6. White Kevin, Hesham M. El Asmar, Monitoring changing position of coastlines using thematic mapper imagery, an example from the Nile data. *Geomorphology*, 1999, **29**, 93–105.
7. Shaghude, Y. W., Wannas, K. O. and Lunden, B., Assessment of shoreline in the western side of Zanzibar channel using satellite remote sensing. *Int. J. Remote Sensing*, **24**, 4953–4967.
8. El-raey, M., Sharaf el-din, S. H., Khafagy, A. A. and Abo Zed, A. I., Remote sensing of beach erosion/accretion patterns along Damietta Port Said shoreline, Egypt. *Int. J. Remote Sensing*, 1999, **20**, 1087–1106.
9. Narayana, A. C. and Priju, C. P., Landform and shoreline changes inferred from satellite images along the central Kerala Coast. *J. Geol. Soc. India*, 2006, **68**, 35–49.
10. Shailesh Nayak, Use of satellite data in coastal mapping. *Indian Cartogr.* CMMC-01, 2002, 147–156.
11. Meijerink, A. M. J., Dynamic geomorphology of the Mahanadi delta. *ITC J*., 1983, 243–250.
12. Rao, P. M. and Harikrishna, M., Shoreline changes around Paradip port after construction. In Third National Conference on Dock and Harbour Engineering, Suratkal, 6–9 December 1989.
13. Rupali, S., Patgaonkar, D., Ilangovan, P., Vethamony, M. T., Babu, S., Jayakumar, M. D. and Rajagopal, Stability of a sand spit due to dredging in an adjacent creek. *Ocean Eng*., 2007, **34**, 638–643.
14. Ananth, P. N. and Sundar, V., Sediment budget for Paradip Port, India. *Ocean Shoreline Manage.*, 1990, **13**, 69–81.
15. Sarma, K. G. S. and Sundar, V., Analysis of nearshore profiles off Paradip Port, east coast of India. *Indian J. Marine Sci.*, 1988, **17**, 94–98.
16. Nayak, S. *et al*., Coastal environment. Scientific note. Space Applications Centre, Ahmedabad, RSAM/SAC/COM/SN/11/92, 1992, p. 114.
17. Nayak, S., Bahuguna, A., Chauhan, P., Chauhan, H. B. and Rao, R. S., Remote sensing applications for coastal environmental management in India. *Env. Manage.* (*Spl. Issue*), 1997, **4**, 113–125.
18. Chauhan, P., Nayak, S., Ramesh, R., Krishnamoorthy, R. and Ramachandran, S., Remote sensing of suspended sediments along the Tamil Nadu Coastal waters. *J. Indian Soc. Remote Sensing*, 1996, **24**, 105–114.
19. Sanil Kumar, V., Pathak, K. C., Pednekar, P., Raju, N. S. N. and Gowthaman, R., Coastal processes along the Indian coastline. *Curr. Sci*., 2006, **91**, 530–536.
20. NIO Report, Comprehensive environmental impact assessment for the proposed marine facilities for the Eastern India Refinery, Paradip, Orissa. Technical Report No. NIO/SP-7/1998, 1998.

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Influence of crop establishment methods on methane emission from rice fields

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A field experiment was conducted to know the effect of rice sowing and transplanting methods as well as nutrient management through 12 treatments were assessed during kharif 2004 at Crop Research Centre, Pantnagar. The maximum methane flux was recorded in 100% NPK + straw + manual transplanting practice (7.70 mg m^{-2} h^{-1}), whereas the lowest 0.70 mg m^{-2} h^{-1} in vermicompost + direct sowing. The treatment 100% NPK + sulphur + manual transplanting gave higher grain yield of rice (6.85 t ha^{-1}) and CH_4 emission (2.25 mg m^{-2} h^{-1}). However, the treatment 100% NPK + sulphur + direct sowing was effective in reducing methane flux (1.57 mg m^{-2} h^{-1}) with higher rice grain yield of 6.62 t ha^{-1}.

Keywords: Aerobic rice, direct seeded rice, mat-type rice transplanter, methane flux.

METHANE, a major component of natural gas is the second most important greenhouse gas (GHG) after CO_2. It plays a major role in global warming and climate change, and its reduced emission is essential without adversely affecting crop production. Methane emitted from rice fields under various cultural practices has been an area of research, as little information is presently available on this aspect. It is important because the warming effect of methane is 21 times greater than that of CO_2. Methane emitted from flooded rice fields is a major source of atmospheric methane[1]. Methane emission is prominent in irrigated rice due to long periods of flooding and anaerobic decomposition of incorporated organic matter[2]. Methane emission from rice fields is affected by climate, water regime, soil properties, irrigation, drainage, organic amendments, fertilizers and rice straw management. Much attention has been devoted in recent years to the 'greenhouse effect' of the atmosphere and its enhancement by increased anthropogenic activities of radioactive gases, which tend to alter the heat budget of the earth's atmosphere, while most often burning of fossil fuels (petroleum, coal and natural gas) has been cited as the major culprit. However, the role of agriculture in climate

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change has come to light because of clearing of forests, transforming virgin soils to cultivated land, rice cultivation under submerged condition, burning of crop residues, rearing ruminant animals and applying nitrogenous fertilizers that have been implicated in the release of GHGs to the atmosphere[3].

Field experiments had been conducted to investigate the effect of cultural practices on methane emission[4]. The factors evaluated were: (a) direct sowing on dry vs wet soil, (b) age of transplanted seedlings (8-day-old and 30-day-old), and (c) autumn vs spring ploughing. The results demonstrated that transplanting of 8-day-old seedlings produced higher emission of 42.4 g CH_4 m^{-2} $season^{-1}$ followed by transplanting of 30-day-old seedlings (40.3 g CH_4 m^{-2} $season^{-1}$) and direct seeding on wet soil (37.1 g CH_4 m^{-2} $season^{-1}$). Direct sowing on dry soil registered the least emission of 26.9 g CH_4 m^{-2} $season^{-1}$. Thus, transplanting of 30-day-old seedlings, direct sowing on wet soil and direct sowing on dry soil reduced CH_4 emission by 5, 13 and 37% respectively as compared to transplanting of 8-day-old seedlings. Methane emission under spring ploughing was 42.0 g CH_4 m^{-2} $season^{-1}$, whereas under autumn ploughing the emission was 31.3 g CH_4 m^{-2} $season^{-1}$. The 26% lower emission in the field ploughed during autumn was caused by slow degradation of organic matter over winter.

Although little information is available from field studies regarding cultural practices and methane emission from rice, it appears feasible to reduce methane by short dry fallow or rotation with an upland crop to permit organic matter to be decomposed under aerobic conditions, before subjecting the soil to anaerobic conditions for irrigated rice cultivation[5]. Rice crop is established through various methods; therefore, a field study was conducted to observe methane emission in three major rice crop establishment methods, viz. direct sowing, manual transplanting and mat-type seed transplanter.

The experiment was conducted during kharif season of 2004 at the Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. The Centre is situated at 29°N lat., 79.3°E long. and 243.8 m amsl, and lies in a narrow belt to the south from the foothills of the Shiwalik range of the Himalayas, known as the tarai region. The climate of Pantnagar is humid sub-tropical with severe cold winter and hot summer.

Tarai soils are silty loam in texture with good moisture storage capacity and are highly productive. According to USDA soil classification, the soil of the experimental site has been placed under order – Mollisol, suborder – Udoll, great group – hapludoll, subgroup – aquic hapludoll, family – fine loamy mixed hyperthermic and series – Beni silty clay loam. The values of some of the specific soil parameters of the experimental site are given in Table 1.

The experiment was conducted in randomized complete block design (RBD) with 12 treatments and three replications. The net plot size for each treatment was 3 m × 2 m. The treatments comprise of T_1: Control with direct sowing; T_2: Control with manual transplanting; T_3: Control with mat-type rice transplanter; T_4: 100% NPK + sulphur + direct sowing; T_5: 100% NPK + sulphur + manual transplanting; T_6: 100% NPK + sulphur + mat-type rice transplanter; T_7: 100% NPK + wheat straw + direct sowing; T_8: 100% NPK + wheat straw + manual transplanting; T_9: 100% NPK + wheat straw + mat-type rice transplanter; T_{10}: Vermicompost + direct sowing; T_{11}: Vermicompost + manual transplanting and T_{12}: Vermicompost + mat-type rice transplanter. Approximately 220 kg ha^{-1} sulphur was provided through sulphur-bearing fertilizers in T_4, T_5 and T_6 treatments.

The nursery of rice was raised in a fertile and well-drained field. Rice seeds (var. Pant Dhan-4) were soaked for 24 h followed by drying under ambient condition before sowing. The nursery was sown in a well-prepared seedbed by puddling twice with a peg-type puddler at a seed rate of 30 kg ha^{-1}. The main field was prepared by disc harrowing thrice in the first and second week of June and later on puddling was done with the help of a peg-type puddler before transplanting.

The field was tilled thrice with a tractor-drawn disc harrow. Mat-type rice nursery was prepared by laying plastic sheets of 50–60 gauge on a level ground followed by placing iron frames of 50 cm × 22 cm × 2 cm size. The frame was filled with well-prepared soil mixed with DAP fertilizer @ 10 g m^{-2}. Pre-germinated seeds were spread uniformly in each frame (78 g per frame) and then covered with a thin layer of soil. The water was sprinkled three to four times a day up to 6 days to keep the seed-

Table 1. Chemical characteristics of the experimental site

Soil parameter	Soil depth (cm) 0–15	15–30
pH	7.74	7.87
Electrical conductivity (dS m^{-1}) (1 : 2, soil : water)	0.105	0.114
Eh (1 : 2 soil : water; mV)	–0.059	–0.070
Organic carbon (%)	1.30	0.95
Available nitrogen (kg ha^{-1})	181.8	106.62
Available phosphorus (kg ha^{-1})	35.84	12.54
Available potassium (kg ha^{-1})	241.9	156.8

beds wet. After a week of sowing, water was applied through the water channel until transplanting. During transplanting, the mats were lifted from the plastic sheets and placed directly on the trays of the transplanter.

Direct sowing of rice (Pant Dhan-4) was done @ 60 kg ha^{-1} after preparing the field by disc harrowing thrice and levelling with a planker. Fifty per cent of N and 100% of P and K were applied during field preparation, while the remaining 50% of nitrogen was applied in two splits.

Manual transplanting was done in the well-puddled field. Fifty per cent of N and 100% of P and K were applied at the time of transplanting and the remaining 50% of nitrogen was applied in two split doses. The 23-day-old rice seedlings were transplanted @ 2–3 seedlings per hill with a spacing of 20 cm × 10 cm.

Mechanical transplanting of 23-day-old rice seedlings was done with a self-propelled mat-type rice transplanter (Figure 1). The machine can transplant eight rows of seedlings at a spacing of 23.8 cm × 12 cm in a well-prepared puddled soil. Fifty per cent of N and 100% of P and K were applied and the remaining 50% of N was applied in two split doses at tillering and panicle initiation stages.

The recommended NPK dose for rice was 120, 60 and 40 kg N, P_2O_5, K_2O, which was applied in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) respectively. Rice straw was incorporated into the soil (10 t ha^{-1}), while vermicompost was applied @ 2 t ha^{-1}. In treatment T_4, NPK was applied through sulphur-containing fertilizers, viz. $(NH_4)_2SO_4$ (ammonium sulphate), SSP, K_2SO_4 (potassium sulphate) and $ZnSO_4$ (zinc sulphate).

Various plant growth parameters such as plant height (cm), number of tillers, dry matter accumulation (g $hill^{-1}$) and yield attributes as numbers of ears $hill^{-1}$, length of ear (cm) and 1000 grain weight (g) were recorded at different stages. After threshing of the whole produce, the grain yield obtained from each plot was weighed in kg $plot^{-1}$ and then converted to t ha^{-1}.

Figure 1. A mat-type rice transplanter in operation.

Collection of gas samples was done by closed chamber technique[5]. The gas samples were collected up to 131 days after sowing (DAS). Six days CH_4 sampling interval was decided for the study, but due to unavoidable circumstances, the actual interval varied between 4 and 13 days. For collecting gas samples, the gas chamber was flushed several times with a 100 ml syringe and then gas samples replicated at intervals of 0, 15 and 30 min. Methane concentration in the gas samples collected from rice field was estimated using Gas Chromatograph (Nucon 5765 series) attached to Flame Ionization Detector (FID) fitted with Molecular Sieve stainless steel column. The temperature for the column, injector and detector was kept at 90°C, 120°C and 120°C respectively. The pressure of the gases was 4, 2 and 2 kg/cm^2 for nitrogen (carrier gas), zero air (supporting gas) and hydrogen (combustion gas) respectively, with total of 8 kg cm^{-2}. The peak area was measured with a microprocessor-controlled integrator connected to a computer. Pre-calibrated standard (100 ppm in helium) of methane was used. The area of methane peaks was used to calculate methane concentration against standard peaks. The standard calibration was done after each 5–6 samples.

The results of average methane emission from rice fields are presented in Table 2. At the tillering stage, treatments T_7, T_8 and T_9 showed higher methane emission, while minimum in T_{11}, T_{12} and T_{10} compared to the control. This might be due to incomplete decomposition of straw during the initial stage, which promoted anaerobic environment and microbial growth. A similar result was obtained by Kludze and Delaune[7] in their field experiment, who reported that the application of straw increased the rate of methane emission at the tillering stage. This showed that direct sowing and mat-type rice transplanting methods reduced methane emission when used in conjunction with vermicompost as they decreased the methanogenesis process in the rice rhizosphere[8].

During the panicle initiation stage, average methane emission was considerably higher than that at the tillering stage. The experimental area had remained under submergence due to either rain or irrigation during that period. Treatments T_9, T_6 and T_8 gave the highest trends. However, T_{11}, T_{12} and T_{10} showed downward trend in methane emission. This reveals that undecomposed amendments increase the rate of emission[9].

At the heading stage, a slight positive trend was observed in methane emission in most of the treatments, viz. T_{12}, T_{10}, T_{11}, T_4, T_6, T_5, T_9, T_8 and T_7. This might have been due to decomposition of organic matter up to this stage, which is in agreement with the findings of Adachi *et al.*[10], who found that the application of organic amendments may enhance the level of methanogenesis. Also, some changes in the microflora surrounding methanogenic bacteria might occur at the rice heading stage[11].

During the ripening stage, treatments T_7, T_9 and T_8 gave higher emission of methane, while it was lower in

Table 2. Methane flux from rice fields during crop growth period of rice

Treatment		Methane flux (mg m^{-2} h^{-1})														
		Number of observations														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Mean
T_1	Control with direct sowing	7.46	5.44	0.66	0.59	0.53	0.47	0.46	0.00	0.73	0.37	0.34	0.34	0.26	0.26	1.28
T_2	Control with manual transplanting	3.44	3.13	1.86	2.11	1.69	0.87	0.84	0.00	0.84	0.66	0.60	0.59	0.31	0.30	1.23
T_3	Control with mat-type rice transplanter	4.39	2.97	1.83	2.26	2.17	0.74	0.61	0.00	0.79	0.37	0.59	0.51	0.31	0.30	1.27
T_4	100% NPK + sulphur + direct sowing	2.94	1.63	0.67	3.11	2.09	1.97	1.79	0.00	2.03	1.74	1.54	1.24	0.64	0.60	1.57
T_5	100% NPK + sulphur + manual transplanting	2.81	2.61	1.60	5.10	2.76	4.13	3.70	0.00	2.66	1.83	1.66	1.33	0.66	0.61	2.25
T_6	100% NPK + sulphur + mat-type rice transplanter	2.69	1.54	1.50	7.10	5.06	3.77	1.76	0.00	2.07	1.79	1.63	1.30	0.64	0.59	2.24
T_7	100% NPK + straw + direct sowing	23.94	14.50	2.53	4.47	25.63	3.01	3.01	3.61	6.83	5.80	4.97	1.94	0.87	0.84	7.28
T_8	100% NPK + straw + manual transplanting	26.51	19.93	2.21	4.91	10.49	12.26	5.96	5.04	7.01	5.93	3.66	2.03	0.96	0.89	7.70
T_9	100% NPK + straw + mat-type rice transplanter	6.53	5.81	2.11	8.46	4.54	6.11	5.80	4.70	6.93	5.87	3.63	2.01	0.93	0.87	4.60
T_{10}	Vermicompost + direct sowing	1.89	1.77	0.41	1.16	0.33	0.84	0.79	0.00	0.61	0.47	0.46	0.44	0.33	0.31	0.70
T_{11}	Vermicompost + manual transplanting	2.37	2.44	0.67	1.33	0.64	1.07	0.77	0.00	0.64	1.16	0.50	0.54	0.37	0.34	0.92
T_{12}	Vermicompost + mat-type rice transplanter	1.87	2.44	0.64	1.09	0.70	0.37	0.36	0.00	0.63	0.77	0.47	0.51	0.36	0.34	0.75

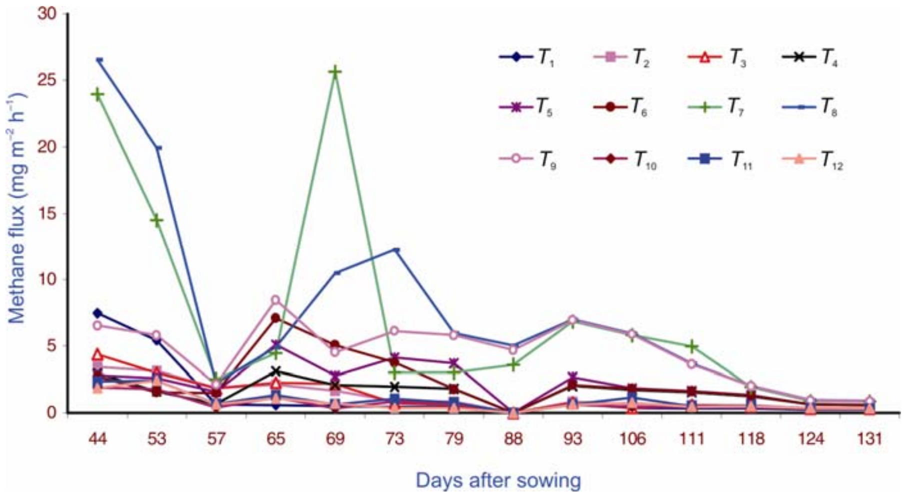

Figure 2. Effect of different treatments on methane flux from rice field during crop growth period.

T_{10}, T_{12}, T_{11}, T_4, T_6 and T_5. This showed that direct sowing in combination with sulphur and vermicompost reduced the CH_4 emission. A similar result was also obtained with sulphur-treated plots, which gave lower peak methane flux during the ripening stage[4,12].

The highest methane flux was reported during the tillering stage due to the development of new tillers and vigorous plant growth at this stage that enhanced the activities of root exudates and the oxidation processes. As the plants mature and flower, there was no further increase of transport efficiency and root exudation was greatly reduced as the roots were fully grown[13,14]. It resulted into the reduced methane flux at later stages. Methane emission rate decreased in the later growth periods and was not detectable after the maturity of rice. This emission pattern followed a trend similar to other researches conducted at different parts of the world[15,16]. This pattern is closely related to temperature change, soil moisture pattern, soil reducing conditions as well as rice growth stages[17].

A significant effect of different treatments on growth and yield was observed at tillering, flowering and maturity stages (Table 3). Plant height was found to be higher in T_5 and lower in T_3. Maximum plant height at flowering stage was observed in T_{10} while minimum in T_1.

Statistical analysis showed a significant difference between the effects of different treatments on the number of tillers at tillering, flowering and maturity stages. Maximum number of tillers was obtained in T_4 and minimum in T_3. Thus, T_4 was found to have a pronounced positive effect on the number of tillers in comparison to other

Table 3. Effect of different treatments on plant growth parameters of rice

	Plant height (cm)			Number of tillers			Dry matter (g $hill^{-1}$)		
Treatment	Tillering	Flowering	Maturity	Tillering	Flowering	Maturity	Tillering	Flowering	Maturity
T_1	21.6	33.6	50.0	36.0	45.3	45.3	7.61	13.52	25.47
T_2	21.6	35.0	50.3	34.6	44.3	45.0	7.93	14.45	25.41
T_3	18.3	32.0	50.3	33.3	42.0	42.6	7.85	14.53	25.61
T_4	31.3	40.6	64.0	65.6	79.0	78.0	11.58	23.72	43.43
T_5	32.6	42.0	65.0	64.0	76.0	76.3	12.25	24.42	43.68
T_6	29.0	39.3	65.0	62.0	74.0	74.0	11.86	24.48	43.60
T_7	23.6	35.3	63.3	34.0	68.0	68.3	8.82	17.63	33.63
T_8	26.3	36.0	55.0	46.3	62.6	63.3	9.52	18.61	33.77
T_9	21.3	32.0	62.0	44.6	60.0	60.0	9.13	18.47	33.62
T_{10}	23.3	31.6	50.0	44.3	55.0	56.0	8.24	16.37	30.37
T_{11}	24.6	35.3	51.6	43.0	54.0	55.0	8.37	17.47	30.68
T_{12}	20.6	30.3	51.3	41.3	51.3	52.0	8.56	16.64	30.61
S.Em. ±	0.80	0.96	1.31	0.80	0.96	1.31	0.67	0.49	1.11
CD at 5%	2.35	2.81	3.8	2.35	2.81	3.80	1.90	1.43	3.26
C.V.	5.66	4.71	4.05	5.66	4.71	7.05	1.26	4.63	5.78

Table 4. Effect of different treatments on yield and yield attributes of rice

	Yield attributes			Yield		
Treatment	No. of ears/hill	Length of ear (cm)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1	9.0	19.3	29.35	3.25	5.17	38.67
T_2	9.6	19.6	29.56	3.34	5.33	38.59
T_3	9.0	19.3	29.50	3.16	5.25	37.57
T_4	13.0	26.0	35.44	6.62	11.05	37.50
T_5	14.6	26.3	35.50	6.85	11.36	37.65
T_6	13.3	26.6	35.33	6.76	11.16	37.72
T_7	12.6	23.3	29.48	5.94	9.66	38.08
T_8	11.6	23.3	30.35	6.14	9.89	38.34
T_9	12.6	23.3	29.65	6.04	9.85	38.01
T_{10}	12.3	22.6	25.34	4.54	7.35	38.24
T_{11}	12.0	22.6	29.60	4.55	7.47	37.91
T_{12}	11.6	22.3	29.72	4.54	7.45	37.86
S.Em. ±	1.22	0.67	0.61	0.99	1.12	–
CD at 5%	3.58	1.98	1.81	2.93	3.28	–
C.V.	17.54	5.10	3.38	3.36	2.30	–

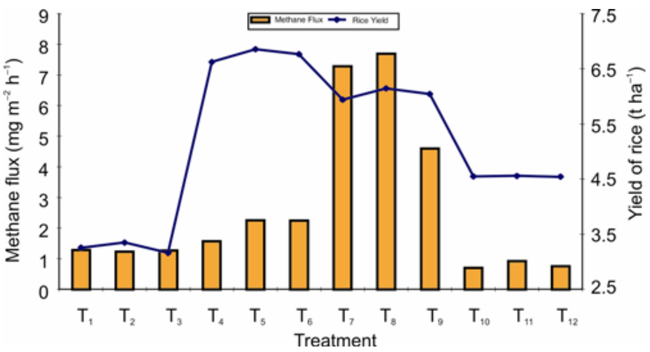

Figure 3. Average methane flux during crop growth period of rice and grain yield.

treatments. Direct sowing gave more time for the development of tillers and sulphur exhausted the nitrogen absorption and assimilation for their sustainable growth.

A significant effect of different treatments was seen at tillering and flowering stages (Table 3). The dry matter was found to be higher in T_5 and lower in T_1. At the maturity stage, the effect of various treatments on dry matter remained significant. Dry matter was found to be lowest under T_2 and highest in T_5. Thus, T_5 was found to be more effective in increasing the dry matter of crop in comparison to other treatments.

The different treatments were significantly affected by the number of ears per hill and length of the ear. As shown in Table 4, the lowest number of ears per hill and length of the ear were found in T_1 and T_3 and the highest in T_5. For 1000-grain weight too, the effect of various treatments was found to be significant. T_{10} recorded the lowest 1000-grain weight, and T_5 the highest. Thus, the number of ears per hill was found to be affected in T_1 and T_3, with a decrease in the length of the ear. The 1000-grain weight was negatively affected by T_{10}. The reason behind this may be due to the exhaustion of nutrients present in vermicompost by the crop during vegetative and early reproductive growth phases. Therefore, lesser nutrients remained in the soil to increase the 1000-grain weight, since the grains require more nutrients for tillering as the yield potential of rice may be characterized by its tillering capacity. It was found that tillering ability in rice is closely related with yield[18] and plants with more tillers showed greater inconsistency in mobilizing assimilates and nutrients among tillers[19].

A significant effect of different treatments was observed in grain yield, straw yield and total biomass yield. Significantly higher grain yield and total biological yield was recorded in T_5, whereas it was lowest in T_3. Higher straw yield was observed in T_6, whereas lower straw yield was observed in T_1. Increasing grain yield in T_5 was found to be better in comparison to other treatments, thus showing its effect on straw and total biological yield.

On an average, grain yield, straw yield and biological yield from sulphur-added treatments registered best response than other treatments. Li and Li[20] also reported that the sulphur component of the fertilizer was found to increase rice plant growth, grain number and rice yield.

It can be postulated from Table 2 that on an average the maximum methane flux was recorded in T_8 (7.70 mg $m^{-2} h^{-1}$), whereas the minimum in T_{10} (0.70 mg $m^{-2} h^{-1}$), but this treatment had an adverse effect on yield due to lower plant nutrients in vermicompost. Treatment T_5 recorded higher yield (6.85 t ha^{-1}), but reduction in methane emission was not found to be remarkable in comparison to other treatments, viz. T_1–T_3, T_{10}–T_{12}. However, treatment T_4 was found to meet both the objectives of effectively reducing methane flux (1.57 mg $m^{-2} h^{-1}$) as well as higher rice yield of about 6.62 t ha^{-1}. Hence the combination 100% NPK + sulphur + direct sowing of rice may be adopted for environment-friendly agriculture.

The present field experiment was conducted with an objective of finding the best method of crop establishment which could effectively control methane emission without much reduction in rice grain yield. The study clearly indicated that sowing and transplanting methods may be one of the most promising measures to reduce methane emission from the rice fields. Treatment T_{10} with vermicompost and direct sowing was found to be the best among all the treatments in reducing methane emission. Direct sowing and application of decomposed organic amendments reduced methane emission. Apart from small-scale quantification and mitigation of emissions, studies on large-scale spatial and temporal quantification and mitigation need to be carried out, as microscale studies cannot be extrapolated into macroscale. The different water-management practices should also be explored, as submergence and alternate wetting and aeration have direct influence on methane emission, to minimize methane emission from different cultural practices in conjunction with application of different plant nutrients for minimizing the adverse impacts of climate change and global warming.

1. Chenwuing, L. and Chungyi, W. V., Evaluation of methane emission from Taiwanese paddies. *Sci. Total Environ*., 2004, **333**, 195–207.
2. Hou, A. X., Chen, G. X., Wang, Z. P., Clemput, O. V. and Patrick, W. H., Methane and nitrous oxide emissions from rice field in relation to soil redox potential and microbiological processes. *Soil Sci. Soc. Am. J*., 2000, **64**, 2180–2186.
3. Bisht, N., Methane and nitrous oxide emission from rice–potato agro-ecosystem. M Sc thesis, G.B. Pant University of Agriculture and Technology, Pantnagar, 2004, pp. 1–5.
4. Ko, J. Y. and Kang, H. W., The effect of cultural practices on methane emission from rice field. *Nutr. Cycle Agroecosyst.*, 2000, **58**, 311–314.
5. Minami and Neue, Rice paddies as a methane source. *Climate Change*, 1994, **27**, 13–26.
6. Hutchinson, G. L. and Moseir, A. R., Improved soil cover method for field measurement of nitrous oxide flux. *Soil Sci. Soc. Am. J*., 1981, **45**, 311–316.
7. Kludze, H. K. and Delaune, R. D., Straw application effect on methane and oxygen exchange and growth in rice. *Soil Sci. Soc. Am. J*., 1995, **59**, 824–830.
8. Corton, T. M. *et al*., Methane emission from irrigated and intensively managed rice fields in central Luzon, Philippines. *Nutr. Cycle Agroecosyst*., 2000, **58**, 37–53.
9. Traore, I., Shen, D. S., Min, H., Chen, M., Feng, X. S., Shen, D. S. and Min, H., Effect of different fertilizers on methane emission from a rice field of Zhejiang, China. *J. Environ. Sci*., 1991, **11**, 457–461.
10. Adachi, K., Oyedirah, G. and Senboku, T., Effect of application of rice straw and cellulose on methane emission and biological nitrogen fixation in a subtropical rice field. *Soil Sci. Plant Nutr.*, 1996, **42**, 713–723.
11. Debnath, G., Jain, M. C., Kumar, S., Sarkar, K., Sinha, S. K. and Kumar, S., Methane emissions from rice fields amended with biogas slurry and farm yard manure. *Climate Change*, 1996, **33**, 97–109.
12. Corton, T. M., Majita, J. B., Pamplona, R. R. and Asis Jr, C. A., Methane emission from irrigated rice field: effect of nitrogen and sulphate fertilizers. *Philipp. Rice Tech. Bull*., 1995, **1**, 101–121.
13. Hale, M. G. and Moore, L. D., Factor affecting root exudation. *Adv. Agron.*, 1979, **31**, 93–124.
14. Minoda, T., Kimura, M. and Wada, T., Photosynthates as dominant source of CH_4 and CO_2 in soil water and CH_4 emitted to the atmosphere from paddy fields. *J. Geophys. Res*., 1996, **101**, 21091–21097.
15. Wang, M. X., Methane emission from a Chinese rice paddy field. *Acta Meteorol. Sin.*, 1990, **4**, 265–274.
16. Minami, K., The effect of agricultural practices on methane emission from rice fields, IUAPPA Regional Conference for Pacific Rim on Air Pollution and Waste Issues. In Proceedings of the Conference at Taipei, Taiwan, 2–4 November 1994, pp. 201–210.
17. Hou, A. X., Chen, G. X., Wang, Z. P., Cleemput, O. Van and Patrick Jr, W. H., Methane and nitrous oxide emissions from a rice field in relation to soil redox and microbiological processes. *Soil Sci. Soc. Am. J*., 2000, **64**, 2180–2186.
18. Wang, Feng, Cheng, Fang-min and Zhang, Guo-ping, Difference in grain yield and quality among tillers in rice genotypes differing in tillering capacity. *Rice Sci.*, 2007, **14**, 135–140.
19. Miller, B. C., Hill, J. E. and Roberts, S. R., Plant population effects on growth and yield in water-seeded rice. *Agron. J.*, 1991, **83**, 291–297.
20. Li, Y. and Li, Y., The characteristics of sulphur requirement and the effect of sulphur on yield and qualities of rice. *Soil Fertil.*, 1999, **1**, 24–26.

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