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Effect of fertilizers to reduce CH_4 emission and increase rice productivity

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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} h^{-1} was found from the urea + rice straw compost treatment and lowest seasonal CH_4 flux 17.468 mg m^{-2} h^{-1} was produced in urea only (no organic amendments). The second lowest CH_4 flux 18.744 mg m^{-2} h^{-1} was recorded from the urea + charcoal + $CaSiO_3$ 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.

INTRODUCTION

Rice (*Oryza sativa* L.) 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)

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emissions while others may infer a net decrease of the CH_4 source strength.

Recent studies have reported global annual CH_4 emissions from paddy fields to be 53 Tg (1 Tg= 1 million metric tons) CH_4 (Cao et al., 1998), 25-54 Tg CH_4 (Mosier et al., 1998) and 33-49 Tg CH_4 (Neue and Sass, 1998) and 29-61 Tg CH_4 (IPCC, 2002). CH_4 is an important greenhouse gas (with a 23-fold higher global warming potential than CO_2 (Carbon di oxide) over a 100 year time horizon (IPCC, 2002), which has been reported to account for 95% of total CO_2 equivalent emissions from paddy fields (Naser et al., 2005). It has been estimated that global rice production must also double by the year 2020 in order to meet the growing demands (Hossain, 1997) and this may increase CH_4 fluxes by up to 50% (Bouwman, 1991). 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).

It is now certain that factors such as temperature, soil properties, kind and amount of fertilizers, organic matter content, fertilizer application, rice plant, pH, redox potential and water management are major factors affecting CH_4 emission from rice field (Sass et al., 1991; Adhya et al., 1994; Banker *et al*., 1995; Buendia et al., 1998). There is positive linear correlation between CH_4 production and incubation temperature from 15° to 37°C and negative linear correlation between 37° to 50°C. Supplementation of rice straw, green manure and compost has a stimulating effect on CH_4 production (Buendia et al., 1998). 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 gas 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). DAP (Di Ammonium Phosphate) contents the N and P element which is important for rice growth.

Agriculture releases significant amount of CH_4 to the atmosphere, but changes in agricultural management regime also offer possibilities for mitigation (Robertson et al., 2000; Mosier et al., 2006; Smith et al., 2008). Various organic techniques have been utilized for about 6,000 years to make agriculture sustainable and improve the environment (Pimentel et al., 2005). Recently, organic agriculture has been promoted as a partial means for mitigating agricultural CH_4 emissions (FAO, 2002). Therefore the present work is aimed 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

Experimental site

The experimental site was located 24.75° N Latitude and 90.50° E Longitude at an elevation of 18m above the sea level, 6 Km to the south of Mymensingh town and 115 Km to the north of

Dhaka under the Old Brahmaputra flood plain (Agro-Ecological Zone-9). The soil of the experimental field belongs to the sonatola soil series of non-calcareous dark grey flood plain soil under the Old Brahmaputra Alluvial Tract which is more or less neutral in reaction with 1.65% organic matter content and pH value 6.5. The experimental field was a medium high land and well drained condition. The morphological and physio-chemical properties of the soil of the site have been obtained (UNDP and FAO. 1998).

The experimental area was under subtropical climate characterized by moderately high temperature and heavy rainfall during the Kharif season (April-September) and scanty rainfall with moderately low temperature during Rabi season (October- March). Monthly meteorological data recorded in weather yard, Department of Irrigation and Water management, Bangladesh Agricultural University, Mymensingh during the study period from January to May, 2010.

Rice variety

BRRI dhan-28 was used as the test crop. This variety was developed by BRRI (Bangladesh Rice Research Institute) and is recommended as high yielding cultivar during Boro season. Field duration of BRRI dhan-28 is 110-120.

Experimental treatments

The treatments included organic and inorganic materials and are indicated as 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})

The Experiment

The experimental was laid out in a Randomized Complete Block Design (RCBD) with three replications. The experimental field was divided into three blocks to represent the replication. Each block was divided into 6 plots with raised bunds to accommodate the treatment combinations. Thus the total number of unit plots ware 18. The area of each plots was 10 square meter (4 m × 2.5 m). The treatment combinations were randomly distributed to unit plots. Seeds of BRRI dhan-28 were collected from Agronomy field laboratory Bangladesh Agricultural University, Mymensingh. Sprouted seeds were sown in the well prepared wet nursery.

Land preparation

The experimental field was opened by a tractor and subsequently ploughed and cross plough three times followed by laddering to obtain the desirable tilth. The land was cleaned by removing weeds, stubbles and crop residues.

Fertilizer application

Fertilizers were applied at the following doses- Rice straw compost-3 t ha^{-1}, Charcoal-1 t ha^{-1} and $CaSiO_3$-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 T.S.P (110 kg ha^{-1}), M.O.P (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.

Transplanting

Nursery beds were made wet by application of water both in the morning and evening on the day before uprooting the seedlings. Seedlings were uprooted carefully early in the morning and transplanting in row in the main field at the three seedlings per hill with 25 cm × 25 cm row and hill spacing. Flooding and drainage, bund repairing and weeding were done regularly and for plant protection measures Koratral was used at the rate of 9.88 Kg ha^{-1} at 35 DAT. Sampling was done at the scheduled time and the harvested crop of each plot was separately bundled, tagged and brought to the threshing floor. The grains were threshed, cleaned, sun dried and weighed to record the grain yield. The grain yield was adjusted to 14% moisture content. Straw was sun dried and weighed to record the straw yield.

Collection of data at harvest

Five plants were randomly selected from each plot prior to harvesting for collection of data on plant characters. Data were collected on the following parameters: Plant height, Total number of tillers hill^{-1}, Number of panicle hill^{-1}, Number of Grains panicle^{-1}, Percentage of ripened grains, weight of 1000- grain, grain yield, straw yield, Harvest index

Measurements of soil redox potential (Eh) and soil pH

Soil redox potential (Eh) and pH were measured every week interval by Eh meter (PRN-41, DKK-TOA Corporation) and pH meter (Orion 3 star, Thermo electron corporation) respectively, during the rice cultivation.

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, 200° C, and 200° C respectively.

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

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

Where,
ρ= gas density (CH_4= 0.714); V= volume of the chamber (m^3); A= area of the chamber (m^2)
Δc/Δt= average increase of gas concentration in the chamber; T= 273+ mean temperature of the chamber (^{o}C)

Statistical analysis

Data on the plant characteristics and methane 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) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effect fertilizers on CH_4 emission during rice cultivation

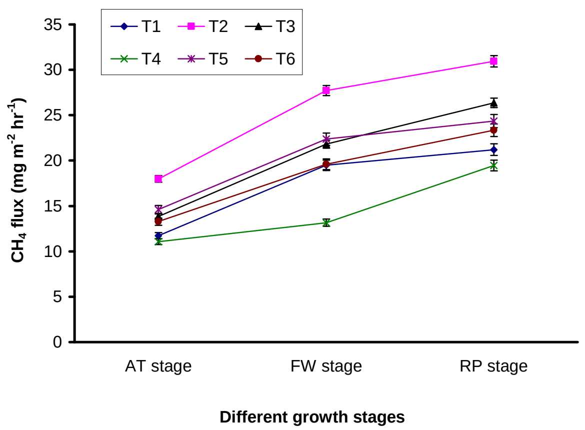
CH_4 emission rate

The organic and inorganic fertilizers significantly influenced CH_4 emission rate during BRRI Dhan-28 cultivation. CH_4 emission was low at the initial growth stage. Then it increased significantly with the application of organic and inorganic fertilizers. At the flowering to ripening stages the CH_4 emission rate were found higher compare to initial growth stage (Figure 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 (Table 2). 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

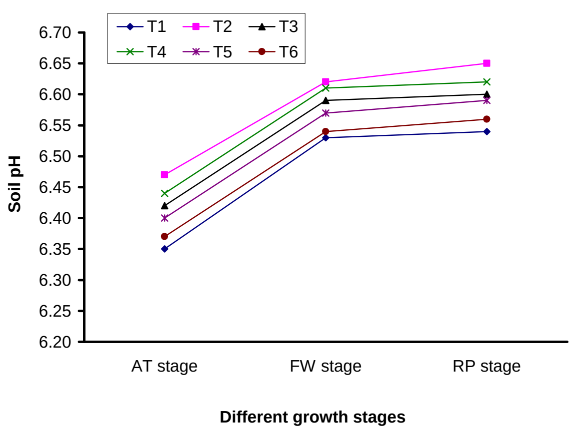
Soil pH was increased with the application of organic and inorganic fertilizers. At the flowering to ripening stages the soil pH value in all treatments were found higher compare to initial growth stage. During the flowering to ripening stage the maximum soil pH value was recorded in treatment T_2 which 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 (Figure 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 figure 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.



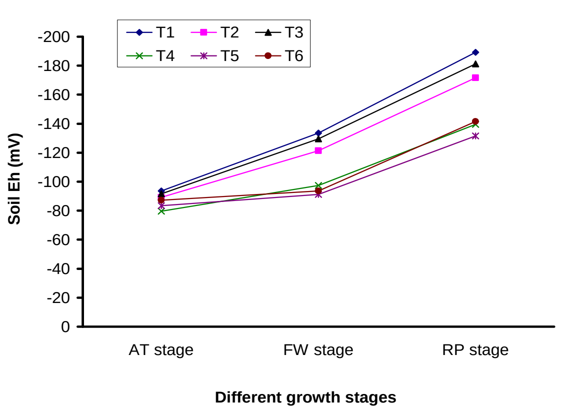
AT=Active tillering, FW=Flowering, RP=Ripening

Figure 1: Trends of CH4 emission rate with plant growth stages under different treatments



AT=Active tillering, FW=Flowering, RP=Ripening

Figure 2: Changes in soil pH with plant growth stages under different treatments



AT=Active tillering, FW=Flowering, RP=Ripening

Figure 3: Changes in soil Eh with plant growth stages under different treatments

Effect of fertilizers on the growth and yield attributes of rice cultivar BRRI Dhan-28

Plant height

Plant height was significantly influenced due to application of various types of organic and inorganic fertilizers. 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 number of tillers hill^{-1} was significantly affected with the application of organic and inorganic fertilizer. The highest number of tillers hill^{-1} (14.29) was found in the treatment T_6 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}

Number of panicle hill^{-1} was significantly affected with the application of organic and inorganic fertilizer. 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}

Number of grains panicle^{-1} was significantly influenced by the organic and inorganic fertilizer. The highest number of grains panicle^{-1} (145.20) was obtained from treatment T3. The lowest number of grains panicle^{-1} (124.30) was found in treatment T_1 (Table 1).

Percentage of ripened grains

Various type of organic and inorganic fertilizer significantly influenced the 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).

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	84.38 ab	12.63 bc	10.93 bc	133.4 b	1458.51 b	86.73 bc	24.71 abc	34.10 b	36.86 c
T_3	85.03 ab	13.13 b	10.30 c	145.2 a	1496.61 ab	85.43 c	24.37 bc	34.45 b	37.53 ab
T_4	85.40 a	12.10 c	11.40 ab	129.8 bc	1480.77 ab	87.07 abc	24.74 ab	34.55 b	38.06 ab
T_5	86.03 a	14.13 a	11.93 a	131.1 bc	1565.65 a	89.27 a	25.95 a	36.93 a	38.97 b
T_6	85.93 a	14.29 a	11.56 ab	135.7 b	1569.76 a	88.95 ab	25.98 a	37.05 a	41.19 a
$LSD_{0.05}$	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

In a column, figure having similar letter (S) or without letter(s) do not differ significantly whereas figures bearing dissimilar letter (S) differ significantly as per DMRT.
**= Significant at 1% level of probability; *= Significant at 5% level of probability

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 CH_4 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 bc	49.26 ab	25.55 a
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	49.68 a	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

In a column, figure having similar letter (S) or without letter(s) do not differ significantly whereas figures bearing dissimilar letter (S) differ significantly as per DMRT.

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

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

In a column, figure having similar letter (S) or without letter(s) do not differ significantly whereas figures bearing dissimilar letter (S) differ significantly as per DMRT.
**= Significant at 1% level of probability; *= Significant at 5% level of probability; NS= Non Significant

1000 grains weight

Organic and inorganic fertilizer significantly influenced on 1000 grains weight. It was observed that higher 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 (Table 1).

Grains weight hill^{-1}

Grains weight hill^{-1} was significantly influenced by the organic and inorganic fertilizer. 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).

Straw weight hill^{-1}

Organic and inorganic soil amendments significantly influenced 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}

Various type of organic and inorganic fertilizer significantly influenced on grain yield. 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 (Fig. 4).

Straw yield ha^{-1}

Straw yield ha^{-1} was significantly influenced by the organic and inorganic fertilizer. 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 (Fig. 4).

Harvest Index (HI)

Harvest index was significantly influenced due to the application of organic and inorganic fertilizer. It was evident that the highest harvest index 49.68% was found in treatment T_5.The lowest harvest index 49.02% was obtained from treatment T_1 (Table 2)

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 CH_4 emission decreased.

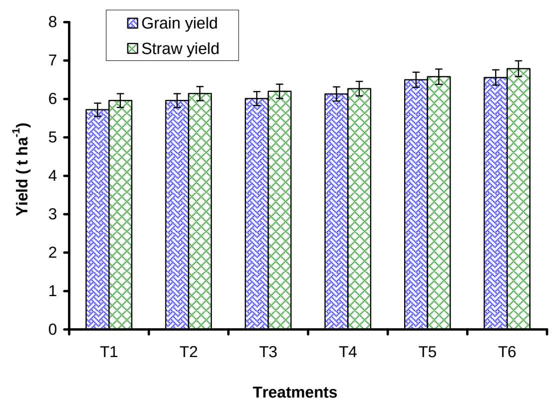


Figure 4: Effect of integrated management of organic and inorganic fertilizer on grain and straw yield (t ha^{-1}) of BRRI Dhan-28

CONCLUSIONS

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 25.98 g, grain wt hill^{-1} 37.05 g, straw wt hill^{-1} 41.19 g, 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.

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.

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