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Effect of organic materials and rice cultivars on methane emission from rice field

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Abstract: *A field experiment was conducted for two years on a sandy loam (Typic Ustochrept) soil of Punjab to study the effect of organic materials and rice cultivars on methane emission from rice fields. The methane flux varied between 0.04 and 0.93 mg m^{-2} hr^{-1} in bare soil and transplanting of rice crop doubled the methane flux (0.07 to 2.06 mg m^{-2} hr^{-1}). Among rice cultivars, significantly ($p < 0.05$) higher amount of methane was emitted from Pusa 44 compared to PR 118 and PR 111. Application of organic materials enhanced methane emission from rice fields and resulted in increased soil organic carbon content. The greatest seasonal methane flux was observed in wheat straw amended plots (229.6 kg ha^{-1}) followed by farmyard manure (111.6 kg ha^{-1}), green manure (85.4 kg ha^{-1}) and the least from rice straw compost amended plots (36.9 kg ha^{-1}) as compared to control (21.5 kg ha^{-1}). The differential effect of organic materials in enhancing methane flux was related to total carbon or C:N ratio of the material. The results showed that incorporation of humified organic matter such as rice straw compost could minimize methane emission from rice fields with co-benefits of increased soil fertility and crop productivity.*

Key words: *Methane flux, Organic materials, Rice cultivar, Greenhouse gases, Global warming*

Introduction

Methane (CH_4) is one of the important greenhouse gases that absorb infrared radiation and increases global mean surface temperature. Methane is present at about 1774±1.8 ppb in the atmosphere (IPCC, 2007). It is primarily a biogenic gas produced in anoxic sediments by the methanogenic bacteria, as the terminal product of organic carbon mineralization (Zehnder, 1978). Over 50% of the global annual methane emission is of anthropogenic origin and the cultivation of irrigated rice accounts for up to 12% of this efflux (IPCC, 2007). The submerged conditions in rice paddies and the rice plants are actively involved in methane production and transport. The submerged rice fields, characterized by oxygen depletion due to high moisture and relatively high organic substrate levels, offer an ideal environment for the activity of methanogenic bacteria.

Methane produced in flooded rice fields is emitted to the atmosphere by molecular diffusion, ebullition or plant-mediated transport. About 90% of methane released from rice soil to the atmosphere is emitted via the rice plant. Various field studies (Adhya *et al.,* 1994; Shalini-Singh *et al.,* 1997; Mitra *et al.,* 1999; Aulakh *et al.,* 2000; Kumar and Viyol, 2009) have indicated substantial differences in the rate of CH_4 emission from different rice cultivars. The differences in CH_4 flux rates could be attributed to differences in CH_4 production, oxidation and gas transport capacities of different cultivars. Wang *et al.* (1997) suggested that rice cultivars influence the CH_4 emission by providing the soil with root exudates, decaying root tissue and leaf litter.

Methane emission from flooded rice fields is influenced by various soil and environmental factors such as water regime, temperature, organic and inorganic amendments (Parashar *et al.*, 1991; Wang *et al.*, 1993; Minami and Neue, 1994). Addition of organic carbon to the soil, whether it comes from the disposal of crop residues or as organic fertilizer, appears to be the most important factor in methane production. Addition of organic amendments to flooded rice soils is required for sustainable agriculture and is encouraged by agriculturists. However, the application of organic materials also increases methane emission from rice fields. Yagi and Minami (1990) observed that application of rice straw to rice fields increased methane emission rates by 2 to 4 times as compared to unamended control plots. Bronson *et al.* (1997) found that organic matter additions as straw (5.5 t ha^{-1}, dry) and green manure (12 t ha^{-1}, wet) stimulated methane flux several folds. Agnihotri *et al.* (1999) observed that application of rice straw before flooding and the biofertilizers after flooding enhanced methane efflux from rice fields significantly, while, composts of cowdung and leaves did not stimulate methane production and rather, decreased methane fluxes. Most of the studies on the effect of organic materials on methane emission have been conducted on low land rice soils where rice fields are continuously flooded. There is very little information available on the soils of semi-arid region where rice fields are alternately flooded and drained. Therefore, the present study was conducted to study the effect of rice cultivars and quality of organic materials on methane emission from rice fields in Indian Punjab.

Materials and Methods

A field experiment was conducted during *kharif* 2005 and 2006 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

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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 rice seedlings of cultivar PR 118 and Pusa 44 were transplanted in June 2005. The experiment was repeated next year on the same site with the same treatments except the cultivar PR 118 was replaced by PR 111. Both PR 118 and PR 111 are semi-dwarf, high yielding varieties and each occupies 8% of the total area under rice in Punjab. Both PR 118 and PR 111 have similar Harvest index (0.45 and 0.46, respectively). Pusa 44 has comparatively low harvest index (0.42) with higher above ground plant biomass and it occupied 36% of the total area under rice in the state during 2005.

Rice field was continuously flooded for first fifteen days after transplanting and then irrigated two days after the flood water has infiltrated into the soil and irrigation was stopped 10 days before crop harvest. The experiment was laid out with six treatments *viz.* (i) Green manure (GM) at 20 t ha^{-1} (ii) Rice straw compost (RSC) at 10 t ha^{-1} (iii) Wheat straw (WS) at 10 t ha^{-1} (iv) Farmyard manure (FYM) at 20 t ha^{-1} (v) Control (without organic material) (vi) bare soil (uncropped plots without organic material). These differential rates of organic materials were chosen as per the general recommendation/ practice in the region.

In control plots and bare soil, only inorganic fertilizers were applied as detailed below. The organic materials were applied a day before puddling along with fertilizer phosphorus (P_2O_5) and potassium (K_2O) each at the rate 30 kg ha^{-1} through single superphosphate and muriate of potash, respectively. Nitrogen at the rate 120 kg N ha^{-1} was applied in three equal splits *i.e.* at transplanting, 21 and 42 d after transplanting (DAT).

Well decomposed rice straw compost and farmyard manure were uniformly spread in the plots. Wheat straw applied to the plots was collected from last season's wheat crop. Green manure, *Sesbania aculeate* was grown *in situ* in the field. After 45 days above ground biomass was harvested and incorporated into the soil at 20 t ha^{-1} a day before transplanting. The organic materials were analyzed for their chemical composition by following standard methods (Table 1). Total N in the samples was determined by micro-kjeldahl method. Total P and K was determined by digesting the sample in di-acid (3 HNO_3 : 1$HClO_4$). Phosphorus in the digest was determined by vanadomolybdophosporic yellow colour method and potassium with a flame photometer (Jackson, 1967). Hot water soluble fraction, cellulose, hemicellulose and lignin were determined by neutral detergent fraction (NDF) and acid detergent fraction (ADF) method (Goering and Van Soest, 1970).

Gas samples were collected between 11 am to 12 noon at 11, 16, 25, 38, 56, 83, 94 and 108 d after transplanting by closed chamber technique (Hutchinson and Mosier, 1981). The rice fields were flooded 24 hr before sampling. The chamber with 54 cm length, 34.3 cm breadth and 71.2 cm height was made of 6 mm thick acrylic sheet. An aluminium base plate was used with each chamber to make it air tight when placed in the field.

The aluminium base plate was inserted into the soil 1 hr before placing the chamber in position, to stabilize the soil environment. The base plate was filled with water in order to seal the diffusion of gases from chamber, which were placed on the aluminium base plate. After one hour, 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).

The 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 $minute^{-1}$, 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.

Statistical analysis of experimental data was accomplished by Analysis of Variance (ANOVA) in randomized block design using locally developed software CPCS1. The difference in mean values of methane emission of different cultivars was tested at 5% level of probability using the least significant difference (LSD) test. Correlation coefficients (*r*-values) were calculated between methane flux and chemical composition of organic materials and above ground plant biomass.

Results and Discussion

Methane flux: The methane emission appeared shortly after rice transplanting in all the treatments. This was probably due to mineralization of native or added organic matter. The methane flux was minimum in bare soil and it ranged between 0.04 and 0.93 mg m^{-2} hr^{-1}. Transplanting of rice doubled the rate of methane emission and it ranged between 0.07 to 2.06 mg m^{-2} hr^{-1} in control plots without organic amendment. This was attributed to the fact that methane emissions from the bare soil was almost exclusively due to ebullition. However, in cropped plots, plant mediated transport is the primary mechanism for the methane emission. The rice plant enhances methane production and flux by providing substrate for methanogenic bacteria through the production of root litter and root exudates (Holzapfel-Pachron *et al.*, 1986; Sass *et al.*, 1990) that contain carbohydrates and amino acids. Most of the methane produced in the soil is transported to atmosphere by aerenchyma of rice plant.

When evaluated across cultivars and years the rate of methane emission from organic material treated plots ranged between 1.58 and 10.85 mg m^{-2} hr^{-1} during the rice season when averaged over the varieties and two years (Table 2). The maximum methane emission was observed at 16 DAT in green manure (17.13 mg m^{-2} hr^{-1}), wheat straw (31.36 mg m^{-2} hr^{-1}) and farmyard manure (23.66 mg m^{-2} hr^{-1}) treated plots. While it was maximum on 25 DAT in rice straw compost treated plots (4.83 mg m^{-2} hr^{-1}). Only one methane

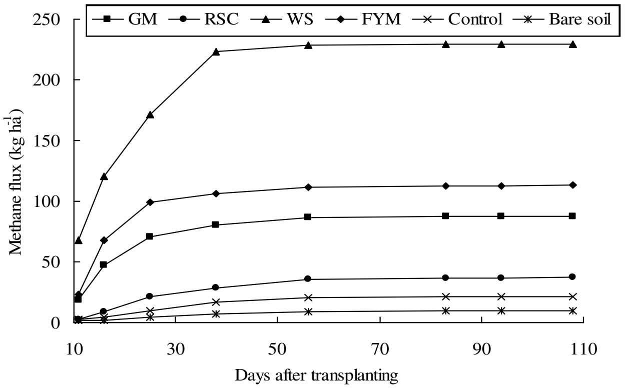

Fig. 1: Cumulative amount of methane emitted (kg ha^{-1}) from soil treated with different organic sources during rice growth (Data averaged over two years) WS, RSC, GM and FYM represent wheat straw, rice straw compost, green manure and farmyard manure, respectively

peak was observed in all the treatments. This was due to frequent draining of the rice fields after continuous submergence for first 15 days after rice transplanting. This is widely adopted practice for rice cultivation in Punjab and develops aerobic conditions which inhibit methanogen activity and thus reduce methane emission.

Effect of rice cultivar: Among the rice cultivars, higher methane emission was observed in Pusa 44 than PR 118 and PR 111 (Table 3). In 2005, the average rate of methane emission was 0.51 mg m^{-2} hr^{-1} from bare soil. Transplanting of Pusa 44 increased the rate of methane emission to 1.21 mg m^{-2} hr^{-1} and PR 118 to 1.16 mg m^{-2} hr^{-1} in control plots. In the wheat straw amended plots average rate of methane emission was 13.63 mg m^{-2} hr^{-1} with Pusa 44 and 11.50 mg m^{-2} hr^{-1} with PR 118.

The rate of methane emission was comparatively lower in 2006 than in 2005. The average rate of methane emission was 0.26 mg m^{-2} hr^{-1} from bare soil which was half of the rate of methane emission in year 2005. This may be due to comparatively higher precipitation in rice season during first year of experiment (596 mm) as compared to that during the second year (403 mm). Transplanting of Pusa 44 increased the rate of methane to 0.55 mg m^{-2} hr^{-1} and PR 111 to 0.50 mg m^{-2} hr^{-1} in control plots.

About 4 to 9% higher methane was emitted from Pusa 44 plots treated with inorganic fertilizer as compared to PR 118 and PR 111, respectively. These differences in methane emission could be attributed to comparatively higher above ground plant biomass of Pusa 44 than PR 118 and PR 111. At 25 DAT the above ground biomass produced by Pusa 44 was 74 g per plant as compared to 60 and 58 g per plant by PR 118 and PR 111, respectively. Subsequently though there was increase in plant biomass till crop maturity but enhancement in methane emission was not observed. This was probably due to frequent drainage of the field. Aulakh *et al.* (2000) also found significant difference in methane transport capacity of hybrid rice cultivars, which was attributed to growth parameters and the development of morphological characteristics of the aerenchyma *i.e.* increase in root or above ground biomass during initial crop growth.

Table - 1: Chemical composition of the organic materials

Constituent	WS	RSC	GM	FYM
Carbon (%)	42.9	36.6	51.8	35.5
Nitrogen (%)	0.44	1.56	3.44	0.95
C:N ratio	97.5	23.5	15.1	37.1
Total P (%)	0.09	1.51	0.33	1.38
Total K (%)	0.84	1.62	1.4	1.55
Soluble components (%)	15.78	16.21	28.59	27.36
Hemicellulose (%)	27.41	23.84	20.64	22.9
Cellulose (%)	29.26	24.47	24.21	25.47
Lignin (%)	20.45	25.96	16.11	12.15
Ash (%)	10.1	9.52	10.45	12.12
Lignin:N	41.9	16.6	4.7	12.8

WS = Wheat straw, RSC = Rice straw compost, GM = Green manure, FYM = farmyard manure, respectively

Effect of organic materials on methane flux: In 108 days crop season, the total amount of methane emitted from rice (mean of two years and cultivars) fields amended with different organic materials is shown in Fig. 1. The control plots emitted 21.87 kg CH_4 ha^{-1}. Among the organic material treated plots, the highest amount of methane was emitted from wheat straw amended plots (229.8 kg CH_4 ha^{-1}) followed by farmyard manure (113.0 kg CH_4 ha^{-1}), green manure (87.7 kg CH_4 ha^{-1}) and lowest from rice straw compost amended plots (37.1 kg CH_4 ha^{-1}). About 50 to 60% of the total amount of methane was emitted up to 16 DAT in case of wheat straw, green manure and farmyard manure amended plots. While, rice straw compost emitted only 23% of the total methane up to this period.

About half of the total methane was emitted within 16 d after transplanting rice (Fig. 1). During this period, the rate of methane emission was positively correlated to the above ground plant biomass with 'r' value of 0.42* (n = 48). Sass *et al*. (1990) reported a linear relationship between plant biomass and methane emission.

Application of organic materials to rice fields significantly increased the rate of methane emission as compared to control plots receiving only inorganic fertilizer as the addition of organic matter selectively enhanced the growth of particular methanogenic populations by providing them carbon source. The rate of increase in methane emission was highest with the application of wheat straw followed by farmyard manure, green manure and least with rice straw compost. The percent of added carbon emitted as methane from organic material treated rice fields was highest from wheat straw (4.07%) followed by from farmyard manure (2.36%), from green manure (2.06%) and from rice straw compost (1.51%).

The methane flux and percent of added carbon emitted as methane was significantly correlated to C:N ratio, lignin:N ratio, cellulose and hemicellulose content of the added organic materials (Table 4). Higher methane emission from wheat straw may be due to its higher C:N ratio (120:1) and hemicellulose (27.4%) and cellulose content (29.3%). Lower methane emission from rice straw compost

Table - 2: Rate of methane emission (mg CH_4 m^{-2} hr^{-1}) from rice fields amended with organic materials (mean of two years and cultivars)

Treatment	**Days after transplanting (DAT)**								
	11	**16**	**25**	**38**	**56**	**83**	**94**	**108**	**Mean**
GM	5.66	17.13	9.01	2.51	1.12	0.18	0.08	0.09	4.47
RSC	0.95	3.28	4.83	1.95	1.35	0.13	0.12	0.07	1.58
WS	20.94	31.36	19.23	14.07	0.87	0.17	0.09	0.10	10.85
FYM	7.05	26.66	12.01	1.92	1.00	0.10	0.08	0.11	6.11
Control	0.81	0.86	2.03	2.06	0.65	0.16	0.07	0.08	0.84
Bare soil	0.44	0.30	0.93	0.85	0.32	0.12	0.08	0.04	0.38
Mean	5.98	13.26	8.01	3.89	0.88	0.14	0.08	0.08	
LSD	Treatment : 1.91		DAT : 2.28		Treatment x DAT : 5.56				
($p<0.05$)									

GM = Green manure, RSC = Rice straw compost, WS = Wheat straw, FYM = Farmyard manure, LSD = Least significant difference

Table - 3: Effect of rice cultivar on rate of methane emission (mg m^{-2} hr^{-1})

Treatment	**2005**			**2006**		
	Pusa 44	**PR 118**	**Mean**	**Pusa 44**	**PR 111**	**Mean**
GM	6.46	3.44	4.95	4.83	3.14	3.98
RSC	2.18	2.00	2.09	1.21	0.91	1.06
WS	13.63	11.50	12.57	11.55	7.33	9.44
FYM	8.69	5.94	7.32	5.45	3.66	4.55
Control	1.21	1.16	1.18	0.55	0.50	0.52
Bare soil	0.51	0.51	0.51	0.26	0.26	0.26
Mean	5.45	4.09		3.97	2.63	
LSD	Cultivar : 1.27			Cultivar : 0.76		
($p < 0.05$)	Treatment : 2.20			Treatment : 1.32		
	Cultivar x Treatment : NS			Cultivar x Treatment : 1.87		

GM = Green manure, RSC = Rice straw compost, WS = Wheat straw, FYM = Farmyard manure, LSD = Least significant difference

Table - 4: Correlation analysis of methane flux vs. chemical composition of organic materials (n = 16)

Chemical constituent of organic material	**Methane Flux (mg m^{-2} hr^{-1})**	**Percent of added carbon emitted as methane**	**Seasonal methane flux (kg ha^{-1})**
Carbon (%)	0.53*	0.52*	0.56*
Nitrogen (%)	-0.49*	-0.49*	-0.53*
C:N ratio	0.82*	0.81*	0.88*
Total P (%)	-0.63*	-0.60*	-0.66*
Total K (%)	-0.83*	-0.81*	-0.88*
Soluble comp. (%)	-0.18	-0.28	-0.26
Hemicellulose (%)	0.61*	0.65*	0.69*
Cellulose (%)	0.84*	0.82*	0.89*
Lignin (%)	-0.24	-0.10	-0.17
Ash (%)	0.16	0.03	0.09
Lignin:N ratio	0.70*	0.72*	0.77*

* = Indicates significant at $p < 0.05$

may be due to higher lignin content (26.0%) which is comparatively resistant to microbial decomposition.

Effect of organic materials on soil organic carbon and rice yield: Application of organic materials significantly ($p < 0.05$) increased the rice grain yield. However, there was no significant difference in grain yield among the organic material amended plots. The grain yield was maximum in rice straw compost amended plots (65.7 q ha^{-1}) followed by farmyard manure (64.0 q ha^{-1}), wheat straw (63.8 q ha^{-1}) and green manure (61.1 q ha^{-1}). The organic materials significantly increased the organic carbon content over the control. Among organic material treated plots, the organic carbon of the soil varied from 0.57 to 0.62%.

The results of the study have shown that methane emission from rice field depends on the flooding status of the soil, crop variety and addition of organic materials. Frequent draining of the field 15 DAT resulted in lower methane emissions. Rice cultivar Pusa 44 with high vegetative growth enhanced methane transport to the atmosphere resulting in greater methane emission. The incorporation of humified organic matter such rice straw compost could minimize methane emission from rice fields with co-benefits of increased soil fertility and crop productivity.

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