Methane efflux from rice-based cropping systems under humid tropical conditions of eastern India


Laboratory of Soil Microbiology, Division of Soil Science & Microbiology, Central Rice Research Institute, Cuttack-753006, India

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Abstract

Tropical rice paddy is considered to be one of the major anthropogenic source of atmospheric methane (CH\textsubscript{4}). In a field study spread over the dry and wet seasons of a calendar year, the CH\textsubscript{4} emission from upland (oilseseed and pulse) crops in the dry season and a succeeding lowland rice (O\textit{ryza sativa} L.) crop in the wet season was compared with rice–rice rotation in both seasons under flooded conditions. Cumulative CH\textsubscript{4} flux from the upland crop followed by lowland rice crop was low (12.52–13.09 g CH\textsubscript{4} m\textsuperscript{-2}) compared to that of the rice–rice rotation (39.96 g CH\textsubscript{4} m\textsuperscript{-2}). What was particularly interesting is that the seasonal mean CH\textsubscript{4} emission from the lowland rice in wet season preceded by an upland crop in dry season was low when compared to that of lowland rice in wet season preceding a dry season flooded rice. Results indicate that the cumulative CH\textsubscript{4} emission from tropical rice ecosystem can be lowered by growing suitable upland crops to reduce the period that rice paddies are submerged during an annual cropping cycle. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Methane efflux; Flooded rice; Upland crops; Cropping system; Wet season; Dry season

1. Introduction

Methane (CH\textsubscript{4}), the most abundant gaseous hydrocarbon, is a radiatively important trace (RIT) gas implicated in global warming. Flooded rice paddies, characterized by predominantly anaerobic conditions, are considered as one of the major anthropogenic sources of CH\textsubscript{4}. It has been proposed that Indian rice paddy, representing some 28% of world’s rice growing area, is one of the major contributors to atmospheric CH\textsubscript{4} (Bachelet and Neue, 1993). Indeed US-EPA estimates, based on data derived from studies in USA, Europe and Japan, indicate that Indian rice fields should contribute 37.8 Tg CH\textsubscript{4} per year (US-EPA, 1990). However, actual measurements of CH\textsubscript{4} emission from flooded rice fields of India have been repeatedly scaled down from their initial high values; the low estimates being strongly influenced by low emissions measured in Indian rice fields (Crutzen, 1995). The detailed studies of the CH\textsubscript{4} emission data, from 46 integrated seasons from 20 locations spread all over India under ‘National Methane Campaign’ upto 1995 and 44 integrated (1993–1998) seasons from four rice growing centers under ICAR-AP Cess
fund project, indicate that the mean annual CH$_4$ emission from irrigated and rainfed lowland rice system in India is likely to be in the range 2.8–5.3 Tg with a mean value of about 4.1 Tg CH$_4$ per year (Mitra, 1992; Adhya et al., 1994; Parashar et al., 1997).

CH$_4$ emission from rice paddy is determined by a large number of factors which include soil type, pH, redox potential, temperature, water regime, fertilizer, sulphate content, rice cultivars and cultural practices used in rice cultivation (Neue et al., 1997; Sass and Fisher Jr, 1997). In a rice-based cropping system, rice is normally rotated with upland crops such as wheat, oilseed and pulse crops. A dryland crop grown in rotation with rice allows the soil to be dried and thus helps in protecting the succeeding lowland rice crop from toxicity associated with continued flooding (Ponnampерuma, 1978). The most common upland crops grown in rotation with rice are corn, bean, cow pea, wheat, mustard, soybean and lentil (Morris et al., 1986; Sharma et al., 1995). Such crop rotation may reduce CH$_4$ emission from lowland rice grown after an upland crop and also help achieve the desired goal of increasing net food production and productivity (Neue, 1993) as compared to a rice–rice rotation alone. In a field study spread over dry (Rabi) and wet (Kharif) seasons in a calendar year, experiments were conducted to monitor CH$_4$ emission from upland crops vis-à-vis lowland rice paddy in a rice–rice rotation.

2. Materials and methods

2.1. Field experiments

Field experiments were conducted during the dry (January–May) and wet (July–December) seasons of 1997 in the experimental plots of Central Rice Research Institute, Cuttack, India. The farm is situated at 20°25’N latitude and 85°55’E longitude. Mean rainfall during the dry and wet seasons was 85 and 1352 mm, respectively. The monthly mean maximum and minimum temperatures were in the range 26.5–37.7°C and 12.7–26.7°C, respectively. The mean sunshine hours during dry and wet seasons were 8.1 and 5.8 h per day, respectively. The soil is a typic haplaquept (deltaic alluvium; FAO, Gleysol) with a sandy clay-loam texture (pH 6.2, clay 259 g kg$^{-1}$, silt 216 g kg$^{-1}$, sand 525 g kg$^{-1}$, organic matter 15.5 g kg$^{-1}$, total N 0.9 g kg$^{-1}$, SO$_4$–S 36.5 g kg$^{-1}$, Olsen’s P 8 g kg$^{-1}$) (Adhya et al., 1994).

2.2. CH$_4$ efflux from upland crop-rice rotation

The field experiments were conducted during the calendar year of 1997 covering both dry and wet seasons. As in the previous years, hot and humid climate with heavy rains was the characteristic feature during the year 1997. The mean meteorological parameters including sunshine (hour), pan evaporation and relative humidity measurements for the year were within the statistical variability limits for the last 30 years with only a marginally high rainfall than the previous years (CRRI, 1998).

Measurement of CH$_4$ flux from upland crops was conducted during the dry season. After the wet season (Kharif) rice crop, the field was ploughed thoroughly to 20 cm depth, breaking up any large clods, and the surface was levelled. The experiment was laid in a randomized block design in field plots (5 m × 5 m) with four replicates. The treatment included three upland crops namely mustard (Brassica juncea Czern & Coss.), chickpea (Cicer arietinum Linn.) and blackgram (Phaseolus mungo Linn.). Mustard (cv. PT 303), Chickpea (cv. ICCV 10) and blackgram (cv. T 9) were sown in lines with a plant to plant distance of 15 cm and row to row distance of 30 cm, respectively. Extra plants were thinned out after 15 days of seeding to allow uniform growth of the plants. The crops were irrigated three times at different growth stages to avoid water stress. A basal dressing of nitrogen as urea (20 kg N ha$^{-1}$), phosphorus as single superphosphate (30 kg P ha$^{-1}$) and potassium as muriate of potash (20 kg K ha$^{-1}$) was applied. Standard crop management practices were adopted to grow the crop and the crop was harvested at maturity and grain yields recorded. CH$_4$ flux from the crop stands was measured periodically during crop growth.

After the harvest of the upland crop, rice was grown in the same field plots in the following wet season under rainfed conditions. The field site preparation was the same as described earlier (Adhya et al., 1994). The field was ploughed, puddled thoroughly to 10 cm depth and levelled. Rice seedlings (cv. IR-72, 28 days
old) were transplanted at a spacing of 15 cm × 15 cm in field plots. Further fertilizer was applied at transplanting at a rate of 40 kg N ha⁻¹ as urea, 30 kg P ha⁻¹ as single superphosphate and 30 kg K ha⁻¹ as muriate of potash, respectively. Standard crop management practices were adopted and the crop was raised till maturity. CH₄ flux from the rice crop was measured at regular intervals as described in Section 2.4.

2.3. CH₄ efflux from rice–rice rotation

CH₄ flux from a rice–rice rotation was studied in an adjacent block of field plots. The experiment was conducted in four replicate field plots each measuring 5 m × 5 m. Rice was grown in these plots in both dry (irrigated) and succeeding wet (rainfed) seasons under flooded conditions. The soil characteristics, field site preparation and flooding patterns were the same as mentioned earlier. Rice seedlings (cv. IR-72, 28 days old) were transplanted at a spacing of 15 cm × 15 cm. For dry season crop, phosphorus and potassium at 30 kg ha⁻¹ level were applied as basal. Fertilizer N (as urea) was applied at 80 kg ha⁻¹ in three equal splits at transplantation, maximum tillering and panicle initiation stages, respectively. The crop was flood irrigated to maintain 10±2 cm of standing water throughout the cropping season. For wet season, nitrogen, phosphorus and potassium were applied at the time of transplantation at a rate of 40 kg N, 30 kg P and 30 kg K ha⁻¹, respectively. The crop was grown exclusively under rainfed conditions wherein the floodwater level remained shallow, i.e. 3–15 cm during most part of its growth. Crops in both the seasons were raised till maturity following standard crop management practices and harvested. CH₄ flux from the growing crop was measured at regular intervals as described in Section 2.4. The cropping pattern and the period of submergence in the experimental plots for both dry and wet seasons are indicated in Fig. 1.

2.4. CH₄ flux measurement

CH₄ emission from the crop fields was measured by the closed chamber method (Adhya et al., 1994) at regular intervals from the day of sowing/transplanting till maturity. Samplings for CH₄ flux measurement were made at 09:00–09:30 and 15:00–15:30 hours, and the average of morning and evening fluxes was used as the flux value for the day. For measuring CH₄ emission, aluminium bases (57 cm length × 37 cm width × 10 cm height) with a channel to accomodate perspex chambers were installed manually in the field plots at the measurement sites at the time of planting. Plant hills enclosed inside the aluminium base, were covered with a locally fabricated perspex chamber (53 cm length × 37 cm width × 71 cm height). A battery-operated air circulation pump with air displacement of 1.51 min⁻¹ (M/s Aerovironment Inc., Monrovia, CA, USA), connected to polyethylene tubing was used to mix the air inside the chamber and draw the air samples into Tedlar® air-sampling bags (M/s Aerovironment Inc., Monrovia, CA, USA), at fixed intervals of 0, 15 and 30 min. The air samples from the sampling bags were analyzed for CH₄.

2.5. Estimation of CH₄

The CH₄ was estimated in a Varian GC (model 3600) equipped with FID and a 5 Å molecular sieve. The column, injector and detector temperatures were maintained at 80, 90 and 100°C, respectively. The GC was calibrated before and after each set of measure-
ments using 1 μl CH$_4$ ml$^{-1}$ N$_2$ (M/s Mathesons, USA) as a primary standard and 1.94, 2.60, 4.40 and 10.90 μl CH$_4$ ml$^{-1}$ N$_2$ as secondary standards (National Physical Laboratory, New Delhi). Under these conditions, the retention time of CH$_4$ was 1.35 min and the minimum detectable limit was 0.5 μl ml$^{-1}$. The CH$_4$ concentrations were expressed as mg m$^{-2}$ per day and the data were subjected to statistical analysis by Duncan’s multiple range test.

3. Results and discussion

CH$_4$ emission was very low in all the field plots planted to various dryland crops throughout the cropping period (Table 1). CH$_4$ emission was always less than 3 mg m$^{-2}$ per day from the field plots planted to mustard, chickpea or blackgram. CH$_4$ emission from the field plots peaked at 55 days in case of mustard and chickpea, while in case of fields planted to blackgram, the CH$_4$ emission peak was just before the harvest (80 days). Among the three dryland crops, fields planted to mustard emitted more CH$_4$ than the fields planted to chickpea and blackgram. CH$_4$ fluxes from fields planted to chickpea and blackgram were statistically at par.

After the harvest of the upland crops, CH$_4$ emission from the succeeding lowland rice crop, grown in the same field plots, was studied (Table 1). CH$_4$ emission from lowland rice in a rice–rice rotation was also studied in the adjacent field plot (Table 2). CH$_4$ flux from the lowland rice crop succeeding an upland crop, though substantial, was lower than that from the rice–rice rotation. Rice grown under flooded condition during wet season, emitted marginally higher CH$_4$ flux than the dry season crop. This could be due to lower redox potential in the wet season (data not shown) because of the continuous flooded regime encountered in the rice–rice rotation. The cumulative CH$_4$ emission from rice–rice rotation was higher than that from the upland crop–rice rotation for an equivalent cropping period (Fig. 2). These results indicate the benefit

Table 1

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Days after germination/transplantation$^a$ (mg CH$_4$ formed m$^{-2}$ d$^{-1}$)$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland crop (dry season)</td>
<td></td>
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<tr>
<td>Mustard</td>
<td>1.58$^{a,c}$ 1.07$^a$ 2.92$^a$ 2.47$^a$ 1.98$^a$ - 2.00</td>
</tr>
<tr>
<td>Chickpea</td>
<td>0.25$^b$ 0.22$^b$ 0.86$^b$ 0.42$^b$ 0.39$^b$ - 0.43</td>
</tr>
<tr>
<td>Blackgram</td>
<td>0.18$^b$ 0.23$^b$ 0.23$^a$ 0.23$^a$ 0.94$^a$ - 0.36</td>
</tr>
<tr>
<td>Flooded rice (wet season)</td>
<td></td>
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<tr>
<td></td>
<td>52.32 102.72 114.00 157.20 43.04 21.36 81.77</td>
</tr>
</tbody>
</table>

$^a$ Days after germination for the upland crops and after transplantation for flooded rice. CH$_4$ efflux was measured at 40% moisture holding capacity of the soil for the upland crop and under flooded condition for lowland rice.

$^b$ Mean of four replicate observations.

$^c$ Means in a column followed by the same letter do not differ significantly ($p < 0.05$) by Duncan’s Multiple Range Test (DMRT); values for flooded rice were not used for statistical analysis.

Table 2

<table>
<thead>
<tr>
<th>Crop season</th>
<th>Days after transplanting (mg CH$_4$ formed m$^{-2}$ d$^{-1}$)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry season (Rabi)</td>
<td>43.20$^b$ 51.48$^a$ 40.68$^a$ 137.28$^a$ 337.20$^a$ 237.48$^a$ 84.36$^a$ 38.52a 27.48a 27.48a 110.85</td>
</tr>
<tr>
<td>Wet season (Kharif)</td>
<td>57.72a 89.04b 124.32b 185.88b 383.64b 272.52b 96.36a 58.80a 43.44a 145.75</td>
</tr>
</tbody>
</table>

$^a$ Mean of four replicate observations.

$^b$ Means in a column followed by the same letter do not differ significantly ($p < 0.05$) by Duncan’s Multiple Range Test (DMRT).
Fig. 2. Cumulative CH$_4$ emission during a calendar year from an alluvial field planted to various crop sequences (The bars indicate standard deviation).

of suitable crop options for minimizing the CH$_4$ emission from the rice paddy ecosystem.

Flooded rice fields are considered as one of the major source of anthropogenic CH$_4$ emission to atmosphere. While CH$_4$ production is an anaerobic process, microbial oxidation at the oxic surface of soil–water interface modulates the CH$_4$ flux to the atmosphere (Conrad, 1996). Microbial oxidation of atmospheric CH$_4$ in terrestrial environment is the only known biological sink process that consumes 1–10% of the total global emission (Adamsen and King, 1993). When the submerged fields are drained at maturity of the rice crop, CH$_4$ production is drastically reduced. During the dry fallow period or when a dryland crop is raised, the rice paddy ecosystem can also serve as an effective sink for CH$_4$ by its oxidation to CO$_2$. In a study on CH$_4$ flux from rice/wheat agroecosystem, CH$_4$ was shown to be consumed by soil during the dryland wheat crop and fallow period when soils were relatively dry and oxic — conditions that are favourable for CH$_4$ oxidation (Singh et al., 1996).

Continuous submergence of rice fields is practiced in some tropical areas where irrigation water and the climate allow the cultivation of two or even three crops of rice in a year. Under these conditions, the soils remain constantly reduced leading to higher CH$_4$ emissions (Trolldenier, 1995). On the other hand, growing a dryland crop in rotation with flooded rice, as suggested by Neue (1993), can cause sufficient aeration of the soil and increase the redox potential periodically, that, in turn, may reduce CH$_4$ emission.

4. Conclusion

Technologies suggested for mitigation of CH$_4$ emission from rice fields include crop diversification, improved water management practices to reduce the duration of flooding, introduction of rice cultivars with low CH$_4$ emission rates and the form, amount and mode of fertilizer application. Growing an upland crop alternating with flooded rice not only reduces CH$_4$ flux, but also increases productivity. The present study conducted during a single calendar year covering two cropping seasons suggests that, crop diversification in a lowland rice ecosystem might be considered as a feasible option to reduce total CH$_4$ emission. However, more in-depth studies involving diverse situations and locally suitable cropping systems should be evaluated before being accepted as field-level technology to mitigate CH$_4$ emission.
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References


