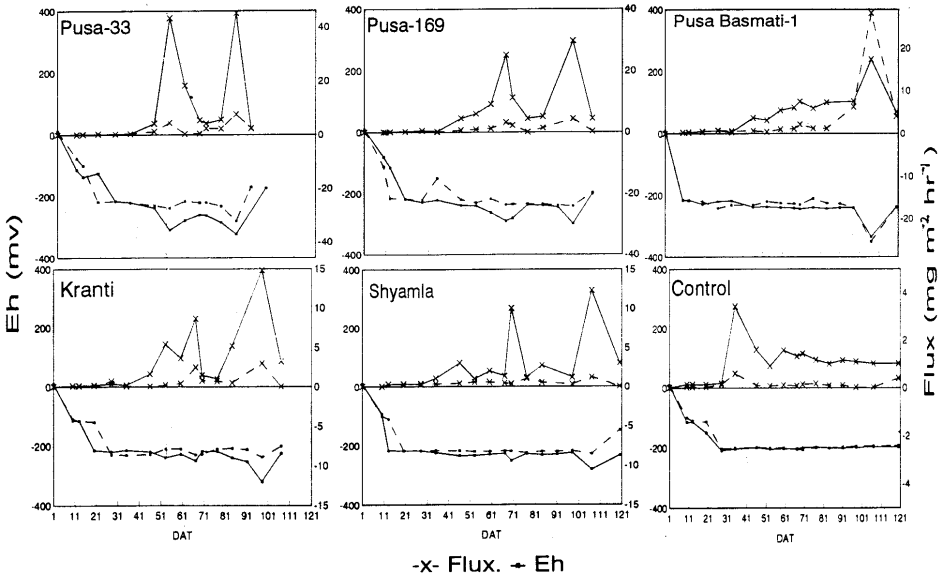

Fig. 1 Methane flux and redox potential (*Eh*) in IARI (–) and Raipur (- - -) soils planted to five rice cultivars

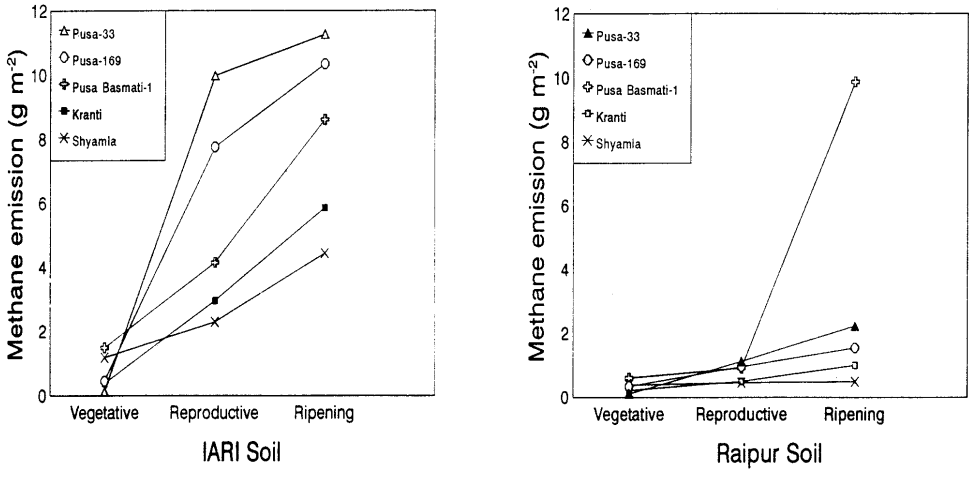

Fig. 2 Cumulative methane emission from different growth stages of rice cultivars

creased during the reproductive stage and was highest in the grain ripening period of all the five cultivars grown in the two soils (Fig. 2). The cumulative emission during the vegetative stage of the rice plant was consistently low, varying between 0.13 and 1.49 g m^{-2} from the IARI soil and 0.11 and 0.61 g m^{-2} from the Raipur soil. The emission was appreciably high during the ripening stage (4.44–11.27 g m^{-2} from the IARI soil and 0.49–2.26 g m^{-2} from the Raipur soil). Emission during the ripening period amounted to more than 50% of the total methane emitted during the cropping season from all the cultivars planted in the two soils. The appearance of the two maximum methane flux peaks varied among the different rice cultivars having varying growth periods. The first maximum methane emission peak appeared between 53 and 70 DAT, corresponding to the reproductive stage of the rice cultivars grown on both soils, Inceptisol (IARI) and Vertisol (Raipur). The second methane flux peak in the case of the different cultivars in the two soils coincided with the grain ripening stage (84–107 DAT). Variation in methane emissions was also observed among rice cultivars grown in the same soil. The total methane emission from the IARI soil (Inceptisol) planted with different cultivars ranged between 8.04 and 20.92 g m^{-2} and was a maximum from variety Pusa-33 followed in the order Pusa-169>Pusa-Basmati-1> Shyamla>Kranti. In the Raipur soil (Vertisol), the emission varied from 1.47 to 10.91 g m^{-2} and was in the order: Pusa-Basmati-1>Pusa-33>Pusa-169>Kranti>Shyamla.

The amount of methane produced and emitted from the two soil types planted with the same cultivar was highly variable. The total methane emitted from the IARI soil (Inceptisol) planted with var. Pusa-33 was 20.92 g m^{-2} while the methane emission from the Raipur soil (Vertisol) with the same cultivar was 3.37 g m^{-2} during the flooding period of 91 days. Similar variations in methane emission were recorded among the other cultivars. Methane emission was found to be greater in the case of varieties having comparatively higher aboveground biomass in all the treatments with the exception of var. Shyamla, which emitted more methane even though it had less aboveground biomass.

The soil redox potential (*Eh*) measured on the day of gas sampling exhibited the lowest values, varying between –205 and –310 mV. The variation in *Eh* during the cropping period in the two soils planted with five cultivars is shown in Fig. 1. The soil *Eh* showed the characteristic steady drop after submergence, attaining the *Eh* value below –200 mV within 3–4 weeks after transplanting. Thereafter the redox potentials were fairly stable over the remainder of the growing season. The soil *Eh* values were low in IARI soil compared with the Raipur soil. The uncropped soils exhibited higher *Eh* values as compared with cropped soils.

The pH of the soils planted with different cultivars ranged between 7.0 and 8.5 throughout the growing period. The lowest pH (6.5) was recorded at 28 DAT, which later tended to reach near neutrality and attained the highest pH (8.5) with prolonged submergence. The soil pH of the uncropped soil remained mostly between 8 and 8.5 without much fluctuation.

Discussion

Methane emission peak during very early stages of growth has been reported by some workers and is attributed to the decomposition of available organic matter in soil (Holzapfel and Seiler 1986). However, no such peak was observed in our experiment, which is plausible since the soils used were very low in organic matter and there was no decaying organic matter present in the soils, which otherwise is normally incorporated in the field crop during land preparation. The methane emission rates varied considerably during the growth period of the rice plant. Low methane emissions during the early growth stages of the rice plant are due to low levels of methanogenesis and poor conduction of methane from the bulk soil to the atmosphere. Relatively low production rates of methane early in the vegetation period have also been observed in slurry experiments (Shutz et al. 1989). Rice plants provide substrates for methanogenic bacteria through root exudation or decaying matter during senescence (Raimbault et al. 1977). The higher rates of methane production during the reproductive and ripening phase are due to the degradation of the available organic carbon in the form of root exudates. The emergence of the first and second maxima of methane flux during the reproductive and ripening phase of the rice plant are thus due to the higher rates of methane production, which in turn is due to availability of organic substrates in the form of root exudates and the intensive reducing conditions in the rice rhizosphere. The second methane flux peak during the grain ripening stage is attributed to the availability of additional organic matter for methanogenic bacteria in the form of sloughed off root cap cells and dead microbial material (Raimbault et al. 1997). The variations in methane production and emission from soils planted with different rice cultivars are in agreement with the findings reported by other researchers (Kludze et al. 1996).

The root exudates have been implicated to be the major source of methane in rice, and a considerable variation in the root exudate pattern of different rice varieties exists (Ghosh 1994). The carbohydrates lost from the plant roots vary among different rice cultivars (Ladha et al. 1986). The variation in downward transport of oxygen in different rice varieties could also cause changes in emission of methane (Yoshida 1981). The combination of various factors such as the supply of organic matter, size of the root space and oxidation rate in the rhizosphere have been identified to affect the methane emission rates from various rice cultivars (Watanabe and Kimura 1996).

The differences in methane emission from two soil types planted with the same cultivar are attributed to soil characteristics. Soils with a high clay content and organic matter are generally more prone to methane emission than soils with a sandy and silty texture (Neue et al. 1990). The low emission from the Raipur soil (Vertisol) may possibly be due to methane being trapped in the soil thereby slowing down the release of methane to the atmosphere (Wang et al. 1993). The differences in methane emission from two soil types planted with the same rice cultivar could be assigned to the different texture of the two soils. The cultivar Shyamla emitted more methane than var. Kranti although it produced less aboveground biomass. This could be due to the longer growth period of Shyamla (135 days) compared to var. Kranti (120 days). A similar observation has also been recorded for a long-duration variety, Ratna, which emitted more methane than Ananda, a short-duration variety (Adhya et al. 1994). The soil *Eh* was negatively correlated with methane emission in all treatments. The soil *Eh* influences methane flux from rice in two ways. Firstly, it directly determines the amount of methane production in the soil and, secondly, it initiates morphological and physiological changes in the rice plant that affect gas exchange between the soil and the atmosphere (Kludze et al. 1993). The pH values were favourable for methanogenesis.

Acknowledgement The first author (S. S.) thanks the Indian Council of Agricultural Research for the award of a Junior Research Fellowship during the tenure of which the present investigation was carried out.

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