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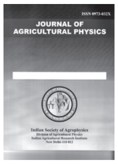

Research Article

Effect of Soil Physico-Chemical Properties on Greenhouse Gas Emission under Organic Rice Cultivation

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ABSTRACT

Organic cultivation of crops is important for maintaining soil health and improving environmental quality. A field experiment was conducted at IARI, New Delhi to quantify the emission of methane (CH_4), nitrous oxide (N_2O), and corban dioxide(CO_2), and their global warming potential (GWP), and correlation with physico-chemical properties of soil of different organic and conventional treatments under rice-wheat-mungbean cropping system. 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. Among soil pH, EC, and bulk density, only bulk density was found to be correlated with CO_2 emission from rice, and the correlation was significantly negative. Soil organic carbon (SOC) also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice, wheat, and mungbean crops. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. The positive and significant correlation was also observed between the N_2O flux and total N, NO_3^--N, and NH_4^+-N.

Key words: Climate change, Soil organic carbon, Methane, Rice, Bulk density

Introduction

Climate change is a crucial environmental issue and has broad implications on the food system, healthy sustainable development, and the future of the economy. Global warming caused by human-induced GHG emission represents significant scientific and political challenges of the 21st century. The ability to respond to the big task of regulating greenhouse gas (GHG) emissions has links to our entire country's overall well-being. 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 longwave 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

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conditions, respectively. In contrast, the use of nitrogenous fertilizers to soils is the leading source of N_2O emissions (Pathak *et al.,* 2003; Bhatia *et al.,* 2005).

Organic farming is a trend since ancient times for growing most of the world's food holistically and naturally by using organic manure with the help of animal and human power. It stimulates and improves agro-ecosystem health by increasing below-ground biodiversity, which assists in performing better nutrient cycling through soil biological activity. It emphasizes the use of mostly on-farm organic inputs with avoiding the use of synthetic chemicals such as fertilizers, pesticides, and hormones. Organic farming is a better way to make agricultural production sustainable (Hazarika *et al.*, 2013). According to the World of Organic Agriculture Report 2018, India is home to 30% of total organic farmers in the world but accounts for only 2.59 % (1.5 Mha) of the total organic cultivation area of 57.8 Mha.

GHG flux varies with the interactions among the physical, chemical, and biological properties of soil and microclimate. Soil micro-organisms are involved in virtually all soil processes, mediating soil organic matter decomposition and nutrient cycling, and are also involved in GHG dynamics between the soil and atmosphere. The main contributor to potential greenhouse gases, i.e., CO_2, CH_4, and N_2O to the atmosphere, is believed to be the terrestrial carbon pool. The exchange rate between the terrestrial pool and the atmosphere is generally affected by various soil biological, physical, and chemical properties (Pramanik and Prasad, 2015), including soil organic matter content. From the literature, it is clear that greenhouse gases produced and released by soil micro-organisms are influenced by various soil physic-chemical properties. However, the full extent of their role in GHG efflux has not been explored, and interactions are not fully understood, and there exists a need for closer examination of the relationships among soil physic-chemical properties and greenhouse gas efflux mechanisms. Therefore, the experiment was carried out to study the effect of Soil Physico-Chemical Properties on Greenhouse Gas Emission under different organic treatments as compared to the conventional one in flooded rice 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 maximum 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 (Typic Ustochrept) is sandy clay loam 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: (T1) FYM + CR + B; (T2) VC+CR+B (T3) FYM + CR; (T4) VC; (T5) FYM; (T6) VC+CR; (T7); recommended dose of fertilizers, and (T8) a non-amended control (Table 1). The specific biofertilizers used to the rice crop were BGA (10 kg ha^{-1}) and Cellulolytic culture (0.8 kg ha^{-1}). FYM (Farm Yard Manure) - equivalent to 60 kg N ha^{-1}; VC (Vermicompost) - equivalent 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 were used. The treatments are laid in randomized block design (RBD) and size of each plot was 6.4 m × 7.6 m. The field is under organic farming since 2003-04 and rice variety 'Pusa Basmati – 1121' was used.

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

Table 1. Treatment details of the experiment

Sr. No.	Treatments	Source of nutrients
T_1	FYM + CR + B	FYM, Crop Residue and Biofertilizers in addition
T_2	VC+CR+B	Through Vermicompost, Crop Residue and Biofertilizers in addition
T_3	FYM + CR	FYM and Crop Residue
T_4	VC	Vermicompost
T_5	FYM	Farmyard manure
T_6	VC+CR	Vermicompost and Crop Residue
T_7	Conventional practice	Recommended dose of N, P, K through synthetic fertilizers (120:60:40)
T_8	Control	No fertilizer or manure is applied

N was applied in conventional treatment through the 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. N application in through organic amendments in all the organic treatments was applied equivalent to 60 kg ha^{-1}.

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).

Soil physico-chemical properties

Soil samples were analyzed at sowing and flowering stages of rice, wheat, and mungbean to assess the effects of long-term organic and conventional rice-wheat-mungbean cropping system on soil physico-chemical parameters. Different soil physico-chemical properties like EC, pH, NO_3^--N , NH_4^+-N, Total Nitrogen, bulk density and organic carbon were measured using the standard methodology.

Statistical Analysis

A two-factor analysis of variance (ANOVA) was performed to determine the effects of soil's physical properties on greenhouse gas emissions. 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 the impact of organic farming on GHG emission and soil physico-chemical properties and their correlation with GHG emissions have been discussed. GHG emission under organic amended and conventional plots has been shown in Table 2.

CH_4 emission from Rice

Organic and conventional plots had shown noticeable variations in average greenhouse gas emissions. Organic plots treated with

Table 2. GHG emission under organic and conventional amended plots

Treatments	GHG emission (kg ha^{-1})		
	CH$_4$	N$_2$O	CO$_2$
Control	11.22	0.21	249.40
Conventional	25.57	1.77	545.02
FYM	30.62	0.51	534.53
VC	28.69	0.38	477.24
FYM+CR	28.24	0.45	635.62
VC+CR	31.63	0.24	655.65
FYM+CR+B	34.56	0.57	706.03
VC+CR+B	32.82	0.58	710.51

FYM+CR+BF (34.56 kg ha^{-1}) and VC+CR+B (32.82 kg ha^{-1}) were recorded highest in methane (CH$_4$) emission (Table 2) while it was relatively lower in organic treatments such as FYM+CR (28.24 kg ha^{-1}) and VC (28.69 kg ha^{-1}) than other organic plots. Though, the initial CH$_4$ emissions from these plots were comparable with FYM+CR+B and VC+CR+B applied plots. CH$_4$ emission from non-amended control (11.22 kg ha^{-1}) and Conventional (25.57 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). The temporal pattern and magnitude of CH$_4$ fluxes during rice significantly differed among the treatments. However, high fluxes of CH$_4$ were observed during the tillering to reproductive stages in all the treatments. The cumulative CH$_4$ emission under rice treatments varied from 11.22 to 34.56 kg CH$_4$ ha^{-1} in the first and second years, respectively (Table 2).

N$_2$O emission from Rice

Average N$_2$O emission was highest from Conventional Plot (1.79 kg ha^{-1}) followed by VC+CR+B (0.58 kg ha^{-1}), FYM+CR+B (0.57 kg ha^{-1}), FYM (0.51 kg ha^{-1}), FYM+CR (0.45 kg ha^{-1}) and then VC (0.38 kg ha^{-1}) during both years (Table 2). N$_2$O emission from the conventional plot was about two times higher than organic treatments during the study. Peaks of emission were observed in conventional plot following fertilizer and irrigation application (Fig. 2).

In the organic plots, N$_2$O emissions were comparatively higher during the later crop growth period. The N$_2$O flux from control plot (0.21 kg ha^{-1}) was lowest among all the treatments. N$_2$O emission was highest from conventionally

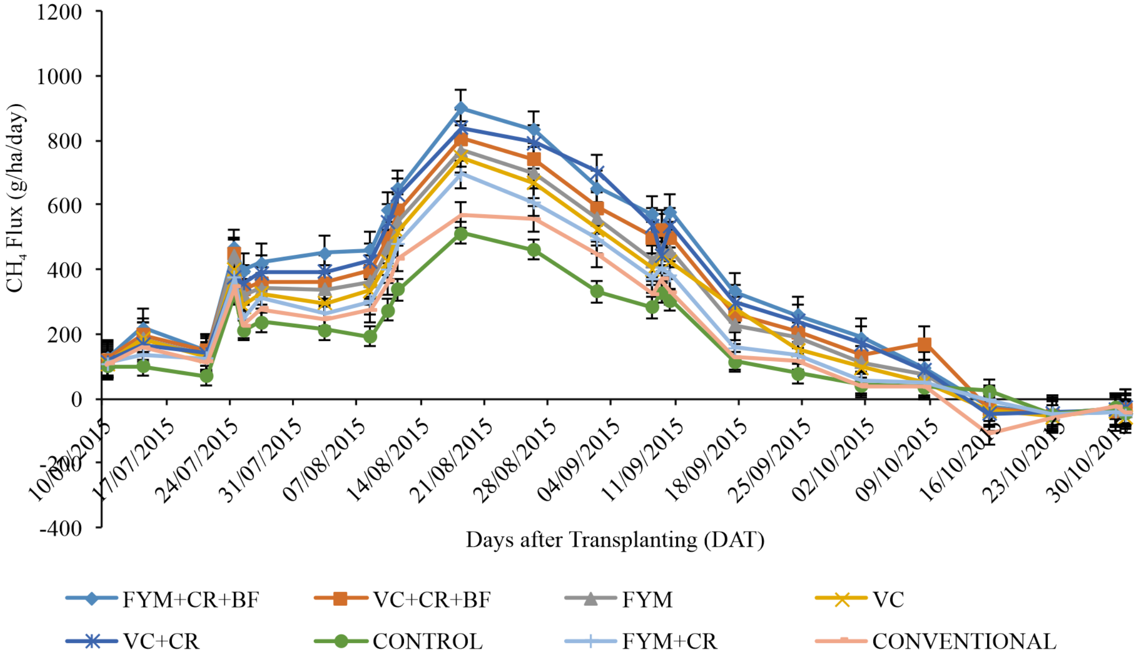

Fig. 1. Temporal variability of CH$_4$ emission under organic and conventional amended plots

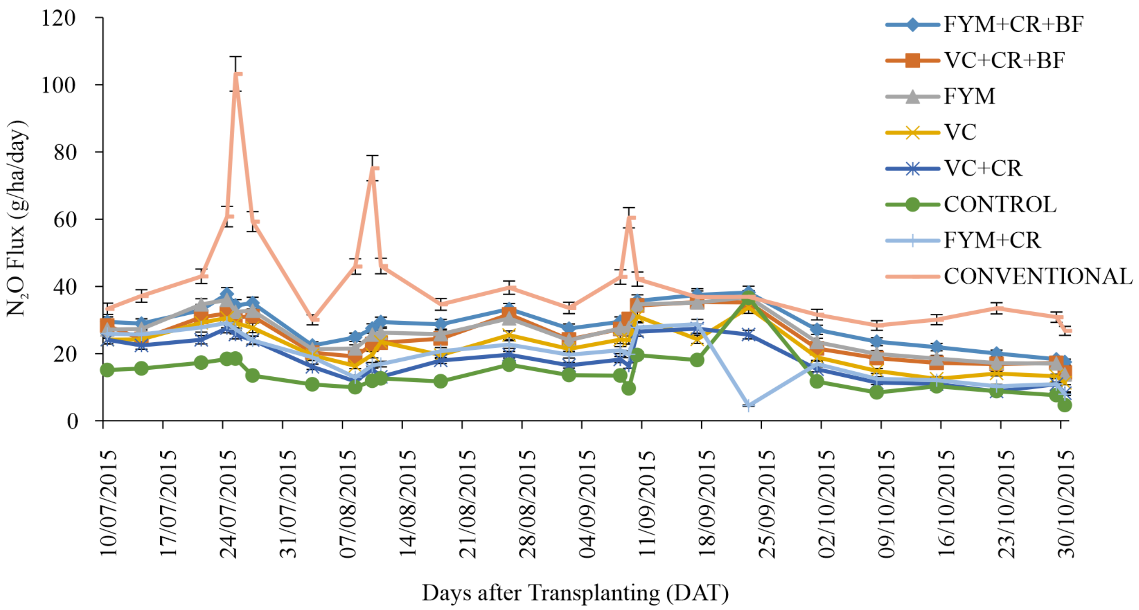

Fig. 2. Temporal variability of N_2O emission under organic and conventional amended plots

managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application through fertilizer. Among organic treatments, VC+CR+B applied plots were high in emitting N_2O, followed by FYM+CR+B, FYM, and FYM+CR.

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 the years. However, the magnitude of flux differed (Fig. 2). Application of urea in crop fields led to increased NH_4^+-N substrate supply to microorganisms for nitrification and denitrification process. N_2O peak was observed after three days of each dose of urea application in the present study. The lowest N_2O emission flux was observed in control treatment compared to the other treatments throughout the cropping seasons. It might be due to the lower availability of nitrogenous substrate for nitrification and denitrification process. The cumulative emission of N_2O from different treatments varied from 0.21 to 1.79 kg ha^{-1} (Table 2). 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.

CO_2 emission from Rice

CO_2 flux also exhibited temporal variability throughout the cropping period. Maximum CO_2 flux was observed in FYM+CR+B (706.03 kg ha^{-1}) treated plots and VC+CR+B (710.81 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 plot (249.40 kg ha^{-1}), while emission from conventional plot (545.02 kg ha^{-1}) was significantly lower as compared to organic plots (Table 2). Different organic treatment combinations led to 23.29 increase in CO_2 flux over the conventional system. CO_2 fluxes were lower during the initial stage, then it increased and reached maximum value between 45-60 DAT and then decreased again.

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 emission flux increased significantly and reached its maximum value during 55-65 DAT (Fig. 3). The cumulative CO_2 emission from different combinations was in the order of control < VC < FYM < conventional <

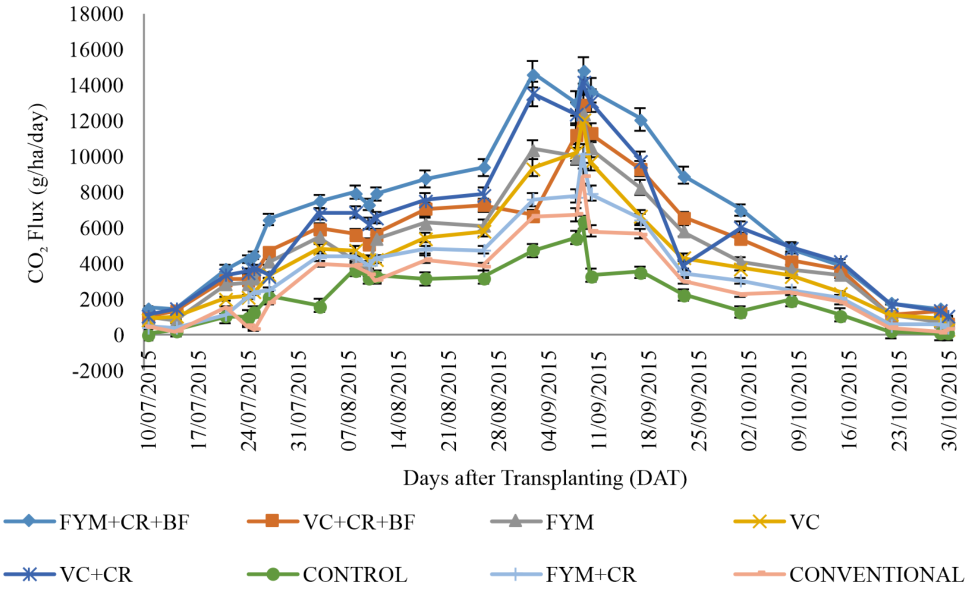

Fig. 3. Temporal variability of CO_2 emission under organic and conventional amended plots

FYM + CR < VC + CR < VC + CR + B < FYM + CR +B.

Impact on soil properties

The soil physico-chemical properties such as pH, EC, SOC, BD, NO_3^--N and NH_4^+-N are presented in Table 3. The results showed that the soil pH values were significantly higher in the conventional system than the organic farming system. The value for pH within the crop grown under both systems ranged from 7.99±0.53 to 8.75±0.49. Soil pH values were maximum in the conventional plot, followed by VC+CR+B treatment and control. The soil pH was decreased slightly, with the addition of organic manure. However, in organic plots, soil pH does not vary significantly. A slight decrease in soil pH with the addition of FYM has also been reported by Laxminarayana and Patiram (2005).

The results showed that the soil EC values were also higher in the conventional system than the organic farming system. The value for EC within the crop grown under both systems ranged from 131.3±7.4 to 256.1±14.5 µmho/cm (Table 3). Soil EC values were maximum in the conventional plot, followed by control, VC, and VC+CR+B treatment, and it was minimum in VC+CR. The soil EC was decreased with the

Table 3. Pooled data of soil physico-chemical properties in Rice

Treatments	pH	EC (µmho/cm)	SOC(%)	BD(Mg/m^3)	NO_3^--N	NH_4^+-N
Control	8.41 ± 0.56^{c}	211.3 ± 12.0^{b}	0.54 ± 0.03^{e}	1.49 ± 0.08^{b}	13.0 ± 0.7^{e}	33.4 ± 1.9^{f}
Conventional	8.56 ± 0.57^{a}	256.1 ± 14.5^{a}	0.53 ± 0.03^{e}	1.50 ± 0.08^{a}	39.5 ± 2.2^{a}	98.3 ± 5.6^{a}
FYM+CR+B	8.29 ± 0.55^{d}	208.6 ± 11.9^{bc}	0.83 ± 0.05^{a}	1.40 ± 0.08^{d}	27.4 ± 1.6^{bc}	59.7 ± 3.3^{d}
VC+CR+B	8.42 ± 0.56^{b}	204.6 ± 11.6^{bc}	0.72 ± 0.04^{b}	1.41 ± 0.07^{d}	28.5 ± 1.4^{b}	75.5 ± 4.2^{b}
FYM	8.29 ± 0.54^{d}	181.5 ± 10.3^{d}	0.65 ± 0.04^{bc}	1.43 ± 0.08^{c}	23.7 ± 1.3^{d}	45.6 ± 2.6^{e}
VC	7.99 ± 0.53^{f}	208.9 ± 11.8^{bc}	0.62 ± 0.04^{bc}	1.42 ± 0.06^{c}	24.9 ± 1.9^{cd}	46.2 ± 2.6^{e}
VC+CR	8.13 ± 0.51^{e}	151.7 ± 8.6^{f}	0.72 ± 0.0^{4b}	1.44 ± 0.07^{c}	27.7 ± 1.5^{bc}	59.1 ± 3.4^{d}
FYM+CR	8.28 ± 0.52^{d}	167.1 ± 9.5^{de}	0.64 ± 0.04^{d}	1.44 ± 0.07^{c}	28.0 ± 1.9^{bc}	66.2 ± 3.7^{c}
Mean	8.51	199.7	0.65	1.44	26.6	60.5
LSD ($p = 0.05$)	0.031	11.3	0.0474	0.0081	3.69	5.84

addition of organic manure. The increase in soil electrical conductivity as influenced by organic manure addition might be due to the amount of dissolved salts in the manures. Similarly, Eghball (2002) also reported that increasing manure rate also increased the soil EC with the application of P and N-based manure on a clay loam textured soil in Nebraska.

The results showed that the soil SOC values were significantly higher in the FYM+CR+B treatment, followed by VC+CR+B and FYM than the conventional system. The value for SOC within the crop grown under both systems ranged from 0.53±0.03 to 0.84±0.05% (Table 3). The soil SOC was increased with the addition of organic manure. Soil organic carbon (SOC) also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice, wheat, and mungbean crops. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. There was a highly significant ($P < 0.01$) correlation between the measured SOC contents and simulated CO_2 emissions (Abbas and Fares, 2009). Our findings are in concurrence with those of Lal and Logan (1995) and Akala and Lal (2001).

The values for BD were higher in conventional plot followed by control, FYM, FYM+CR, and VC+CR applied plots. The minimum bulk density was observed in FYM+CR+B and VC applied plots (Table 3). Our results showed that organic farming practices resulted in lower soil bulk densities as compared to conventional and control. The lower bulk density observed in the organic system is due to the permanent addition of organic amendments that contribute to increased organic matter input, decreasing soil bulk density (Valpassos *et al.*, 2001). Araújo*et al.*, 2009 also reported that Soil bulk density was lower in organic management than in conventional management. In our study, all organic treatments had much-reduced values for bulk density, possibly because of higher values of SOC content in soil and recorded lower penetration resistance than conventional fertilizer treatment and unfertilized control.

NO_3^--N was also found higher in conventional treatment as compared to organically treated plots and minimum in control. NO_3^--N was notably higher in conventional plot followed by VC+CR+B, FYM+CR, FYM+CR+B, and VC+CR, and VC applied plots. At the same time, it was the lowest in non-amended control. NH_4^+-N showed similar trends like NO_3^--N. The values for NH_4^+-N were higher in conventional plot followed by VC+CR+B, FYM+CR, VC+CR, FYM+CR+B, and VC applied plots. The control plot exhibited relatively lower amounts of soil NH_4^+-N. The use of N substrates directly influences the amount of NH_4^+ or NO_3^- available in the soil. Ammonium nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) are the substrates of nitrification and denitrification, respectively, and both can affect soil nitrous oxide emission. The higher the amount of NH_4^+-N, the greater the nitrification process (Khalil *et al.,* 2004, Liu *et al.,* 2005). As a consequence, the loss of N_2O increases, because the NO_2^- formed during the nitrification process can be used as an electron acceptor, if O_2 is limited, and also because the denitrification can occur after the nitrification when soil conditions are favorable. Emissions of N_2O will also be more significant when NO_3^--N in the soil is high as reported by Ruser *et al.* (2006) and Zanatta *et al.* (2010). When the NO_3^--N availability decreases, N_2O emissions will also decrease because denitrification is reduced (Hellebrand *et al.*, 2008; Sánchez-Martín *et al.,* 2008). The results were in line with the findings of Briggs *et al.* (2005). Inorganic N is readily available to plants in the form of ammonium and nitrate). However, over 90% of the N in most soils is held in organic forms, which must first undergo mineralization. The use of N-fertilizers directly influences the amount of NH_4^+-N or NO_3^--N available in the soil. (Khalil *et al.,* 2004; Liu *et al.,* 2005).

Correlation of soil pH, EC, and BD with CH_4 and CO_2 flux

Correlation of soil pH, EC, and BD with CH_4 and CO_2 flux in rice is shown in Table 4. The result showed that pH and EC had no significant correlation with CO_2 and CH_4 emission. While

Table 4. Correlation of soil pH, EC, and BD with CH_4 flux

	pH	EC	BD	CH_4 Rice
pH	1			
EC	0.43	1		
BD	0.88	0.48	1	
CH_4 Rice	-0.56	-0.49	-0.81**	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

bulk density (BD) was negatively correlated with methane emission (-0.81) from rice.

Among soil pH, EC, and bulk density, only bulk density was correlated with CO_2 emissions from rice. The correlation was significantly negative. A similar result was also reported by Novara *et al.* (2012). Bauer *et al.* (2006) showed that in conventional tillage, CO_2 efflux had a negative correlation with bulk density. According to the findings of Chappell et al. (2015), there was no significant relationship between pH and CO_2 efflux, but there was a significant relationship between bulk density and CO_2 efflux. Soil organic carbon (SOC) was significantly positively correlated with CH_4 flux from rice (+0.944). The SOC also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice crop. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. There was a highly significant ($P < 0.01$) correlation between the measured SOC contents and simulated CO_2 emissions (Abbas and Fares, 2009). Our findings are in concurrence with those of Lal and Logan (1995) and Akala and Lal (2001).

Correlation of total N, NH_4^+-N, and NO_3^--N with GHG emission

Correlation of total N, NH_4^+-N, and NO_3^--N with N_2O emission in rice is shown in Table 5. The positive and significant correlation was observed between the N_2O flux from rice with NO_3^--N (+0.84) and NH_4^+-N (+0.74).

Table 5. Correlation between Soil Nitrogen and N_2O Flux in Rice

	Total N	NH_4^+-N	NO_3^--N	Rice N_2O
Total N	1			
NH_4^+-N	0.88	1		
NO_3^--N	0.84	0.91	1	
Rice N_2O	0.92***	0.74*	0.85**	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

The use of N substrates directly influences the amount of NH_4^+ or NO_3^- available in the soil. Ammonium nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) are the substrates of nitrification and denitrification, respectively, and both can affect soil nitrous oxide emission. The higher the amount of NH_4^+-N, the greater will be the nitrification process (Khalil *et al.,* 2004; Liu *et al.,* 2005). As a consequence, the loss of N_2O increases, because the NO_2^- formed during the nitrification process can be used as the electron acceptor, if O_2 is limited, and also because the denitrification can occur after the nitrification when soil conditions are favorable. Emissions of N_2O will also be more significant when NO_3^--N in the soil is high as reported by Ruser *et al.* (2006) and Zanatta et al. *(*2010). When the NO_3^--N availability decreases, N_2O emissions will also decrease because denitrification is reduced (Hellebrand *et al.*, 2008 and Sánchez-Martín *et al.,* 2008).

Conclusions

Among soil pH, EC, and bulk density, only bulk density was found to be correlated with CO_2 emission from rice and the correlation was significantly negative. Soil organic carbon (SOC) also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice crop. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. The positive and significant correlation was also observed between the N_2O flux from the RWM cropping system and total N, NO_3^--N, and NH_4^+-

N. The use of nitrogenous fertilizers directly influences the amount of NH_4^+ or NO_3^- available in the soil. Ammonium nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) are the substrates of nitrification and denitrification, respectively, and both can affect soil nitrous oxide emission. The greater the amount of NH_4^+-N, the greater will be the nitrification process. From these results, it may be concluded that GHG flux varies with the interactions among various physic-chemical properties of soil. Thus the study of the factors that have a relationship with GHG emission is of the utmost importance to try to understand the dynamics of the greenhouse gases in the soil.

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