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Effect of organic rice (*Oryza sativa*) cultivation on greenhouse gas emission

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ABSTRACT

Organic cultivation of crops is important for improving and maintaining soil health and reducing environmental pollution. The organic sources of fertilizer also have impact on emission of greenhouse gases. A field experiment was conducted during 2015-16 and 2016-17 in organic rice (*Oryza sativa* L.) field to study the impact of organic farming on Global Warming Potential (GWP).Treatments consisted of eight combinations namely: (T_1) non-amended control; (T_2) Recommended dose of fertilizers; (T_3) FYM; (T_4) VC; (T_5) FYM + CR; (T_6) VC+CR; (T_7) FYM + CR + B; and (T_8) VC+CR+B. Experimental results revealed that Global Warming Potential (GWP) of various treatments varied from 569.95 kg to 1840.55 kg CO_2 eq. ha^{-1} and 634.66 kg to 1899.20 kg CO_2 eq. ha^{-1} during both years, respectively. Different organic treatment combinations led to about 3.0 to 29.4%reduction in GWP over the conventional system, while 67.78%reduction was observed in control.The order of GWP among different combination of treatments was as follows: Control < VC < FYM < FYM+CR < VC+CR < VC+CR+B < FYM+CR+B < Conventional. This study indicated that replacement of existing conventional systems with various organic practices could reduce GWP of the system and thus needs to be considered for development of sustainable farming systems.

Key words: Biofertilizer, Conventional system, FYM, GHG emissions, Organic system, Rice

Climate change is a crucial environmental issue and has broad implications on the food system, healthy sustainable development, and future of the economy. Global warming caused by human-induced GHG emission represents significant scientific and political challenges of 21st century. The ability to respond to big task of regulating greenhouse gas (GHG) emission has links to overall well-being of our entire country. IPCC 2018 (SR15) special report highlights several climate-change impacts that could be overcome by limiting global warming to 1.5°C compared to 2°C or more (IPCC 2018).

The GHGs, viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), trap some of the outgoing radiation (infrared) emitted by the Earth's surface and radiate it back downward, thereby warming the atmosphere of the Earth. Among various sources, agricultural soil is the major contributor to the greenhouse effect. Globally, agriculture contributes 54% of anthropogenic CH_4 and 58% of N_2O emissions (Pathak and Aggarwal 2012). In soils, CH_4 and CO_2 are produced during microbial decomposition of organic matter under anaerobic and aerobic conditions, respectively, while the use of nitrogenous fertilizers to soils is the leading source of N_2O emissions (Pathak *et al.* 2003; Bhatia *et al.* 2005).

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There are contradictory statements regarding the contribution of organic farming to total greenhouse gas emissions from agriculture. Some researchers (Gomiero *et al.* 2008; Nemecek *et al.* 2011) suggested that organic farming is a way to mitigate GHG emission while others (Gattinger *et al.* 2007; Radl *et al.* 2007) found that organic farming can contribute more to GHG emission as compared to conventional farming. Although much research has been carried out in this field, there is still ambiguity regarding the contribution of organic and conventional farming to GHG emissions. Therefore, the study was carried out to estimate/ quantify the net Global Warming Potential (GWP) of different organic treatments as compared to the conventional one in flooded rice (*Oryza sativa* L.) ecosystems under Indo-Gangetic plains.

MATERIALS AND METHODS

Characteristics of the experimental site

The field experiment was conducted in the prime block 14-C of the research farm of the ICAR-IARI, New Delhi, India, during 2015-16 and 2016-17. The site is situated at 28.4° N, and 77.1° E at an elevation of 228.6 m above mean sea level. It has a semi-arid and sub-tropical climate with hot and dry summers and cold winters. During summer months (May and June), the temperature ranges from 41°C to 48°C, while January is coldest with the minimum temperature ranging between 3°C and 7°C. The mean rainfall of Delhi is 650 mm, which is mostly received during

July–September with occasional rain during winter. The soil of the experimental field is a sandy clay loam (typical Ustochrept) in texture, having 52.06% sand, 22.54% silt, and 25.40% clay.

Treatments and cropping systems

Treatments consisted of eight combinations and summarized as namely: (T_1) FYM + CR + B; (T_2) VC+CR+B (T_3) FYM + CR; (T_4) VC; (T_5) FYM; (T_6) VC+CR; (T_7); Recommended dose of fertilizers, and (T_8) a non-amended control (Table 1). These treatments were applied to the rice crop during the period 2015-16 and 2016-17. The specific biofertilizers used to the rice crop were BGA (10 kg ha^{-1}) and cellulolytic culture (0.8 kg ha^{-1}). FYM (FarmYard manure) - equivalent to 60 kg N ha^{-1}; VC (Vermicompost) – equal to 60 kg N ha^{-1}; CR (Crop residue) – incorporation of the residue of the previous crop in succeeding crop and B (Biofertilizer) – BGA and cellulolytic culture. Cropping history of the experimental field: Organic farming since 2003-04; Experimental design: RBD, Plot size: 6.4 m × 7.6 m; Variety: Pusa Basmati - 1121.

The field was flooded with water and then puddled. All the organic amendments (FYM, VC, and residues)were incorporated into the soil 10-15 days before the transplanting of rice. Inorganic N was applied in conventional treatment through surface broadcast of urea in three split doses of 60 kg N ha^{-1}, 30 kg N ha^{-1} and 30 kg N ha^{-1} at 20, 40 and 60 days after transplanting (DAT) of rice. Phosphorus and potassium were incorporated into the soil at the time of transplanting using single super phosphate and muriate of potash, respectively.

Greenhouse gas sampling and analysis

The collection of gas samples was carried out by the closed chamber technique (Gupta *et al.* 2016). Gas samples were drawn with a 50 ml syringe with the help of a hypodermic needle (24 gauges) at 0, 30, and 60 minutes and syringes were made airtight with a 3-way stopcock. Headspace volume inside the box was recorded, which was used to calculate the flux of N_2O, CO_2, and CH_4. The concentration of gases in the gas samples were analyzed using a gas chromatograph.The concentration of CH_4 and N_2O in the sample was analyzed using a flame ionization detector (FID) and electron capture detector (ECD), respectively. Whereas the concentration of CO_2 was measured using FID fitted with methanizer. Total CO_2, CH_4, and N_2O emissions during crop growth period was estimated by successive linear interpolation of the average emission of these gases on sampling days assuming a linear trend of emission during the periods when no sample was taken (Bhatia *et al.* 2005; Gupta *et al.* 2016).

Table 1 Number of treatments and treatment details

	Treatment	Source of nutrients
T_1	Control	No fertilizer or manure is applied
T_2	Conventional	Recommended dose of N, P, K through synthetic fertilizers (120:60:40)
T_3	FYM	Through FYM
T_4	VC	Through vermicompost
T_5	FYM + CR	Through FYM and crop residue
T_6	VC+CR	Through vermicompost and crop residue
T_7	FYM + CR + B	Through FYM, crop residue and biofertilizers in addition
T_8	VC+CR+B	Through vermicompost, crop residue and biofertilizers in addition

Estimation of global warming potential

Global warming potential (GWP) is an index used to compare the effectiveness of each greenhouse gas in trap heat in the atmosphere relative to a standard gas by convention CO_2. The GWP for CH_4(based on a 100-year time horizon) is 21, while that for N_2O is 310 when the GWP value for CO_2 is taken as 1. The global warming potential (kg CO_2 equivalent ha^{-1}) for each treatment was calculated using the following equation (Watson *et al.* 1996).

$$\text{GWP (kg ha}^{-1}\text{ CO}_2\text{ eq.)} = \text{CH}_4\text{ (kg ha}^{-1}) * 21 + \text{N}_2\text{O (kg ha}^{-1}) * 310 + \text{CO}_2\text{ (kg ha}^{-1})$$

Statistical analysis

Data analysis for all soil parameters was performed using the SAS software. For statistical analysis of data, the least significant difference (LSD at P = 0.05) was used to determine whether means differed significantly.

RESULTS AND DISCUSSION

The salient findings in terms of differences in GHG emission and GWP among different treatments are discussed below.

Methane emission

Organic and conventional plots had shown noticeable variations in greenhouse gas emissions during both the years. Organic plots treated with FYM+CR+B (34.56 kg ha^{-1}) and VC+CR+B (32.82 kg ha^{-1}) were recorded highest in CH_4 emission (Table 2). CH_4 emission from non-amended control (11.22 kg ha^{-1}) and conventional (21.57 kg ha^{-1}) plots were less as compared to all organic plots. Methane emission from all the plots increased gradually after transplanting, attains peaks about 40 days after transplanting (DAT), and then decreased until harvesting (Fig 1 and 2). The peak of emission appeared after around 40 DAT probably because soil redox potential (Eh) values decreased rapidly after flooding and stabilized at −200 to −240 mV within 5–7 weeks to produce a significant amount of methane (Ali 2008).

Overall, CH_4 emission in organic rice was considerably high as compared to conventional and control plots. High flux from organic plots might be due to a low C/N ratio of

Table 2 Seasonal variability of CH_4 emission under organic and conventional amended plots

Treatment	Seasonal cumulative CH_4 emission (kg ha^{-1})		
	2015-16	2016-17	Average pooled
Control	10.51±0.46	11.93±0.80	11.22
Conventional	20.35±0.64	22.78±1.61	21.57
FYM	29.40±1.62	31.83±2.10	30.62
VC	27.48±2.49	29.91±2.63	28.69
FYM+CR	28.19±2.45	28.29±1.36	28.24
VC+CR	31.41±0.94	31.85±2.06	31.63
FYM+CR+B	34.28±2.66	34.84±1.45	34.56
VC+CR+B	32.10±2.59	33.53±1.52	32.82

organic manures added, resulted in faster mineralization to emit high CH_4. Organic matter acts as a source of the electron (Singh *et al.* 1998) and favours CH_4 emission in anaerobic (flooded) condition. The availability of more amount of labile carbon substrate at the methanogenic environment enhances CH_4 emission (Zhu *et al.* 2017; Aslam 2019).

The temporal pattern and magnitude of CH_4 fluxes significantly differed among the treatments (Fig 1 and 2). However, high fluxes of CH_4 were observed during the tillering to reproductive stages in all the treatments. At the beginning of the crop cycle, bubble formation and vertical movement is the primary CH_4 transfer mechanism in the soil. After tillering, diffusion through the aerenchyma becomes the dominant process, responsible for more than 90% of the CH_4 emission during active tillering and reproductive stage (Tyler *et al.* 1997). The observed trend was in agreement with Liu *et al.* (2011), Malla *et al.* (2005) and Pandey *et al.* (2012).

When compared to a conventional plot, organic treatments increased CH_4 emissions in flooded rice system as nitrogen fertilization in conventional plot stimulates the growth and activity of CH_4 oxidizing bacteria, leading to a reduction in emissions. The same was also reported by Bodelier and Laanbroek (2004) and Bruce *et al.* (2012). The cumulative CH_4 emission under rice treatments varied from 10.51 to 34.28 kg ha^{-1} and 11.93 to 34.84 kg ha^{-1} in the first and second years, respectively (Table 2). Similar findings were also obtained by Gupta *et al.*(2016).

Nitrous oxide emission

Average N_2O emission was highest from conventional plot (3.17 kg ha^{-1}) followed by VC+CR+B (0.98 kg ha^{-1}), FYM+CR+B (0.97 kg ha^{-1}), FYM (0.91 kg ha^{-1}), FYM+CR (0.85 kg ha^{-1}) and then VC (0.78 kg ha^{-1}) (Table 3). N_2O emission from the conventional plot was about 3.23 to 4.95 times higher than organic treatments during the study. Skinner *et al.* (2019) also reported that organic farming emitted on average 2.78 kg less N_2O-N ha^{-1} than non-organic farming on an annual basis.

Peaks of emission were observed in conventional plot following fertilizer and irrigation application (Fig 3). N_2O fluxes after irrigation might be because of the creation of an anoxic condition after each irrigation speed up the denitrification process (Arah and Smith 1989). N_2O flux from control plot (0.38 kg ha^{-1}) was lowest among all the treatments. Ali *et al.* (2015) also reported the reduction in seasonal cumulative N_2O emission with biochar and biochar plus *Azolla*-cyanobacteria amendments.

N_2O emission was highest from conventionally managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application. In conventional plots,

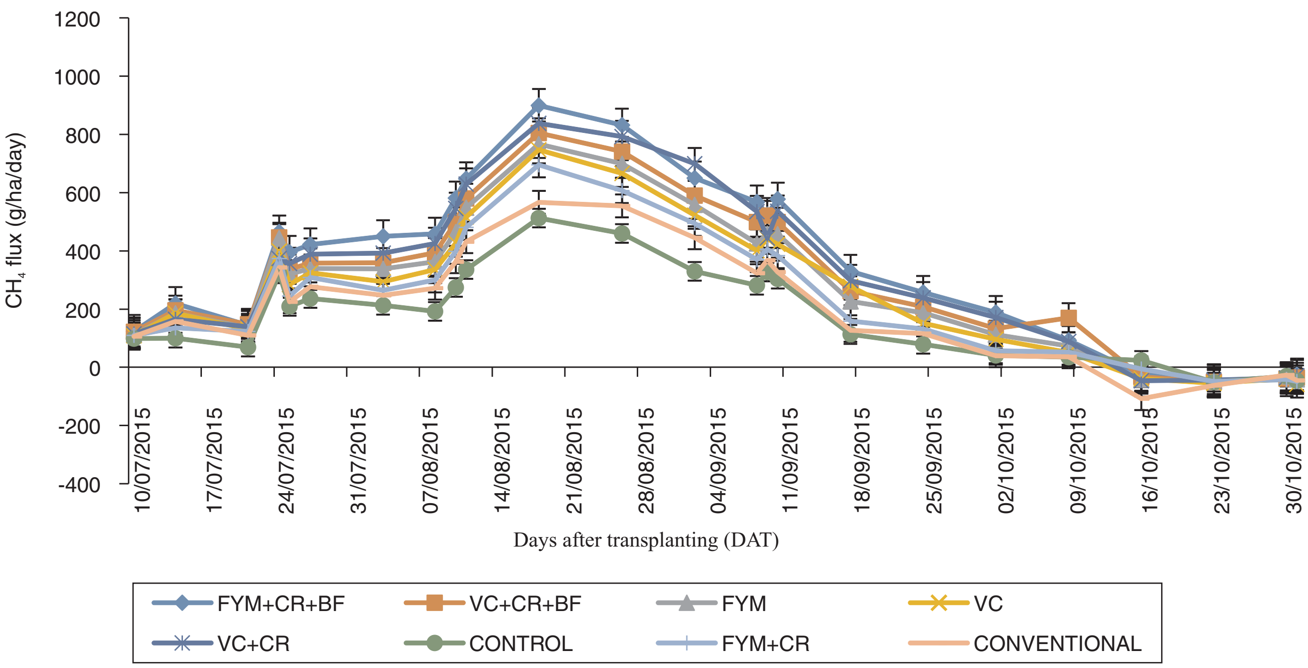

Fig 1 Temporal variability of CH_4 emission under organic and conventional amended plots during 2015-16.

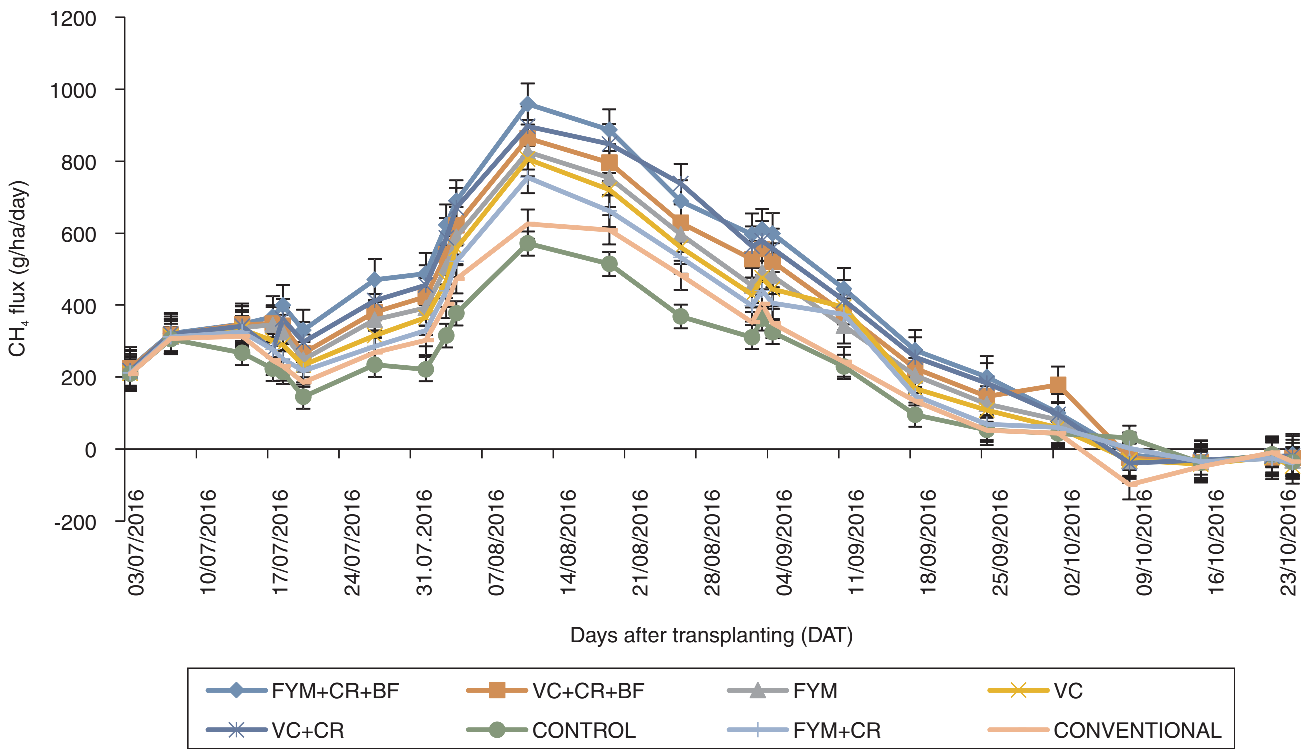

Fig 2 Temporal variability of CH_4 emission under organic and conventional amended plots during 2016-17.

high N_2O fluxes might be because of readily available nitrogen responsible for more denitrification losses. Among organic treatments, VC+CR+B applied plots were high in emitting N_2O, followed by FYM+CR+B, FYM, and FYM+CR. Narrow C/N ratio of FYM and VC might be mineralized faster and made NH_4^+ substrate available for nitrification enhanced N_2O emission (Bhatia *et al.* 2005). *Azolla* cover increased N_2O emission from rice paddies due to nitrogen fixation by *Azolla*, providing a source for N_2O production through nitrification and denitrification (Ma *et al.* 2012). This might be probable reason for higher emission of N_2O from biofertilizer applied plots as compared to other organic plots.

N_2O flux from the treatments showed more or less similar temporal trends with the appearance of a peak after 3-4 days of urea applications during both years. However, magnitude of flux differed (Fig 3). The observed trend of N_2O flux was in agreement with Bhatia *et al.* (2012) and Malla *et al.* (2005). Urea takes two to three days for hydrolysis into NH_4^+-N under optimum moisture and temperature condition (Pathak *et al.* 2003, Gupta *et al.* 2016) which undergoes further nitrification to NO_3^--N resulting in a peak of N_2O flux generally three to four days after urea application.

The cumulative emission of N_2O from different treatments varied from 0.37 to 3.14 kg ha^{-1} in the first year and from 0.38 to 3.21 kg ha^{-1} in second year (Table 3). The cumulative N_2O emission from different combinations were in the order of Control < VC+CR < VC < FYM+CR < FYM< FYM+CR+B< VC+CR+B< Conventional.

Table 3 Seasonal variability of N_2O emission under organic and conventional amended plots

Treatment	Seasonal cumulative N_2O emission (kg ha^{-1})		
	2015-16	2016-17	Average pooled
Control	0.37±0.10	0.38±0.04	0.38
Conventional	3.14±0.07	3.21±0.12	3.17
FYM	0.90±0.08	0.93±0.09	0.91
VC	0.76±0.08	0.79±0.07	0.78
FYM+CR	0.85±0.07	0.85±0.10	0.85
VC+CR	0.63±0.05	0.65±0.06	0.64
FYM+CR+B	0.96±0.06	0.97±0.05	0.97
VC+CR+B	0.98±0.13	0.99±0.11	0.98

Carbon dioxide emission

Maximum CO_2 flux was observed in FYM+CR+B (786.03 kg ha^{-1}) and VC+CR+B (785.81 kg ha^{-1}) treated plots followed by other organic plots (VC+CR-655.65 kg ha^{-1}, FYM+CR-635.62 kg ha^{-1}, FYM-534.53 kg ha^{-1}and VC-477.24 kg ha^{-1}). It was minimum from non-amended control (249.40 kg ha^{-1}), while emission from conventional plot (433.76 kg ha^{-1}) was lower as compared to all the organic plots (Table 4). Different organic treatment combinations led to about 9.1 to 44.8% increase in CO_2 flux over the conventional system.

All the treatments were lower in CO_2 flux after the sowing of the rice crop. However, during the later crop growth stage, particularly vegetative growth, the CO_2

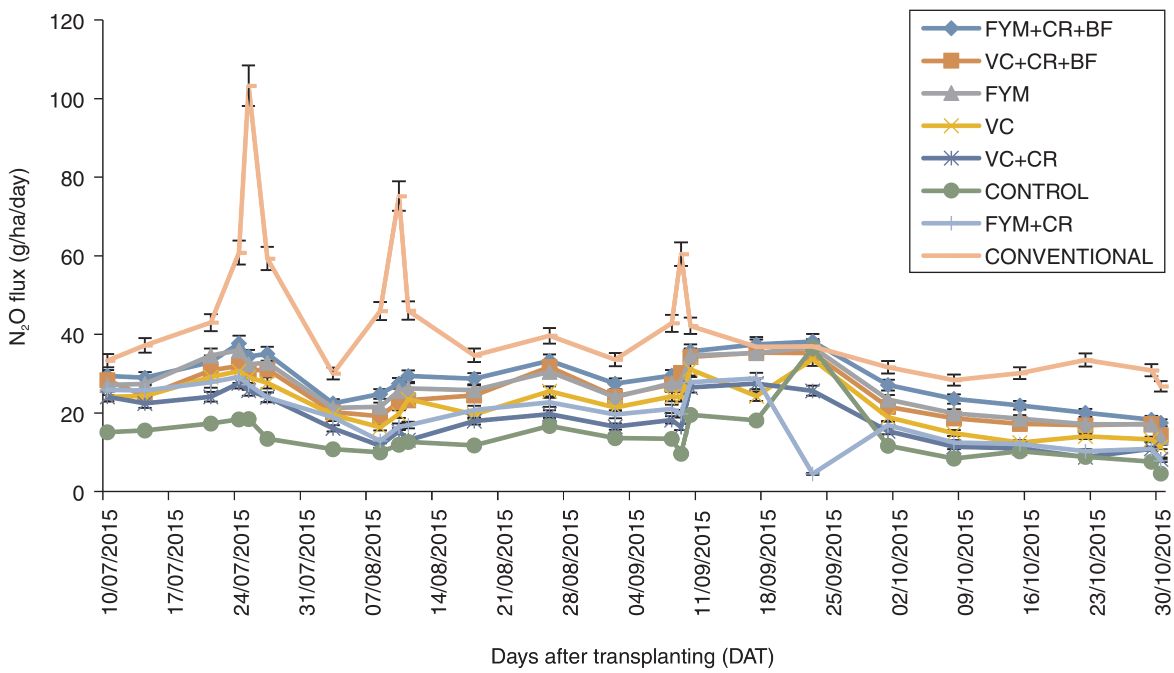

Fig 3 Temporal variability of N_2O emission under organic and conventional amended plots during 2015-16.

emission flux increased significantly and reached its maximum value during 55-65 DAT . This higher flux might be due to the higher availability of the carbon substrates in the corresponding period and higher microbial activity (Campbell *et al.* 2001; Iqbal *et al.* 2009). In rice crop, the highest CO_2 flux during this period has also been reported (Pandey *et al.* 2012; Bhattacharyya *et al.* 2012). This may also be explained by oxidation of CH_4 produced in the anaerobic zones of submerged soils into CO_2 by methanotrophs in aerobic wetland soils and upland soils (Le Mer and Roger 2001).

The soluble/labile organic carbon is the immediate source of carbon for microorganisms, and it enhances CO_2 emission (Pathak *et. al.* 2003). This might be the probable reason for higher CO_2 emission from FYM+CR+B and VC+CR+B, followed by VC+CR applied plots than the conventional and control treatments (Fig 4), which result in significantly higher cumulative CO_2 emission from organic treatments (Table 4). These results are in line with Huifang *et al.* (2014). Similar kind of results was also reported by Jianwen *et al.* (2004) under the application of rapeseed cake and wheat straw application.The cumulative CO_2emission from different combinations were in the order of Control < Conventional< VC < FYM < FYM+CR < VC+CR < VC+CR+B < FYM+CR+B.

Table 4 Seasonal variability of CO_2 emission under organic and conventional amended plots

Treatment	Seasonal cumulative CO_2 emission ($kg\ ha^{-1}$)		
	2015-16	2016-17	Average pooled
Control	233.58±12.94	265.23±14.06	249.40
Conventional	440.77±50.55	426.75±20.51	433.76
FYM	535.47±16.97	533.58±16.30	534.53
VC	469.74±15.31	484.74±19.91	477.24
FYM+CR	639.02±62.45	632.23±41.09	635.62
VC+CR	650.77±22.39	660.52±20.81	655.65
FYM+CR+B	764.57±33.53	807.50±14.11	786.03
VC+CR+B	794.92±26.23	776.09±37.86	785.51

Global warming potential

Net Global Warming Potential was calculated by adding the GWPs of all three greenhouse gases from rice crops. GWP of organic and conventional treatments was depended on the flux of CH_4, CO_2, and N_2O throughout the cropping season. The GWP (CH_4+N_2O+CO_2) of various treatments varied from 569.95 to 1840.55 kg CO_2 eq. ha^{-1} and 634.66 to 1899.20 kg CO_2 eq. ha^{-1} in the first and second years, respectively (Table 5).

From the results, it was evident that the net GWP of conventional treatment was significantly higher as compared to the organic treatments. Lowest GWP was observed in unfertilized control. The high Global Warming Potential from some of the organic plots was due to higher flux of CH_4 that may be attributed to high carbon substrate available in these plots to be acted upon by the methanogens (Zhu *et al.* 2017). But overall GWP of organic plots was lower than the conventional plot because of much less emission of N_2O from these plots as compared to the conventional one. Due to their high GWP, the reduction of N_2O emission gives organic farming an additional advantage over conventional farming decreasing overall GWP significantly (Venterea *et al.* 2012).

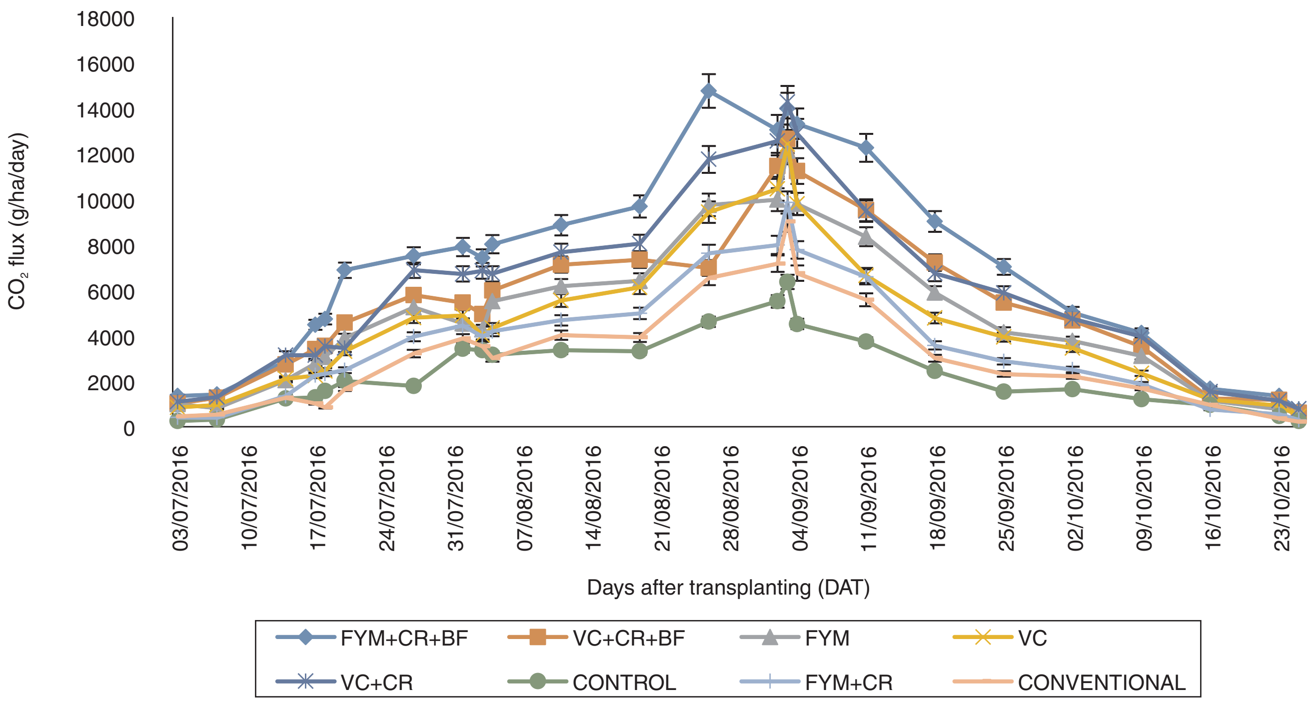

Fig 4 Temporal variability of CO_2 emission under organic and conventional amended plots during 2016-17.

Table 5 Net Global Warming Potential under organic and conventional amended plots during years 2015-16 and 2016-17

Treatment	GWP (kg CO_2 eq. ha^{-1})		
	2015-16	2016-17	Average pooled
Control	569.95±22.08	634.66±40.37	602.31
Conventional	1840.55±36.44	1899.20±55.05	1869.88
FYM	1431.87±68.14	1489.28±87.19	1460.57
VC	1283.39±45.81	1357.75±50.95	1320.57
FYM+CR	1494.58±94.68	1488.86±97.64	1491.72
VC+CR	1505.75±52.57	1529.84±53.43	1517.80
FYM+CR+B	1783.08±35.80	1840.87±31.13	1811.98
VC+CR+B	1771.86±87.13	1787.12±99.62	1779.49

Different organic treatment combinations led to about 3.0 to 29.4% reduction in GWP over the conventional system, while 67.78% reduction was observed in control. Ali *et al.* (2015) also obtained similar results with biochar and biochar plus *Azolla*-cyanobacteria amendments. The order of GWP among the different combination of treatments was as follows: Control < VC < FYM < FYM+CR < VC+CR < VC+CR+B < FYM+CR+B <Conventional during both the years (Table 5).

Conclusion

The conventional system of growing rice in IGPs contributes significantly to GHG emission, having a greater GWP due to higher emissions of CH_4 and N_2O. The adoption of an organic system of rice farming can substantially reduce GHG emissions. This study indicated that replacement of existing conventional systems with various organic practices could reduce GWP of system by 3.0 to 29.4%. Net GWP (CH_4, N_2O, and CO_2) of organic plots was lower than conventional plot because of much loweremission of N_2O from these plots as compared to the conventional one. Nitrogen sources like VC, FYM, crop residue, and also biofertilizers can be effectively utilized for reduction of N_2O emission under organic farming. In longer term, this practice might even lead to an increase in soil organic carbon. These results indicate that adoption of organic practices over a conventional system can be an efficient low carbon-emitting option. It may be concluded that organic farming delivers more vital ecosystem services, social and environmental benefits, and thus needs to be considered for development of sustainable farming systems.

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