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Methane emission from rice fields in relation to management of irrigation water

Author Details

Maninder Kaur Khosa (*Corresponding author*)	Department of Soils, Punjab Agricultural University, Ludhiana - 141 004, India e-mail: manupurba@gmail.com
B.S. Sidhu	Department of Soils, Punjab Agricultural University, Ludhiana - 141 004, India
D.K. Benbi	Department of Soils, Punjab Agricultural University, Ludhiana - 141 004, India

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Abstract

A field experiment was conducted for two years to find out best water management practice to mitigate methane emission from the rice-fields. Continuously flooded conditions yielded two major flushes of methane emission and on an average resulted in relatively higher rate of methane emission (2.20 and 1.30 mg m^{-2} hr^{-1}, respectively in 2005 and 2006) during the kharif season. The methane flux was reduced to half (1.02 and 0.47 mg m^{-2} hr^{-1}, respectively in 2005 and 2006) when rice fields were irrigated 2-3 days after infiltration of flood water into the soil. Irrigating the field at 0.15 bar matric potential reduced seasonal methane flux by 60% (0.99 and 0.41 mg m^{-2} hr^{-1}, respectively in 2005 and 2006) as compared to completely flooded conditions, without any decline in grain yield (60 q ha^{-1}).

Key words

Methane flux, Water regime, Greenhouse gases, Global warming, Rice fields

Introduction

Methane is as an important greenhouse gas which can contribute to global warming. It has the second largest radiative forcing (0.48 Wm^{-2}) after CO_2 (1.66 Wm^{-2}) and contributes some about 16% of the global warming resulting from the increasing concentrations of greenhouse gases in the atmosphere (Nieder and Benbi, 2008). The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 to 1774 ppb in 2005 (IPCC, 2007). Atmospheric methane originates from both natural and anthropogenic sources. More than 50% of the global annual methane emission is of anthropogenic origin and the cultivation of irrigated rice may account for up to 12% of this flux (IPCC, 2007). Recent estimates of methane from rice fields range between 39 and 112 Tg CH_4 $year^{-1}$ (Denman *et al.,* 2007). Using region-specific methane emission factors, Yan *et al.* (2003) estimated the global emission of 28.2 Tg CH_4 $year^{-1}$ from rice fields. Asian region accounts for 25.1 Tg CH_4 $year^{-1}$, of which 7.67 Tg CH_4 yr^{-1} is emitted from China and 5.88 Tg CH_4 $year^{-1}$ from India.

Methane is produced in soils by the microbial breakdown of organic compounds in strictly anaerobic conditions at redox potential less than-150 mV (Wang *et al.,* 1993). Flooded rice fields, characterized by oxygen depletion, high moisture and relatively high organic substrate levels, offer an ideal environment for the activity of methanogenic bacteria. Methane is produced in rice fields after the sequential reduction of molecular oxygen, nitrate, iron (III), manganese (IV) and sulfate, which serves as electron acceptors for oxidation of organic matter to CO_2 (Ponnamperuma, 1972). Rate of methane emission from rice fields is affected by a number of interacting soil, plant, management and climatic factors. A statistical analysis of the methane emission fluxes from rice fields in Asia showed that the average methane flux during the growing season is significantly affected by water management, organic matter application, soil organic carbon content, soil pH, preseason water status and climate (Yan *et al.,* 2005).

Manipulation of the factors that regulate methane emission, particularly water and nutrient management, cultural practices and choice of crop cultivar can help to reduce methane emission from rice fields. Since irrigated rice is considered to contribute about 70-80% of methane emission from global rice fields it provides the most promising target for mitigation strategies (Wassmann *et al.,* 2000). Several studies (Sass *et al.,* 1992; Cai *et al.,* 1994; Wassmann *et al.,* 2000) have shown that proper water management such as midseason drainage and intermittent irrigation is one of the most effective strategies for decreasing methane emission, as it prevents the development of soil reductive condition. Methane flux was almost 10 times more pronounced under continuously flooded conditions than under continuously nonflooded conditions. Intermittently flooded regimes (alternately flooded and nonflooded cycles of 40 or 20 days each) emitted distinctly less methane than the continuously flooded system (Mishra *et al.,* 1997).

One or the multiple drainage systems have been reported to decrease methane emission compared to continuous flooding. Numerous studies reported a significant decrease in methane emission from rice fields that are drained once or several times during the crop cycle (Sass *et al.,* 1992; Cai *et al.,* 1994; Zheng *et al.,* 2000). Mid season drainage has been reported to reduce methane emission by about 50% compared to continuous flooding (Gupta *et al.,* 2002). Tyagi *et al.* (2010) observed that there was 9% less methane flux when dariange was done at tillering stage drainage while mid-season drainage and multiple drainage reduced methane flux by 36.7 and 41%, respectively. Compilation of the published methane emission data from major rice growing areas in Asia showed that the average methane flux with single and multiple drainages were 60 and 52% of that from continuously flooded rice fields (Yan *et al.,* 2005). Suppression of methane production due to field drainage usually persists for quite some times even when fields are flooded again (Yagi *et al.,* 1996).

Punjab is a predominantly agricultural state. Rice-wheat is the dominant cropping system in Punjab with 2.61 m ha area under rice. The rice crop in Punjab currently needs to be irrigated 24 to 28 times. There are 11.9 lakh tube wells, out of which 9 lakh are electrical (Anonymous, 2006). Due to free supply of electricity to farmer's fields, the farmers keep the rice fields continuously flooded, which leads to lowering in redox potential and thus high methane emission from rice fields. In view of this, there is a need to develop inexpensive irrigation water management strategies to mitigate methane emission from rice-fields. The present study was therefore, conducted in rice fields by irrigating the fields at different levels of water regimes.

Materials and Methods

Field experiment was conducted during *kharif* 2005 and 2006 in a semiarid irrigated soil at Punjab Agricultural University, Research farm, Ludhiana. The experimental soil was sandy loam in texture (Typic Ustochrept) and contained 70.6 sand, 17.3 silt and 12.1% clay. The field soil tested 7.4 in pH, 0.46% in organic carbon, 68.7 mg kg^{-1} in available nitrogen and 20.4 mg kg^{-1} in available phosphorus and 66.3 mg kg^{-1} in potassium. The rainfall during rice season (from June to October) in year 2005 and 2006 was 596 and 403 mm, respectively.

Forty days old seedlings of rice variety PR 118 were transplanted in June 2005. The experiment was repeated next year on the same site with the same treatments. Fertilizer nitrogen at 120 kg N ha^{-1} was applied in three equal splits *viz*. at transplanting, 21 and 42 days after transplanting. Fertilizer phosphorus at 30 kg P_2O_5 ha^{-1} and potassium at 30 kg K_2O ha^{-1} were mixed in the soil at time of puddling.

The plots were continuously flooded for first two weeks and then irrigated under six different water regimes *viz.* continuously flooded throughout the cropping season, alternate flooding and draining *i.e.* irrigate the field 2-3 days after flood water has infiltrated into the soil which is a recommended irrigation practice in Punjab, irrigate the field when matric potential reached the value of 0.10, 0.15, 0.20 and 0.30 bar. The matric potential was measured by ceramic porous cup tensiometer fitted at 15 cm soil depth. The plots were irrigated (10 cm irrigation) only after the specified water potential was attained.

Gas samples were collected between 11 am to 12 noon at different growth stages of rice by closed chamber technique. The rice fields were flooded 24 hr before sampling. An aluminium base plate was inserted into the soil 1 hr before placing the chamber in position, to stabilize the soil environment. After 1 hr, the chamber was fixed on aluminium base plate and fan fitted inside the chamber was put on. The gas samples were withdrawn from top of the chamber using 50 ml gas tight syringes at 0, 15 and 30 min after placing the chamber on its place. Methane flux was determined by measuring the temporal increase of the methane concentration of the air within the chamber (Hutchinson and Mosier, 1981).

Gas samples were analyzed using Chrom Pack gas chromatograph (438A model) equipped with flame ionization detector (FID) operated at 150°C. The injection port and the column temperature were 120 and 70°C, respectively. The carrier gas was N_2. The flow rate of N_2, H_2 and air were 20, 25 and 235 ml min^{-1}, respectively. A glass column of 2 m length with internal diameter of 2 mm containing porapak-T (80-100 Mesh) was used to separate methane in the gas samples.

Methane flux for the whole rice growing season (118 days) termed seasonal methane flux (SMF, kg ha^{-1}) was calculated as:

$$\left[D_1 + \frac{(D_2 - D_1)}{2}\right] X\ F_1 + \left[\frac{(D_2 - D_1)}{2} + \frac{(D_3 - D_2)}{2} X\ F_2 + ------+\right]$$

$$\left[\frac{(D_n - D_{(n-1)})}{2} + (118^* - D_n)\right] X\ F_n$$

Where D - Number of days after transplanting
F - Methane flux in kg ha^{-1} d^{-1}

The subscript 1,2.........., n indicate the numher of days after transplanting at 1st, 2nd and nth sampling.

Statistical analysis of experimental data was accomplished by Analysis of Variance in randomized block design using locally developed software (Cheema and Singh, 1990). The difference in mean values of methane emission of different cultivars was tested at 5% level of probability ($p \leq 0.05$) using the least significant difference (LSD) test. Correlation coefficients (*r*-values) were calculated between methane flux and above ground plant biomass.

Results and Discussion

Pattern of methane emission: During both the years methane emission appeared shortly after rice transplanting (Table 1 and 2) as flooding of rice fields created reduced conditions congenial for methane production by reduction of carbon dioxide (Ponnamperuma, 1972;

Table - 1: Effect of water regime on rate of methane emission (mg m^{-2} h^{-1}) from rice fields in year 2005

Treatment	Days after transplanting (DAT)							
	1	10	26	55	82	97	111	Mean
Continuously flooded	0.47	1.72	5.81	2.80	3.67	0.65	0.29	2.20
Alternate flooding-draining	0.67	1.19	1.53	2.40	0.60	0.60	0.17	1.02
0.10 bar matric potential	0.50	1.43	3.26	4.17	0.23	0.21	0.12	1.42
0.15 bar matric potential	0.73	1.49	1.08	2.61	0.42	0.43	0.16	0.99
0.20 bar matric potential	0.78	1.22	1.90	0.76	0.30	0.30	0.15	0.77
0.30 bar matric potential	0.56	1.18	1.48	0.44	0.08	0.07	0.08	0.56
LSD (p=0.05)	Water regime : 0.43			DAT : 0.46		Water regime x DAT : 1.13		

Table - 2: Effect of water regime on rate of methane emission (mg m^{-2} h^{-1}) from rice fields in year 2006

Treatment	Days after transplanting (DAT)								
	11	15	25	31	38	59	82	93	108	Mean
Continuously flooded	0.80	0.65	3.22	2.05	1.13	1.20	2.27	0.11	0.24	1.30
Alternate flooding-draining	0.55	0.55	0.42	0.94	0.43	0.37	0.51	0.26	0.21	0.47
0.10 bar matric potential	0.75	0.63	0.59	1.38	0.63	0.94	0.26	0.20	0.17	0.62
0.15 bar matric potential	0.67	0.52	0.45	0.84	0.29	0.45	0.20	0.14	0.16	0.41
0.20 bar matric potential	0.96	0.56	0.26	0.47	0.38	0.35	0.19	0.15	0.12	0.38
0.30 bar matric potential	0.83	0.59	0.28	0.65	0.15	0.21	0.24	0.08	0.17	0.36
LSD (p = 0.05)	Water regime : 0.15				DAT : 0.19			Water regime x DAT : 0.45		

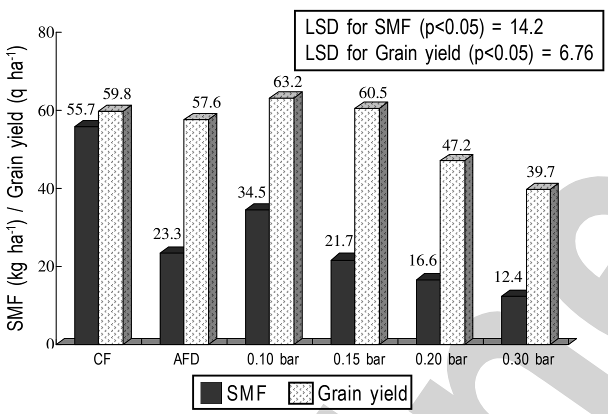

Fig. 1: Effect of water regime on seasonal methane flux (SMF) and grain yield (average of two years)
Where, CF = Continuously flooded, AFD = Alternate flooding and drying, 0.10, 0.15, 0.20 and 0.30 bar matric potential when the field water irrigated

Takai and Kamura, 1966). The average rate of methane emission in kharif 2005 ranged between 0.56 and 2.20 mg m^{-2} hr^{-1} under different water management treatments. The methane emission rate was slightly lower during 2006 and averaged between 0.36 and 1.30 mg m^{-2} hr^{-1} under different treatments. In both the years, the largest methane flux was observed at early growth stage of rice.

In case of continuously flooded conditions two major flushes of methane were detected on 26 and 82 days after transplanting (DAT). The highest rate of methane emission was relatively greater (5.81 and 3.22 mg m^{-2} hr^{-1} in 2005 and 2006, respectively) during the first flush period than during the second flush (3.67 and 2.27 mg m^{-2} hr^{-1} in year 2005 and 2006, respectively). The first flush is governed by methane production from soil organic matter (Neue *et al*., 1994) and the second methane flush is due to increased release of plant-borne carbon sources and increasing capacity of plant-mediated methane emission.

Under alternate flooding and draining condition and at 0.10 and 0.15 bar matric potential only single methane flush was observed at 55 and 31 DAT during 2005 and 2006, respectively. No distinct methane flush was observed under 0.20 and 0.30 bar matric potential. Alternate flooding and draining of rice fields eliminated the second flush of methane because strong anaerobic conditions could not develop under alternate flooded and drained irrigation schedule (Cai *et al*., 1997).

Comparatively higher rates of methane emission (2.20 and 1.30 mg m^{-2} hr^{-1}, in 2005 and 2006, respectively) were observed under continuously flooded conditions than under other water regimes. The mean rate of methane emission under 0.10 bar matric potential was 1.42 and 0.62 mg m^{-2} hr^{-1} in year 2005 and 2006, respectively, which was 42% that of continuously flooded condition. The alternate flooding and draining of the rice field reduced the mean rate of methane emission to half that of continuously flooded condition. The rate of methane emission with alternate flooding and draining of the rice field varied from 0.17 to 2.40 mg m^{-2} hr^{-1} in year 2005 and 0.21 to 0.94 mg m^{-2} hr^{-1} in year 2006. Compared to continuous flooded conditions, the mean rate of methane emission further dropped by 60, 67 to 74% under 0.15, 0.20 and 0.30 bar matric potential, respectively.

Methane flux during whole rice season: Fig. 1 shows the influence of water management practice on seasonal methane flux. Significantly ($p<0.05$) higher amount of methane (55.7 kg ha^{-1}) was emitted when rice field was continuously flooded than other water regimes. There was 37 to 77% reduction in total seasonal methane flux under different water regime than under continuously flooded conditions. Seasonal methane flux was reduced to half (34.5 kg ha^{-1}) when rice fields were alternately flooded and drained. Methane flux was reduced by 38 and 60% by keeping matric potential at 0.10 and 0.15 bar, respectively, without affecting the grain yield. This is attributed to aeration of soil by alternate flooding and draining of the rice fields which increased oxygen supply to the soil and thus inhibiting methane production by methanogens (Wang *et al*., 1999).

Water regime and grain yield: The grain yield was highest under 0.10 bar matric potential (63.2 q ha^{-1}) followed by 0.15 bar (60.5 q ha^{-1}), continuously flooded water regime (59.8 q ha^{-1}), alternate flooding and draining (57.6 q ha^{-1}), 0.20 bar matric potential (47.2 q ha^{-1}) and lowest under 0.30 bar matric potential (39.7 q ha^{-1}). The differences in grain between continuously flooded, 0.1 and 0.15 bar matric potential were statistically non-significant ($p<0.055$). The results showed that compared to continuous flooded conditions seasonal methane flux from rice fields could be reduced by 38 and 61% by applying irrigation at 0.10 and 0.15 bar matric potential without affecting the grain yield. Also, alternate flooding and draining the rice fields reduced the methane from rice fields by half with any reduction in grain yield. Irrigating at 0.20 and 0.30 bar matric potential though decreased seasonal methane flux but these also resulted in 21 and 34% reduction in grain yield. Earlier De Datta (1981) observed that soil water content of -50 kPa (slightly above field capacity) may reduce rice grain yield by 20-25% as compared to continuously flooded treatments. This is due to water stress at different growth stages of rice especially at reproductive stage. Water shortage at this growth stage can cause yield loss by lowering sterility (Yoshida, 1981).

The seasonal methane emission from rice fields range between 2.20 to 0.56 mg m^{-2} h^{-1} depending on water management practices. The results of the present study have shown that methane emission from rice fields can be mitigated by proper management of irrigation water. Irrigation the rice fields at 0.15 bar soil matric potential could minimize methane emission from rice paddies and thus decreased environmental pollution without any loss in rice grain yield.

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