Full Length Article

Nitrogen Fertilization Effects on Methane and Nitrous Oxide Emissions from Wetland Rice Fields of Central Vietnam

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Abstract

Nitrogen (N) is one of the most limiting inputs for intensive cropping systems and commonly applied to rice crop in Vietnam. However, farmers in Vietnam use high rates of nitrogen fertilizer which leads to environment problem like greenhouse gas emissions (GHG). This study evaluated the impact of N fertilizer management on CH_4, N_2O emissions and grain yield within rice fields of Central Vietnam for two growing seasons. The experiments were comprised of different N rates including 0, 40, 80, 120 kg ha^{-1} and three N fertilizer types as urea, ammonium chloride and calcium nitrate. The seasonal cumulative CH_4 and N_2O emissions increased by 35.5 g m^{-2} and 42.6 mg m^{-2} for ammonium chloride; 51.5 g m^{-2} and 53.2 mg m^{-2} for urea, 26.6 g m^{-2} and 48.4 mg m^{-2} for calcium nitrate at 120 kg N ha^{-1} respectively as compared to no nitrogen fertilizer use. Mean CH_4 and N_2O emissions decreased by 33 and 20% when urea was substituted by ammonium chloride at 120 kg N ha^{-1} in both cropping seasons. Highest rice yields and agronomic N use efficiencies ranged from 6.09 t ha^{-1} to 6.45 t ha^{-1} at 120 kg N ha^{-1} and 20.8 to 22.5 kg grain yield kg N^{-1} for urea applied at 80 kg N ha^{-1} in summer and spring growing seasons, followed by ammonium chloride. Yield based CH_4 and N_2O emission intensities were highest at 120 kg N ha^{-1} for urea, following by calcium nitrate and higher than control from 12–22% for CH_4 and 28–37% for N_2O. Amount of CH_4 and N_2O emissions reduced and rice grain yield increased significantly with application of 80 kg N ha^{-1} at urea following ammonium chloride. Thus, optimizing N fertilizer management can be viable mitigation option for paddy GHG emission in Central Vietnam. © 2018 Friends Science Publishers

Keywords: Alluvial soil; Growing season; GHG emission; N management; Rice yield

Introduction

Agricultural practices have the prospective to influence methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions, the potent greenhouse gases (GHG) by contributing around 20–30% of the earth's global warming radiative force (Bálint *et al.,* 2013; Myhre *et al.,* 2013; Ciais *et al.*, 2013). Decaying organic matter in oxygen-deprived environment from fermentative digestion of ruminant livestock, rice planted under flooded condition and manures storage are main sources of CH_4 emissions (Mosier *et al.*, 1998; Huang *et al.*, 2004). Likely, nitrification and denitrification induced N_2O production by microbes with application of high rates of N fertilizers are main sources of N_2O emissions in soils (Stehfest and Bouwman, 2006).

Nitrogen (N) is deemed as the major limiting nutrient in intensive crop farming systems (Ortega, 2015). The farmers in Vietnam have used diverse sources of N fertilizers including urea, ammonium chloride, calcium nitrate, etc. and often applied with higher rates than 100 kg ha^{-1} for rice (Ha and Bo, 2013). N fertilizers are necessary for increasing crop yields and can have impacts on CH_4 and

N_2O emissions (Cai *et al.,* 2007; Gao *et al*., 2013; Skinner *et al*., 2014; Mai *et al*., 2016). Methane and N_2O emissions depend on N fertilizer type and rate (Liou *et al*., 2003; Binfeng *et al*., 2016; Mai *et al.,* 2016; Malyan *et al.,* 2016; Traore *et al.,* 2017), type of N-form in soil (Cai *et al.,* 2007) and N fertilizer applied crop yield (Banger *et al.,* 2012), cultivar type (Liou *et al.,* 2003), substrate available and cultivation system (Cheng-Fang *et al.,* 2012). Comprehensive understanding between CH_4, N_2O emissions and N fertilizer management practices are therefore necessary to collect information on management policies that target to decrease the CH_4 and N_2O emissions without influencing yield and economic gains (Sampanpanish, 2012).

Several reports have projected numerous management technologies to decrease farming CH_4 and N_2O emissions in the world (Mosier *et al.,* 2001; CAST, 2004; Follett *et al*., 2005; Eusufzai *et al*., 2011) and the consequence of definite forms of nitrogen fertilizers at different levels on their emissions from rice fields (Ibrahim *et al*., 1999; Bruce *et al.,* 2012; Datta *et al.,* 2013). There were also some field experiments for paddy CH_4 and N_2O emissions conducted

in the Red River Delta, Northern Vietnam (Pandey *et al.*, 2014; Vu *et al.*, 2015; Mai *et al.,* 2016), Mekong Delta, Southern Vietnam (Arai *et al.,* 2015) and Central Vietnam (Tran *et al.*, 2018). Most of these studies concentrated only on impact of saving water (AWD) and using organic sources on CH_4 and N_2O emissions. And, there are still lack of studies which highlight the emissions of CH_4 and N_2O with applied N fertilizers type and rates including grain yield in Central Vietnam. Therefore, the present research evaluated the impacts of rates and forms of nitrogen fertilizer use on rice grain yield production, CH_4 and N_2O emissions and agronomic use efficiency of nitrogen fertilizers during the two rice cropping seasons in Central Vietnam.

Materials and Methods

Experimental Site

The experiments were conducted in Huong village (16°28′2″N and 107°31′2″E) of Huong Tra town, Thua Thien Hue province, Central Vietnam. The experimental soil is Gleyi-Dystric Fluvisols (Bat and Khanh, 2015). Weather within experimental region is tropical monsoon with annual mean temperature of 26.7˚C and rainfall of 2,300 mm. The basic top soil properties (0–20 cm) prior to the sowing of experiment were 4.10 pH_{KCl}, 1.14% organic carbon, 0.085% total N, 0.034% total P_2O_5 and 0.48% total K_2O, respectively.

Nitrogen and Fertilization Treatments

The field experiments were carried out for two rice growing seasons in summer 2014 and spring 2015 and comprised of four nitrogen rates viz., 0, 40, 80 and 120 kg N ha^{-1} from three nitrogen fertilizer sources including ammonium chloride (NH_4Cl), urea, and calcium nitrate (Ca $(NO_3)_2$). The experimental design was split plot arrangement with N fertilizer types in main plots and N fertilizer rates in subplots to examine the effect of N rates and their interaction with N types. Each subplot size was of 3 m× 5 m and main plot of 60 m^2 with three replications. The whole plots were alienated using 0.6 m wide buffer zone, each having a drainage and irrigation outlet. Lime was added to the field at 15 days prior to sowing and incorporated through plowing. Farmyard manures (FYM) with chemical composition of C 25%; N 0.89%; P 0.30% and K 0.5% was applied at 5 t ha^{-1} to the field and later ploughed to the depth of 10 cm. The N fertilizers were applied in three splits with 30% of N as basal dose before sowing, 45% at the tillering and remaining 25% at the panicle initiation stages. Phosphate (single superphosphate, P_2O_5) and potassium (KCl, K_2O) fertilizers were applied each at 60 kg ha^{-1} as basal and in two splits with 50% at 10 days after sowing (DAS) and 50% at panicle stage during both seasons, respectively.

Crop Husbandry Practices

Rice cultivar Khang Dan 18 obtained from China was grown for the field experiments during both summer 2014 and spring seasons 2015 correspondingly. Rice seed was direct seeded on 1st June, 2014 and 17th January, 2015 and harvested in 1stSeptember 2014 and on 10th May 2015. Rice fields were kept flooded (3–7 cm) at nursery, tillering, panicle initiation and flowering stages followed by a consequent drainage from maturity till harvesting.

Measurements for CH_4 and N_2O Emissions

Two weeks after direct seeding, CH_4 and N_2O fluxes were started to measure and continued to ripening stage from each replicate using the static chamber technique (Parkin and Venterea, 2010). The samples were collected with one week interval during 8 to 10 am.

The closed polythene buckets with dimensions (40 cm top × 50 cm bottom × 70 cm height) were used to take measurements of CH_4 and N_2O fluxes from each treatment during both rice seasons. Each chamber was anchored by a round polyethylene base (cylinder) with dimensions of 50 cm base and 30 cm height. The chamber opened into the soil in around 10 cm comprising rice plants on the inside and mounted in the plots one day before the sample collection for stabilization and kept in the field throughout the crop growing season. These chambers were kept in field throughout the growing season and at each sampling, the water depth and base height inside the round polyethylene frames were monitored. The gas collection chambers were placed on the furrow of the plastic bases with water seal at the sampling time. By means of a 60 mL syringe fixed with a stopcock gathered gas specimens inside the chambers at 0, 10, 20, and 30 min following chamber closure. A syringe siphoned off the gases inside the chamber and instantly transmitted into a 20 mL vacuum glass container. Air temperature and temperature inside chamber were determined concurrently when gas specimens gathered.

Gas chromatograph (GC-SRI 8610) with two detectors i.e., flame ionization detector (FID) and an electron capture detector (ECD) for CH_4 and N_2O analysis was used (Parkin and Venterea, 2010).

Rice Yield and Agronomic use Efficiency

At physiological maturity when grain at tertiary and secondary panicles obtained the hard dough phase and turned yellow, an area of 4 m^2 was harvested for rice grain yield. Agronomic effectiveness of N fertilizer was computed by increase in grain yield per kg of N input.

Cumulative Emissions and Yield based CH_4 and N_2O Emission Intensity

Seasonal cumulative CH_4 and N_2O emissions from every sample position (collar) were computed by adding up every day approximate CH_4 and N_2O emissions by formula following Huang *et al.* (2014):

$$T = \sum ((F_{i+1} + F_i)/2) \times (D_{i+1} - D_i) \times 24/1000$$

Where, T = seasonal gross CH_4 emission in g m^{-2} and N_2O emission inmg m^{-2}; F_i and F_{i+1} indicate the average CH_4 and N_2O emission fluxes sampled at times i and (i + 1) in mg m^{-2} h^{-1} and μg m^{-2} h^{-1} ; D_i and D_{i+1} indicate sampling time at time points i and (i + 1).

Yield based CH_4 and N_2O emissions intensity was computed as the proportion of cumulative CH_4 and N_2O to yield for every treatment plot articulated as g CH_4 ton^{-1} rice grain yield and mg N_2O ton^{-1} rice grain yield.

Statistical Analysis

Standard error means (*n* = 3) were used for normal distribution of data. Statistical analysis was executed to examine the consequences of N fertilizer rate and form on the CH_4, N_2O fluxes and grain yield by two–way ANOVA employing the SPSS general linear model procedure. At *P*<0.05 probability level, to compare the difference among treatments, Tukey's test was applied.

Results

Effect of N Rates and Types on CH_4 and N_2O Emissions

Results showed that CH_4 and N_2O emissions were influenced by N fertilizer rates and forms used in both rice growing seasons. Overall increasing rates of nitrogen using different fertilizers led to significant increase of CH_4 and N_2O emissions. The highest CH_4 flux was observed using 120 kg N ha^{-1} for the each of three N fertilizer types during both growing seasons, which ranged from 17.4 to 42.2 mg m^{-2} h^{-1}, 12.0 to 29.9 mg m^{-2} h^{-1} and 13.7 to 34.9 mg m^{-2} h^{-1} for urea, ammonium chloride and calcium nitrate, respectively. There were significant differences of CH_4 emission between 120 kg N ha^{-1} and control, beyond 55–65% (urea); 49–65% (ammonium chloride) and 75–90% (calcium nitrate) as compared to control during both seasons. N_2O emission also increased with the application of N fertilizer from 0 to 120 kg N ha^{-1} for each type of N fertilizer. The highest N_2O emissions were found at 120 kg N ha^{-1} with 52.8–56.6%; 47.1–54.0% and 53.3–54.9% for ammonium chloride, urea and calcium nitrate compared to control respectively in both spring and summer seasons.

At 120 kg N ha^{-1} fertilizer use, significant differences on CH_4 emissions were observed among three N fertilizers types with the highest for urea. There was also seasonal variation in CH_4 emission at each level of nitrogen fertilizer with emissions of 16.1 mg m^{-2} h^{-1} during spring season and 36.1 mg m^{-2} h^{-1} for summer season. At 80 kg N ha^{-1}, variation was beyond 56–66% and 37–56% as compared to use of ammonium chloride and calcium nitrate fertilizers during the both seasons (Fig. 1). In contrast, there were no significant differences in N_2O emissions among three types of N fertilizer use (*P* < 0.05) (Fig. 2). Seasonal growing of rice also influenced CH_4 and N_2O production (Fig. 1 and 2)

with higher emissions during summer season i.e., 38% vs. 8% with urea, 49% vs. 10% with ammonium chloride, 55% vs. 15% with calcium nitrate compared with spring rice crop at 120 kg N ha^{-1} of respective fertilizer. Nonetheless, CH_4 and N_2O emissions were also affected by rice growth stages and time of N fertilizer application with highest at tillering and flowering stages during the both seasons.

Effect of N Rates and types on Rice Yield and Agronomic use Efficiency of Fertilizer

The different N rates of fertilizers had positive influence on the rice yield, but less significant differences were observed with types of N fertilizer applied (Table 1). The rice yield increased following the N fertilizer application rates compared to the control from 38 to 45% for urea, 31 to 38% for calcium nitrate, and 36 to 44% for ammonium chloride. The grain yield for N treatments varied from 4.10 to 6.45 t ha^{-1} across N fertilizer forms and seasons (Table 1). The rice grain yield increased with N application from 0 to 80 kg N ha^{-1}, however, no significant difference was found in grain yield between 80 and 120 kg N ha^{-1} for all three N fertilizers types. Likely, interaction of grain yield with N fertilizer rates and forms was non-significant during both seasons. Therefore, seasonal variability in rice yieldwas found and higher grain yields observed during spring season than during summer.

Agronomic use efficiency of different levels of N applied varied from 12.0 to 22.5 kg rice for every kg N during spring, and 11.5 to 21.3 kg rice for every kg N during summer. Agronomic use efficiency was the highest at 80 kg Nha^{-1} during spring season and at 40–80 kg N ha^{-1} during summer season for each of N fertizer types used.

Seasonal Cumulative and Yield based CH_4 and N_2O Emission Intensity

Application of N fertilizer rates and types significantly affected the cumulative CH_4 and N_2O emissions which varied during both seasons (Table 1 and 2). The N fertilizer application at 40 to 120 kg ha^{-1} increased the cumulative CH_4 and N_2O emissions over control. The average growing season cumulative emission of CH_4 and N_2O for all treatments in summer 2014 was 2.1 and 1.1 times higher than in spring 2015. In addition to growing season, increasing N fertilizer rate also enhanced cumulative emissions during both seasons. On average, ammonium chloride reduced CH_4 and N_2O emissions than urea by 51 and 21% in spring; 50 and 27% in summer season and calcium nitrate by 6 and 4% in spring; 14 and 20% in summer season (Table 2 and 3). There was a close relationship between grain yield and yield based CH_4 and N_2O emissions intensity in both spring and summer seasons (Table 2 and 3). The maximum yield based CH_4 and N_2O emissions intensity were obtained with 120 kg N ha^{-1} application in spring and summer seasons.

Table 1: Effect of N rates and types on rice yield and agronomic use efficiency in two rice cropping systems

Treatment		Rice yield (t ha^{-1})			Agronomic use efficiency (kg grain yield kg N^{-1})		
N type	N rate (kg ha^{-1})	Summer 2014	Spring 2015	Means	Summer 2014	Spring 2015	Means
Urea	0	4.24^c	4.72^{de}	4.48^{de}	-	-	-
	40	5.12^{abc}	5.45^{cd}	5.28^{bc}	22.0	18.3	20.2
	80	6.04^a	6.38^a	6.21^a	22.5	20.8	21.7
	120	6.09^a	6.45^a	6.27^a	15.4	14.4	14.9
Ammonium chloride	0	4.10^c	4.49^e	4.29^e	-	-	-
	40	4.59^c	5.34^{bcd}	4.97^{cd}	12.2	21.3	16.8
	80	5.75^a	5.95^{ab}	5.85^{ab}	20.6	18.3	19.5
	120	5.86^a	6.13^a	5.99^a	14.7	13.7	14.2
Calcium nitrate	0	4.20^c	4.50^e	4.35^{de}	-	-	-
	40	4.68^{bc}	5.18^{cd}	4.93^{cd}	12.0	17.0	14.5
	80	5.65^{ab}	5.82^{abc}	5.74^{ab}	18.1	16.5	17.3
	120	5.77^a	5.88^{ab}	5.83^{ab}	13.1	11.5	12.3
Analysis of variance							
Source	d.f						
N rate (R)	3	***	***	**	-	-	-
N type (T)	2	ns	ns	***	-	-	-
(R x T)	6	ns	ns	ns	-	-	-

Means followed by different letters in each column are significant different ($p< 0.05$); *** $p<0.001$, ns non-significant

Table 2: Seasonal cumulative CH$_4$ and yield based CH$_4$ emission intensity for different N fertilizer rates and types in two rice cropping systems

Treatment		Seasonal cumulative CH$_4$ (g m^{-2})			Yield based CH$_4$ emission intensity (g CH$_4$ t^{-1} rice yield)		
N type	N rate (kg ha^{-1})	Summer 2014	Spring 2015	Means	Summer 2014	Spring 2015	Means
Urea	0	42.4^{efg}	22.2^{cde}	32.3^{bcd}	9.96^{ab}	4.96^a	7.46^{ab}
	40	52.6^{bcd}	24.9^{bcd}	38.8^{a-d}	10.29^a	4.73^{abc}	7.51^{ab}
	80	59.7^b	30.6^{ab}	45.2^{ab}	9.95^{ab}	4.90^{ab}	7.43^{ab}
	120	69.1^a	33.8^a	51.5^a	11.43^a	5.46^a	8.45^a
Ammonium chloride	0	29.1^h	15.7^{ef}	22.4^d	7.10^d	3.58^{cd}	5.34^{bc}
	40	33.9^{gh}	17.4^{ef}	25.7^{cd}	7.38^d	3.47^d	5.43^{bc}
	80	38.2^{fgh}	18.6^{def}	28.4^{bcd}	6.69^d	3.17^d	4.93^c
	120	48.6^{cde}	22.4^{cde}	35.5^{a-d}	8.26^{bcd}	3.71^{bcd}	5.99^{bc}
Calcium nitrate	0	33.1^h	14.1^f	23.6^{cd}	8.00^{cd}	3.14^d	5.57^{bc}
	40	37.4^{fgh}	17.9^{ef}	25.7^{cd}	7.38^d	3.53^{cd}	5.46^{bc}
	80	44.9^{def}	19.9^{c-f}	32.3^{bcd}	8.08^{cd}	3.66^{cd}	5.87^{bc}
	120	55.6^{bc}	26.6^{bc}	41.1^{abc}	9.69^{abc}	4.70^{abc}	7.19^{ab}
Analysis of variance							
Source	d.f						
N rate (R)	3	***	***	÷	***	÷	÷
N type (T)	2	**	**	***	**	**	***
(R x T)	6	ns	ns	ns	ns	ns	ns

Means followed by different letters in each column are significant different ($p< 0.05$); †$p<0.10$, ** $p<0.01$, *** $p<0.001$, ns non-significant

Table 3: Seasonal cumulative N$_2$O and yield based N$_2$O emission intensity for different N fertilizer rates and types in two rice cropping systems

Treatment		Seasonal cumulative N$_2$O (mg m^{-2})			Yield based N$_2$O emission intensity (mg N$_2$O t^{-1} rice yield)		
N type	N rate (kg ha^{-1})	Summer 2014	Spring 2015	Means	Summer 2014	Spring 2015	Means
Urea	0	26.4^a	28.0^a	27.2^{efg}	6.2^{ab}	5.9^{ab}	6.1^{bc}
	40	41.9^{ab}	33.4^a	37.7^{b-e}	8.2^{ab}	6.1^{ab}	7.2^{ab}
	80	45.0^{ab}	43.7^{ab}	44.4^{abc}	7.5^{ab}	6.8^{ab}	7.1^{ab}
	120	56.1^b	50.2^b	53.2^a	9.2^b	7.8^{ab}	8.5^a
Ammonium chloride	0	19.5a	20.4^a	20.0^g	4.8^a	4.5^a	4.6^c
	40	25.8^a	29.5^a	27.7^{d-g}	5.6^{ab}	5.5^{ab}	5.6^{bc}
	80	34.0^a	32.2^a	33.1^{c-f}	5.9^{ab}	5.4^{ab}	5.7^{bc}
	120	44.0^{ab}	41.2^{ab}	42.6^{abc}	7.5^{ab}	6.7^{ab}	7.1^{ab}
Calcium nitrate	0	23.8^a	21.2^a	22.5^{fg}	5.7^{ab}	4.7^a	5.2^{bc}
	40	34.6^a	26.2^a	30.4^{d-g}	7.4^{ab}	5.1^a	6.2^{bc}
	80	42.4^{ab}	36.5^a	39.5^{bcd}	7.5^{ab}	6.3^{ab}	6.9^{ab}
	120	52.7^{ab}	44.0^{ab}	48.4^{ab}	9.1^b	7.5^b	8.3^a
Analysis of variance							
Source	d.f						
N rate (R)	3	***	***	÷	***	***	***
N type (T)	2	ns	ns	***	ns	ns	ns
(R x T)	6	ns	ns	ns	ns	ns	ns

Means followed by different letters in each column are significant different ($p< 0.05$); †$p<0.10$, *** $p<0.001$, ns non-significant

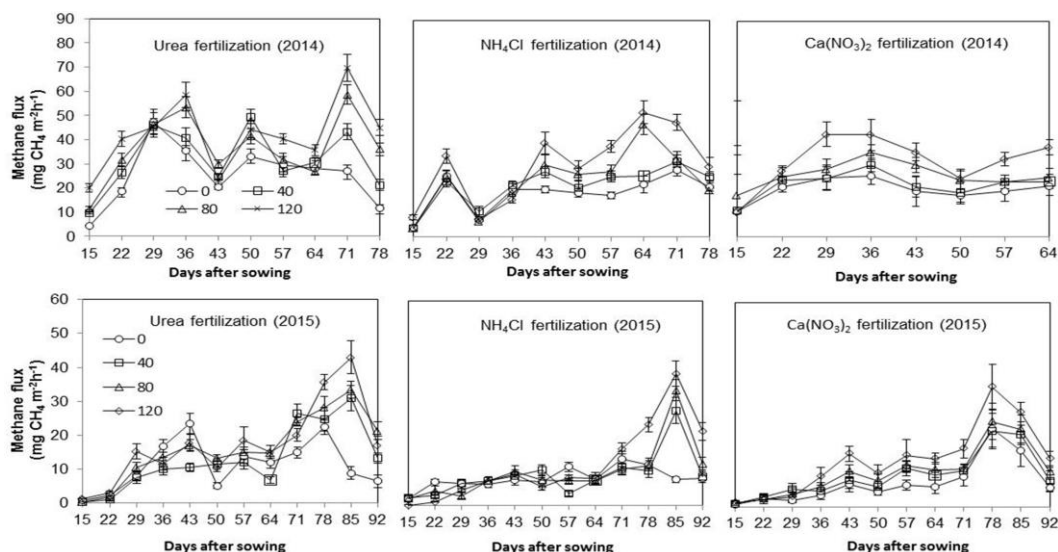**Fig. 1:** Effect of N rates and types on CH_4 emission flux in two rice cropping systems (Means ± SE)
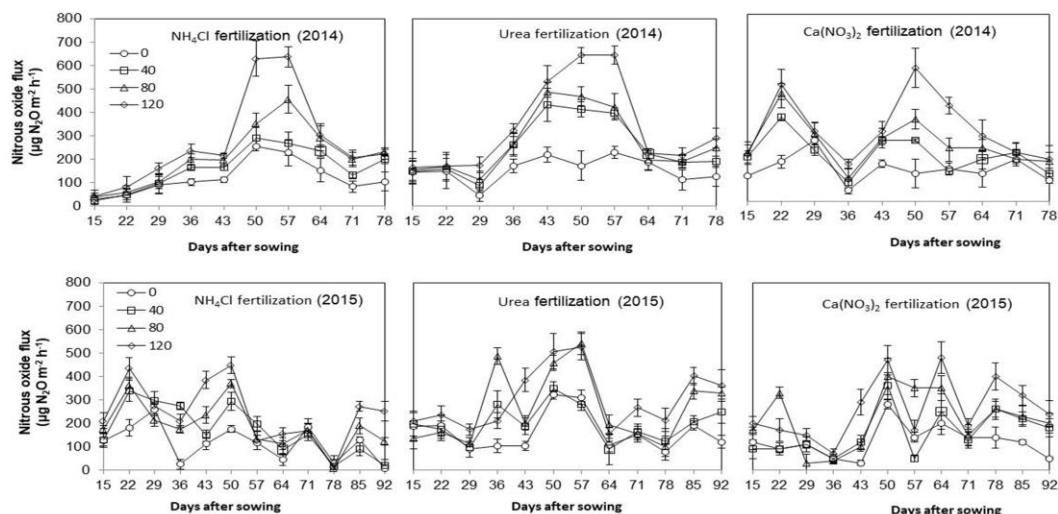

Fig. 2: Effect of N rates and types on N_2O emission flux in two rice cropping systems (Means ± SE)

The yield based CH_4 emission intensity for this treatment increased by 10% for urea, 4% for ammonium chloride and 50% for calcium nitrate during spring and by 15% for urea, 16% for ammonium chloride and 21% for calcium nitrate in summer compared to the control without N application (Table 2). While, the yield based N_2O emission intensity at 120 kg N ha^{-1} increased by 32–37% for ammonium chloride, 24–32% for urea and 37–38% for calcium nitrate compared to control in spring and summer seasons (Table 3).

Discussion

Earlier studies have shown that N fertilizers induced CH_4 emission from rice fields (Cai *et al*., 2007; Mai *et al*., 2016).

Some reported that CH_4 production is augmented by N fertilizers use owing to rising rice plant growth, resulting in improvement of the carbon provision for methanogenic microorganisms and favor CH_4 transportation to the environment under flooded circumstances (Schimel, 2000; Kruger and Frenzel, 2003; Zhang *et al*., 2015). Jia *et al*. (2006) showed that rapid development of shoot in rice provides substrate for CH_4 production. Under field condition, Inubushi *et al*. (2003); Xu *et al*. (2004); Zheng *et al*. (2006); Gutierrez *et al*. (2014);showed that increased rates of N stimulate emission of CH_4 than application of low N fertilizer which is associated with enhanced C/N proportion within crop straw and roots, and rice grain with high N fertilizer use. Singh *et al*. (1999); Mai *et al*. (2016) reported higher CH_4 emissions when fertilized with urea at

100 kg ha^{-1} compared to no fertilizer application as observed in present study. Reduced CH_4 emission observed for calcium nitrate and ammonium chloride fertilizers as compared to urea corresponds with Cicerone and Shetter (1981); Dong *et al*. (2011) that ammonium sulfate use in the rice is five times better as observed with CH_4 fluctuations even with no N use. Likely, CH_4 emission augmented at 210 kg CH_4 ha^{-1} in treatment with no urea use and 370 kg CH_4 ha^{-1} at 300 kg N ha^{-1} supplied with urea over the 86-day sampling duration (Lindau *et al*., 1991). Jay (2013) reported that urea is the most frequently used chemical N fertilizer but hydrolysable into ammonia upon its application into rice fields, therefore, higher CH_4 emissions reported with its application. While reduced CH_4 production from rice paddies upon application of ammonium chloride as fertilizers compared to urea because of the rapid decay of NH_4Cl within flooded soil throughout an extensive rice growing period (Kimura *et al*., 1992; Ibrahim *et al.,* 1999; Rath *et al.,* 2002). Another possibility can be that chloride might have toxic effects for methanogenic microorganisms which further repress CH_4 discharge (Minami, 1994). Likewise, even reduced CH_4 emissions were found with calcium nitrate as compared to urea of present study. Banik *et al.* (1996) reported that application of ammonium sulfate and nitrate fertilizers reduces the CH_4 levels compared to urea even when used at similar rates. In another study conducted within a flooded Louisiana rice farm, each of these fertilizer types had stimulatory effects on CH_4 production, however, decreased CH_4 emissions were only observed for nitrate based N fertilizers only than urea (Lindau, 1994) without decrease in redox potential (Bouwman, 1990). However, this occurs either at the cost of poor rice and root growth associated with denitrification of NO_3^- which becomes unavailable for plant development (Lindau *et al.,* 1991). The cumulative CH_4 emission affected by growing season can be explained by methanotrophs process stimulating CH_4 oxidation within rice paddies (Bergamasch, 1997; Jain *et al*., 2000) as observed with higher seasonal emissions during summer (Schütz *et al.,* 1989). Our results indicated that CH_4 emissions were considerably increased following N rates and decreased by ammonium chloride application as compared with calcium nitrate and urea application. These findings may be clarified by the different consequences of N fertilization on CH_4 emission. Generally, rice growth is restricted within flooded soils; however, low nitrogen rates are more favorable to improve rice growth due to better efficient use of each N unit applied than high N rates. And high growth provides additional substrate for carbon methanogenesis as roots and root exudates act as a main source for CH_4 emission (Lu *et al*., 2000). Further, with high plant density in direct seeding provide larger pathway for CH_4 transport to the environment due to higher tillering density (Wassmann and Aulakh, 2000). Accounting these facts, Bodelier and Laanbroek (2004) reported that at low to moderate N rates, rice plants removes NH_4^+ from the soil solution and can't stimulate

CH_4 oxidation. On other hand, at higher N rates, plant productivity is decreased because excessive NH_4^+ within soil solution is used to stimulate CH_4 oxidation rather than affecting rice plant growth (Bodelier and Laanbroek, 2004).

Like CH_4 emissions, McSwiney and Robertson (2005) reported that the excessive N is susceptible to emission of N_2O but improved nitrogen use efficiency (NUE) can reduce its emissions consequently reducing GHG emissions for applied N (Schlesinger, 1999).The highest emissions for ammonium chloride as compared to urea and calcium nitrate may be due to its least stability by converting into anhydrous ammonia (82% N) being the most concentrated form of N fertilizer which causes the greatest N_2O emissions among the synthetic N fertilizers (Bretenbeck and Bremner, 1986; Thornton *et al.*, 1996; Venterea *et al.*, 2005; Burton *et al.*, 2008; Venterea *et al.*, 2010). The present study findings also corresponds with Tenuta and Beauchamp (2003) that relatively order of magnitude of total N_2O emitted was calcium ammonium nitrate>urea>ammonium sulfate with highest for former and lowest for latter on an Ontario silt loam. Likely, higher N_2O emissions observed for N fertilizers applied during autumn rather than in spring season of present study correspond with Hao *et al.* (2001) where seasonal variation was also reported. Increased N_2O emission with N applied at different rates of present study confirms the positive relationship of N_2O with N fertilizer rates (Millar *et al.,* 2010; Hoben *et al.,* 2011). Higher N inputs stimulates the production and emissions of N_2O because nitrogenous fertilizer provides a rich N source for the nitrification and denitrification processes (Cai *et al*., 1997; Zhu *et al*., 2005; Allen *et al*., 2010; Guo *et al*., 2010). Bin-feng *et al*. (2016) also reported that the effects of N application on N_2O emissions were primarily related to the N application rate.

Nitrogen is one of the mainly yield-restricting nutrients within lowland rice production and its absorption is influenced by the varietal features, type of fertilizers, soils, climate circumstances and cultivars (Ohnishi *et al*., 1999; Yee *et al*., 2007; Rehman *et al*., 2013). Improved rice yield of present study was accredited to growing of yield index instead of the total dry matter production (Ju *et al.,* 2009). Peng *et al.* (2000); Chen *et al.* (2010) reported that the increases in rice grain yield must be dependent on the rise in dry matter production. In brief, grain yield increased parallel with a larger N use. Nevertheless, with the highest application of N level, grain yield did not increase too much and seemed to lessen owing to the reduced proportion of ripened grains. This outcome can be accredited to the reality that use of larger rates of N fertilizer renders plants vulnerable to lodging (Islam *et al.,* 2012). Murtaza *et al.* (2014) indicated that farmers aiming at higher yields seem to employ higher levels of N fertilizers. Nevertheless, such high rates do not all times contribute to the yield. Therefore, use of N requires being deemed cautiously to decrease extreme N losses to the grounds and possible contamination matters. The lesser grain yield during summer is attributable

to the lesser rice growing duration and higher temperatures (Table 4) as observed with higher average temperature in summer crop i.e., 6.2°C higher than in spring crop, and lack of irrigation, leads to a raise of N volatilization (Bergamasch, 1997; Van Hulzen *et al.*, 1999; Fan *et al.*, 2011).

Table 4: Climatic condition in spring-2014 and summer-2015 rice seasons

Months	Temperature (°C)			Rainfall	
	$T°_{average}$	$T°_{max}$	$T°_{min}$	No. of days	Amount (mm)
Summer season 2014					
June	30.4	38.8	24.7	5	6.7
July	29.0	38.0	23.6	15	224.7
August	28.6	38.2	22.8	10	133.3
September	27.8	37.0	22.5	9	28.3
Spring season 2015					
January	19.5	29.1	13.3	13	48.1
February	21.8	33.5	14.5	8	52.6
March	25.1	35.8	18.6	9	180.4
April	25.9	39.0	16.1	10	151.7
May	29.5	38.9	23.5	9	40.4

Conclusion

Cumulative CH_4 and N_2O emissions and yield based CH_4 and N_2O intensity decreased at lower rate N fertilizer and much lesser in spring season than in summer season. Among three types of N fertilizer used, ammonium chloride decreased CH_4 and N_2O productions compared to calcium nitrate and urea. Rice yields were highest at 120 kg N ha^{-1} application and the agronomic use efficiency was highest for 80 kg N ha^{-1} in three types of N fertilizer applied. Adding 80 kg N ha^{-1} (urea or ammonium chloride) reduced CH_4 and N_2O emissions without decreasing rice yield and agronomic use efficiency.

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