Integrated management of organic and inorganic fertilizers to reduce methane (CH_4) emission and increase rice production in irrigated rice field

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Abstract: An experiment was conducted to evaluate the integrated management of organic and inorganic fertilizers to reduce CH_4 emission and increase rice productivity (rice cultivar BRRI Dhan 28) in Boro season during the period of January to May 2012 at the experimental field, Department of Environmental Science, Bangladesh Agricultural University, Mymensingh. Six different treatments such as, urea only (no organic amendments), urea + rice straw compost, urea + charcoal, urea + $CaSiO_3$, urea + rice straw compost + $CaSiO_3$, urea + charcoal + $CaSiO_3$ were applied in different plots in this experiment. The treatments were replicated three times and arranged under RCBD in the field. The highest seasonal CH_4 flux 25.546 mg m^{-2} ha^{-1} was found from the urea + rice straw compost treatment and lowest seasonal CH_4 flux 17.468 mg m^{-2} ha^{-1} was produced in urea only (no organic amendments). The second lowest CH4 flux 18.744 mg m^{-2} ha^{-1} was recorded from the urea + charcoal + CaSiO3 treated plot. Inorganic fertilizers such as $CaSiO_3$ significantly improved the soil redox potential status which reduced CH_4 emission. Total grain yield were recorded 5.72, 5.96, 6.012, 6.127, 6.497 and 6.56 t ha^{-1} under the treatments urea only (no organic amendments), urea + rice straw compost, urea + charcoal, urea + $CaSiO_3$, urea + rice straw compost + $CaSiO_3$, and urea + charcoal + $CaSiO_3$, respectively. Among the treatments urea + charcoal + $CaSiO_3$ was found the best for reducing CH_4 emission and increasing rice production followed by urea + rice straw compost + $CaSiO_3$ and urea + $CaSiO_3$ treatments, respectively. Calcium silicate which contains mainly silicon and active iron oxides (electron acceptors) could be introduced with the conventional N, P, K fertilizer for reducing CH_4 emissions and increasing rice productivity under irrigated rice farming system.
Key words: Integrated, organic, fertilizers, methane emission, rice, irrigated.

Introduction

Rice (*Oryza sativa* L.) is the most important staple food in Asia and also in Bangladesh. Bangladesh is a small country with a large population and each year, nearly 1.47 million people are added to its current population of about 162.2 million and at present population growth is 1.29% (BBS, 2009). Profitable rice farming ensures political stability for the country and provides a sense of food security to the people (Bhuiyan *et al*., 2002). Rice has been growing over 25 million ha of land under irrigated and rainfed condition which cover about 84% of total cropped area in Bangladesh (BBS, 2008). Boro, T. Aman and Aus rice cover of 11386, 12474 and 2270 acres with production of 17762, 9662 and 1507 metric ton respectively (BBS, 2008). Aman rice covers the largest area of 9.82 million hectares with production of 12.84 million tons. The yield of rice in Bangladesh is 2.21 t ha^{-1} (AIS, 2008). The pressure on Bangladesh land resources to produce more rice will aggravate in the coming years due to increasing population and demand for food. Rice demand would increase by 25% to keep pace with population growth (Maclean, 2002). High fertilizer responsiveness is an essential criterion for a high yielding rice varieties and nitrogen is one of the major nutrient elements for crop production that can contribute a lot for higher yield of rice (Chang and Bardenas, 1964). Future technologies will rely on the adoption of high-yielding cultivars, efficient water management, and increased use of different fertilizers. Some production practices may promote CH_4 (methane) emissions while others may infer a net decrease of the CH_4 source strength.

Rice is produced at least twice in the same crop field in Bangladesh. In case of Rice- Fallow-Rice cropping pattern, one rice crop is fully irrigated (Boro rice) and another is mostly rainfed (T.Aman rice). The flooded rice paddy has been identified as one of the most important sources of anthropogenic CH_4 emission (Jacobson, 2005). CH_4 exerts significant effect on the global heat balance and is the second most important greenhouse gas next to CO_2 (Mosier *et al*., 1998). Before the industrial revolution the atmospheric concentration of CH_4 was 0.7 ppmv. By 2000, the CH_4 concentration has increased to 1.75 ppmv and has been continuing to increase at an annual rate of 1% (Schimel, 2000). Although alternate drying and wetting of rice field decrease CH_4 emission, but increase the N_2O (nitrous oxide) emissions under well dry condition, which is another most potential greenhouse gass and global warming potential is 310 times higher compared to CO_2 (IPCC, 2001). Silicate fertilizer, contain high amount of available silicate, active iron, free iron and manganese oxides, may act as electron acceptor. CH_4 flux was significantly decreased by use of silicate fertilizer in rice field (Ali et al., 2009). Using experimental data collected from different areas of the world, Denier van der Gon and Neue (1995) have developed a relationship between CH_4 emissions and added organic matter. Rice straw is also applied on purpose as an organic fertilizer (Watanabe and Kimura, 1995). Urea increased grain and straw yields significantly but harvest index was not increased significant but a significant increase in CH_4 emission due to application of urea has been reported by Singh *et al*., 1996. Since all known methanogens use NH_4+ as nitrogen source (Palmer and Reeve, 1993), the stimulatory effect of ammonium based fertilizer on CH_4 production is not surprising. It has been argued that application of N-fertilizer decreases the soil C to N ratio and promotes activity of soil micro- organisms, thus contributing to the increase CH_4 production (Wang *et al*., 1992). The specific objectives of this experiment were to quantify CH_4 fluxes under organic and inorganic fertilizers applied during rice cultivation, and to increase rice productivity with integrated management of organic and inorganic fertilizers.

Materials and Methods

The experiment was conducted in Transplanted Aman (T. Aman) seasons (BRRIdhan28) at Departmental experimental field of Environmental Science, Bangladesh Agricultural University, Mymensingh during the period of 15 January to 28 May 2016 farming season. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

In 2016 T. Aman season, seeding was done in 15 January and twenty-two days old seedlings were transplanted in the main field at the three seedlings per hill with 25cm × 25cm row and hill spacing. Land preparation for rice cultivation was done by 3-4 times plowing and cross-plowing followed by laddering. Fertilizers were applied at the following doses-Rice straw compost-3 t ha^{-1}, Charcoal-1 t ha^{-1} and CaSiO3-100 Kg ha^{-1}, respectively in all plots. At the time of final land preparation nitrogenous fertilizer in form of urea (prilled or gooti) was applied as basal doze and rest of urea was applied in two equal splits at 30 DAT and 60 DAT. But all other fertilizers such as TSP (110 kg ha^{-1}), MoP (70 kg ha^{-1}) and gypsum (45 kg ha^{-1}) were applied as per respective doses in two equal splits at the land preparation time and 30 DAT. Hand weeding was done when deemed necessary. Two times Koratral was used to prevent the plant from attack of insect. The water depth was 40-45 cm. The experimental field was divided into three blocks. Each block was divided into 6 plots. There are 6 treatments in each block. Thus the total numbers of unit plots were 18. The area of each plot was 10 square meter (4m × 2.5 m). The treatment combinations were randomly distributed to unit plots. The experimental treatments were: T_1: Urea (220 Kg ha^{-1}) only (no organic amendments); T_2: Urea (220 Kg ha^{-1}) + rice straw compost (2 t ha^{-1}) ; T_3: Urea (220 Kg ha$_{-1}$) + Charcoal (1 t ha^{-1}) ; T_4: Urea (220 Kg ha^{-1}) + $CaSiO_3$ (100 Kg ha^{-1}); T_5: Urea (220 Kg ha^{-1}) + rice straw compost (2 t ha^{-1}) + $CaSiO_3$ (100 Kg ha^{-1}); T_6: Urea (220 Kg ha^{-1}) + Charcoal (1 t ha^{-1}) + $CaSiO_3$ (100 Kg ha^{-1})

Analytical techniques: Gas samples were collected by using the closed-chamber method (Ali *et al*., 2008) during the rice cultivation. The dimensions of close chamber were 62 cm × 62 cm × ll2 cm. Two chambers were installed in each experimental plot. Gas sample was collected out at two times (11.00 am- 2.00 pm) a day per week to get the average CH_4 emissions during the cropping season. Gas sample was collected in 50 ml gas-tight syringes at 0 and 30 minutes intervals after chamber placement over the rice planted plot. The samples were analyzed for CH_4 by using gas chromatograph (Varian star 3400, USA) equipped with an FID (Flame Ionization Detector). The analysis column used a stainless steel column packed with Porapak NQ (Q 80-100 mess). The temperatures of column, injector and detector were adjusted at 100º C, 200º C, and 200º C respectively.

Calculation of CH_4 flux: Flux (F mg or µg m^{-2} hr^{-1}) was calculated

$$F = \rho*(V/A)*(\Delta c/\Delta t)*273/T$$

Where; F = methane flux (mg m^{-2} hr^{-1}); ρ = gas density (0.714 mg CH_4 m^{-3}); V = volume of the chamber (m^3); A = surface area of chamber (m2); Δc/Δt = rate of increase of methane gas concentration in the chamber (mg m-3 hr-1); T = 273 + mean temperature in chamber (°c)

Statistical Analysis

Data on the plant characteristics and CH4 emission were analyzed using the analysis of variance (ANOVA) technique with the help of computer package program MSTATC and mean differences were adjusted by Duncan's Multiple Range Test (DMRT).

Results and Discussion

Effect of organic and inorganic fertilizers on CH_4 emission during rice cultivation

CH_4 emission rate: flowering to ripening stages the CH_4 emission rate were found higher compare to initial growth stage (Fig. 1). The highest CH_4 emission 25.5 mg m^{-2} h^{-1} was observed in treatment T_2 and the second highest 21.9 mg m^{-2} h^{-1} was observed in treatment T_4. The lowest CH_4 emission 17.5 mg m^{-2} h^{-1} was found in treatment T_1 and the second lowest 18.7 mg m^{-2} h^{-1} was found in treatment T_6. 20.7 mg m^{-2} h^{-1} and 20.4 mg m^{-2} h^{-1} CH_4 emission were found in treatment T_3 and treatment T_5, respectively. As a silicate fertilizer, $CaSiO_3$ significantly increased the soil Eh and thus depressed the growth of methanogens bacteria and reduced CH_4 emission.

Effect of fertilizers on soil pH and soil Eh during rice cultivation:

During the flowering to ripening stage the maximum soil pH value was recorded in treatment T_2 which might cause maximum CH_4 flux at this treatment. The lower pH values were found in treatments T_1, T_6 and T_5, respectively which may cause lower CH_4 emission (Fig. 2). Wang et al. (1993) observed that the CH_4 production rate in paddy soil peaked at a pH between 6.9 and 7.1. From Fig. 3 it was found that maximum soil reduction condition i.e. soil Eh value (- ve) was recorded in the treatments T_1, T_3 and T_2 during the flowering and ripening stages which causes significantly higher CH_4 flux compare to other treatments.

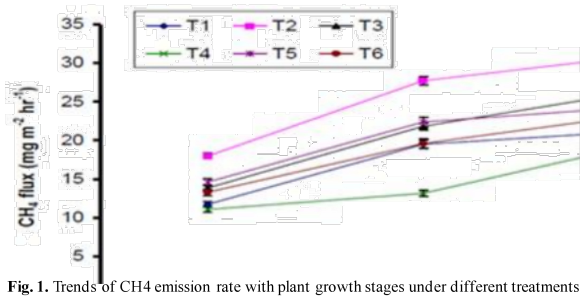

Fig. 1. Trends of CH4 emission rate with plant growth stages under different treatments

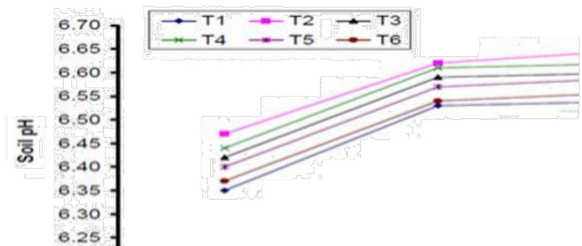

Fig. 2. Change in soil pH with plant growth stages under different treatments

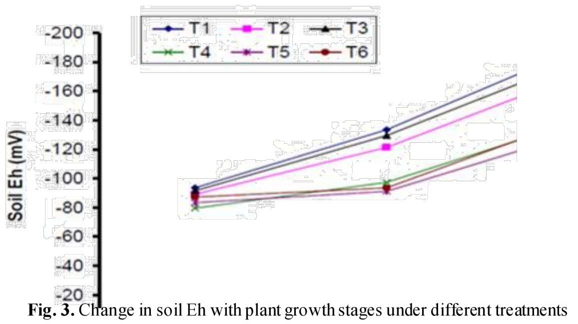

Fig. 3. Change in soil Eh with plant growth stages under different treatments

Effect of organic and inorganic fertilizers on the growth and yield attributes of rice cultivar BRRI Dhan28

Plant height: The highest plant height 86.03 cm was found in the treatment T_5, which was statically similar to the treatment T_6 (85.93 cm), T_4 (85.40 cm), T_3 (85.03 cm) and T_1 (84.67 cm). The lowest plant height 84.38 cm was found with the treatment T_2 (Table 1).

Number of tillers hill^{-1}: The highest number of tillers hill^{-1} (14.29) was found in the treatment T6 followed by (14.13) with T_5, while the lowest number of tillers hill^{-1} (12.10) was found in treatment T_4 (Table 1).

Number of panicle hill^{-1}: The highest number of panicle hill^{-1} (11.93) was obtained from treatment T_5. The lowest number of panicle hill^{-1} (10.30) was found in treatment T_3 (Table 1).

Number of grains panicle^{-1}: The highest number of grains panicle^{-1} (145.20) was obtained from treatment T_3. The lowest number of grains panicle^{-1} (124.30) was found in treatment T_1 (Table 1).

Percentage of ripened grains: The highest percentage of ripened grains (89.27%) was obtained from treatment T_5. The lowest percentage of ripened grains (85.43%) was found in treatment T_3 (Table 1).

1000 grains weight: The highest 1000 grains weight 25.98g and 25.95g were found in treatments T_6 and T_5, respectively. The lowest 1000 grains weight 22.57g was obtained from the treatment T_1 (Table1).

Grains weight hill^{-1}: The highest grains weight hill^{-1} 36.93g and 37.05g were in treatments T_5 and T_6. The lowest grains weight hill^{-1} 32.19g was obtained from T_1 treatment (Table 1).

Table 1. Effect of integrated management of organic and inorganic fertilizer on rice growth and yield components of BRRI Dhan 28

Treatment	Plant height (cm)	No. of tillers hill^{-1}	No. of panicle hill^{-1}	No. of grains panicle^{-1}	No. of grains hill^{-1}	% Ripened grain	1000 grains wt. (g)	Grain wt. g hill^{-1}	Straw wt. g hill^{-1}
T_1	84.67 ab	12.17 c	11.47 ab	124.3 c	1426.23 c	87.10 abc	22.57 abc	32.19 c	33.13 c
T_2	84.38ab	12.63bc	10.93bc	133.4b	1458.51b	86.73bc	24.71abc	34.10b	36.86c
T_3	85.03ab	13.13b	10.30c	145.2a	1496.61abc	85.43c	24.37bc	34.45b	37.53ab
T_4	85.40a	12.10c	1.40ab	129.8bc	1480.77ab	87.07abc	24.74ab	34.55b	38.06ab
T_5	86.03a	14.13a	11.93a	131.1bc	1565.65a	89.27a	25.95a	36.93a	38.97b
T_6	85.93a	14.29a	11.56ab	135.7b	1569.76a	88.95ab	25.98a	37.05a	41.19a
$LSD_{0.05}$	1.527	0.698	0.878	6.84	94.30	2.11	0.474	1.82	2.45
SE(±)	0.326	0.434	0.255	2.41	29.15	0.513	0.109	0.799	0.852
Level of sign.	*	**	**	**	**	**	*	**	**
CV%	1.01	3.06	4.45	2.89	3.59	1.36	1.18	3.06	3.98

**= Significant at 1% level of probability ; *= Significant at 5% level of probability

Straw weight hill^{-1}: The highest Straw weight hill^{-1} 41.19g was found in treatment T_6. The lowest straw weight hill^{-1} 33.13g found in treatment T_1 (Table 1).

Grain yield ha^{-1} : The highest grain yield 6.56 t ha^{-1} was observed in treatment T_6. The lowest grain 5.72 t ha^{-1} was obtained from treatment T_1 (Table 2).

Straw yield ha^{-1}: The highest straw yield 6.79 t ha^{-1} was obtained from treatment T_6. The lowest straw yield 5.96 t ha^{-1} was obtained from treatment T_1 (Table 2).

Harvest Index (HI): The highest harvest index 49.68% was found in treatment T5.The lowest harvest index 49.02% was obtained from treatment T1 (Table 2).

Table 2. Effect of integrated management of organic and inorganic fertilizer on yield (t ha^{-1}) and total CH_4 emission of BRRI Dhan 28

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI (%)	mg CH4 m^{-2} h^{-1}
T_1	5.720 c	5.960 c	48.97 b	17.47 d
T_2	5.960 bc	6.140 c	49.26 ab	25.55a
T_3	6.010 abc	6.200 bc	49.24 ab	20.67 bc
T_4	6.130 abc	6.270 bc	49.41 ab	21.85 b
T_5	6.500 ab	6.580 ab	49.68a	20.43 c
T_6	6.560 a	6.790 a	49.03 b	18.74 d
LSD $_{0.05}$	0.5210	0.4674	0.422	1.276
SE(±)	0.133	0.125	0.106	1.14
SD	0.326	0.306	0.259	2.80
Level of sign.	*	**	*	**
CV%	4.65	4.05	0.47	3.37

**= Significant at 1% level of probability ; *= Significant at 5% level of probability

Chemical properties of soil after rice harvest: Silicate fertilizer significantly increased active iron in soil after rice harvesting (Table 3), which depressed the methanogens bacteria. As a result CH4 emission decreased.

Different type of organic and inorganic soil fertilizers significantly affect plant parameter (plant height, no. of tillers hill^{-1}, no. of panicle hill^{-1}, no. of grains panicle^{-1}, % ripened grain, 1000 grains wt, grain wt hill^{-1}, straw wt hill^{-1}, grain yield ha^{-1}, straw yield ha^{-1} and HI %). The highest plant height (86.03 cm), no. of panicle hill^{-1} (11.93) and % ripened grain (89.27) were found in urea + rice straw compost + $CaSiO_3$ treatment. The highest no. of grains panicle-1 (145.20) was found in urea + charcoal treatment. The highest no. of tillers hill-1 (14.29), no. of grains hill-1 (1568.76), 1000 grain wt 25.98g, grain wt hill-1 37.05g, straw wt hill-1 41.19g, grain yield 6.56 t ha^{-1} and straw yield 6.79 t ha^{-1} were observed in urea + charcoal + $CaSiO_3$ treatment. Urea + $CaSiO_3$ reduced CH_4 emission 14.48% and increased grain yield 7.12%. Urea + rice straw compost + $CaSiO_3$ reduce CH_4 emission 20.04% and increased grain yield 13.58%. Urea + charcoal +$CaSiO_3$ reduce CH_4 emission 26.65% and increased grain yield 14.69%. So, among the treatments urea + charcoal + $CaSiO_3$ is the best for reducing CH_4 emission and increasing rice production followed by urea + rice straw compost + $CaSiO_3$ and urea + $CaSiO_3$ treatments, respectively.

Table 3. Soil properties at harvesting stage

Treatment	% OM	pH	T-N%	P (ppm)	K (meq/100g)
T_1	1.63 b	6.44 b	0. 138	3.51 bc	0.070
T_2	1.69 ab	6.63 a	0.127	3.95 a	0.073
T_3	1.72 a	6.54 ab	0.119	3.85 ab	0.073
T_4	1.71 a	6.57 ab	0.135	3.98 ab	0.073
T_5	1.73 a	6.47 b	0.134	3.41 c	0.073
T_6	1.73 a	6.45 b	0.133	3.52 bc	0.070
$LSD_{0.05}$	0.0974	0.13	0.056	0.373	0.056
SE(±)	0.026	0.032	0.003	0.084	0.001
Level of sign.	**	**	NS	*	NS
CV%	3.45	1.17	27.89	5.68	32.90

**= Significant at 1% level of probability; *= Significant at 5% level of probability NS= Non Significant

Therefore, calcium silicate, which contains mainly silicon, active and free oxides (electron acceptors) could be introduced with the conventional N, P, K fertilizer for reducing CH_4 emissions and increasing rice productivity under irrigated rice farming system.

References

AIS (Agricultural Information Service). 2008. Krishi Diary; Agricultural Information Service. Khamarbari, Farmgate, Dhaka. pp. 10-25.

Ali, M.A., Lee, C.H., Lee, Y.B. and Kim P.J. 2009. Silicate fertilization in no tillage rice farming for mitigation of methane emission and increasing rice productivity. Agril. Ecosyst. Environ., 132:16-22.

BBS (Bangladesh Bureau of Statistics). 2008. The yearbook of Agriculture Statistics. Bangladesh Bureau of Statistics, Ministry of planning Govt. people's Repub. of Bangladesh. Dhaka. pp. 123-127.

Bhuiyan, N. I., Paul, D. N. R. and Jabber, M. A. 2002. Feeding the extra million by 2025 challenges for rice research and extention in Bangladesh. A key note paper. National workshop on rice research and extention 2002, January 29-31, Bangldesh Rice Research Institute, Gazipur.

Chang, T.T., and Bardenas, E. A. 1964. The morphology and vertical characteristics of the rice plant, IRRI Tech. Bull. 4:40.

Denier van der Gon HAC, and Neue, H.U. 1995. Influence of organic matter incorporation on the methane emission from a wetland rice field. Global Biogeochem. Cycle., 9:11-22.

Intergovernmental Panel on Climate Change (IPCC). 2001. Special Report on Emission Scenario. A special report of Working Group III of IPPC (eds Nakicenovic et al.) .Cambridge University Press, Cambridge. UK.

Jacobson, M.Z. 2005: Atmospheric Pollution: History, Science and Regulation. Cambridge University Press, New York.

Maclean, J. L., Dawe, D. C., Hardy, B. and Hettel. 2002. Rice Almanac (3rd ed.) International Rice Research Institute, Los Banos, Philippines: 253.

Mosier, A.R., Duxbury, J.M., Frency, J.R., Heinemeyer, O., Minami, K. and Johnson, D.E. 1998: Mitigation agricultural emissions of methane. Climate Change., 40:39-80.

Schimel, J. 2000. Microbes and methane. Nature., 403:375-377

Wang, Z. P., Delune, R. D., Masscheleyn, P. H. and Patrick, W. H. 1993. Soil redox and pH effects on methane production in flooded rice soil. Soil Sci. Soc Am J., 57: 382-385.