Studies on emission potentiality of nitrous oxide from wheat field under changed climate

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Emission of nitrous oxide (N_2O) from wheat field under various management practices was measured over two years. The experimental design consisted of two winter wheat (*Triticum austivum* L.) varieties with three nutritional treatments and two dates of sowing. The results revealed that soil moisture and soil temperature at different depths are the key parameters influencing N_2O emission. A positive increase of N_2O flux was noticed with increasing soil moisture along with decreasing soil temperature at specific wheat phenophases. Maximum N_2O was emitted at the flowering stage. Individual factors, viz. nutrient, date of sowing and variety, and an interactive combination of these factors significantly influenced N_2O emission rates. It was also found that there was no significant association between wheat grain yield and seasonal N_2O flux.

Keywords: Emission potentiality, nitrous oxide, soil environment, wheat yield.

NITROUS oxide (N_2O) is produced in agricultural soil through the microbial processes of nitrification and denitrification. Emission rates of N_2O from agricultural soils are strongly affected by various factors, e.g. soil temperature and moisture, soil aeration status and carbon availability[1,2], crop type and residue management[3,4], and application of nitrogen fertilizers[5,6]. There are also spatial and temporal variability in N_2O emission rates[7]. Emission of nitrous oxide from Indian wheat fields varies from 0.31 to 0.71 kg N_2O–N/ha/year depending upon fertilizer and irrigation treatments. In rice–wheat systems in the Indo-Gangetic plains, where generally 240 kg N/ha/year is applied through urea, N_2O–N emission is 1.57 kg/ha (0.38% of applied N)[8]. It has been estimated that N_2O emission from rice and wheat fields in India is 0.19 and 0.27 Tg/year respectively[9]. To quantify N_2O emission from Indian agriculture, it is important to take into account the inputs of fertilizer, its application rates and fertilizer type as well as other factors, including soil environment and atmospheric condition. This is because interactive effect of these factors greatly influences the real-time N_2O emission from wheat crop.

An effort has been made here to achieve the following objectives: (i) To estimate the N_2O emission rate from promising wheat varieties during important phenophases under varied management schedules. (ii) To assess the effect of soil environment on nitrous oxide emission density.

Nitrous oxide emissions from wheat field were evaluated during two consecutive winter seasons of 2012–13 and 2013–14 respectively. Field experiment was established at the agronomic experimental station (Kalyani 'C' Block Farm) of Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, West Bengal, India (22°57′N lat., 88°20′E long.; about 7.8 m altitude). This zone is classified as New Alluvial Agro Climatic Zone of West Bengal, India.

Total precipitation was 18.2 and 54.7 mm along with mean ambient temperature of 21.45°C and 21.30°C during the wheat-growing period of 2012–13 and 2013–14 respectively (Figure 1). The soil is entisol with a sandy loam texture. It is alkaline with pH ranging from 6.5 to 7.9.

The experimental treatments consisted of two promising winter wheat varieties (V1 – K0307 and V2 – HD2733) with three types of nutritional treatments, viz. N1 – 100% chemical (synthetic fertilizer as N : P : K :: 60 : 40 : 40; nitrogen applied as 263 kg/ha through urea); N2 – 50% organic + 50% chemical (applied nitrogen: 131.5 kg urea/ha + 71.5 kg vermicompost/ha), and N3 – 100% organic (143 kg vermicompost/ha). There were two dates of sowing, viz. D1 – 15 November and D2 – 30 November. The experiment was laid out on randomized block design with three replications. Nitrogen was applied in two halves, i.e. basal dressing (60%) was done during land preparation and top dressing (40%) after three weeks of sowing followed by irrigation.

Sampling for N_2O emitted from wheat soil was performed using closed chamber technology. The chamber is made of PVC (polyvinyl chloride) sheet covering 1.22 m^2 area and a portable sensor-based nitrous oxide analyser (Technovation Series 2005, serial no. 12045) was fitted to the chamber to measure the emission rate. At the time of gas measurements, this chamber was fitted to an iron

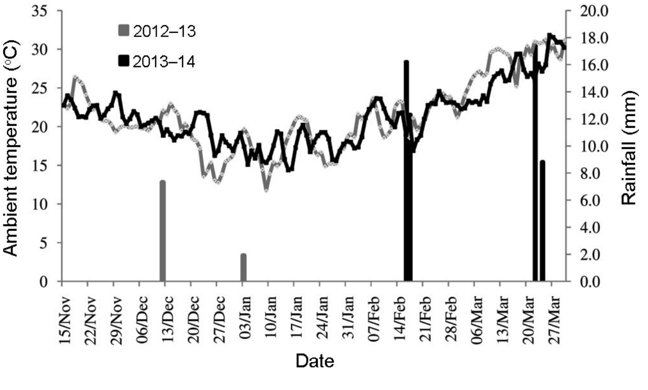

Figure 1. Climatic condition during wheat growing seasons of 2012–13 and 2013–14.

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*For correspondence. (e-mail: ts.karmakar007@gmail.com) base inserted 5 cm into the soil. Internal air temperature of the chamber was measured using a thermometer fitted to the chamber. There was an internal fan for homogenizing the chamber atmosphere before sampling.

The data were verified through gas chromatography (gas chromatograph with electron capture detector; Perkin Elmer Model Clarus 480). Measurements were done during 9 am to 2 pm. Nitrous oxide emission was continuously observed at 0, 15 and 30 min intervals from each of the treatment combinations during phenological phases of wheat crop, i.e. crown root initiation (CRI), tillering, jointing, flowering and milking. Flux rate was calculated according to the equation

$$F = \frac{PVMU}{ART} \times \frac{\mathrm{d}c}{\mathrm{d}t} \times 1000,$$

where F is the flux rate (mg/m²/d), P the pressure (1 atm), V the chamber volume (3.66 m^3), M the molar mass of nitrous oxide (44 g/mol), U the units conversion factor (0.00144 L min/μL d), A the area covered by the chamber (1.22 m^2), T the chamber temperature (K), and R is the gas constant (0.08205 litre atm/K mol).

Soil temperature at different depths, viz. 5, 15 and 25 cm was recorded for each sampling using a digital soil thermometer. Simultaneously, soil moisture content at 15 and 25 cm depth was measured by gravimetric method. Daily weather data were collected from the university weather station. Yield was calculated during harvesting.

Results of N_2O emission from wheat field throughout two consecutive seasons as well as yield were subjected to analysis of variance (ANOVA) in order to evaluate the importance of each driving factor on N_2O emission throughout the entire wheat growing period. Relationship between soil physical parameters and N_2O emission was evaluated by means of determination coefficient (R^2) of linear regression.

Seasonal average N_2O fluxes from wheat grown under various management practices during two successive winter seasons varied markedly in all the treatments under field experiments (Figure 2). During both consecutive winter wheat seasons, N_2O flux rate showed approximately similar trend. The N_2O fluxes ranged from –3.56 to 12.99 and –8.89 to 7.69 $\mathrm{mg/m^2/day}$ respectively, for the seasons of 2012–13 and 2013–14. Fluxes generally increased sharply where N fertilizer was added at the rate of 263 kg/ha through urea (N1).

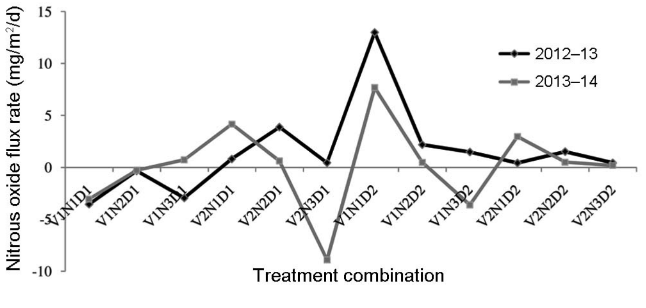

Figure 2. Seasonal nitrous oxide efflux from wheat crop grown under various management practices at important phenological phases during two consecutive wheat-growing seasons. V1, K0307; V2, Hd2733; N1, 100% Inorganic; N2, 50% Inorganic + 50% organic; N3, 100% Organic; D1, 15 November; D2, 30 November.

Peak N_2O emission was observed for variety K0307 fertilized with 100% synthetic fertilizer (N1) and sown on 30 November (D2) during both seasons (7.69 and 12.99 $\mathrm{mg\ m^2/day}$ for both seasons respectively). But when this variety was sown on 15 November (D1) with the same nutritional amendment, negative N_2O flux was observed. Variation in attaining phenological phases for wheat sown during two different dates under changed soil water status with changing meteorological condition, including ambient N_2O content in the atmosphere may be responsible for this.

Application of different types of nutrient resulted in varied N_2O efflux. With addition of 100% chemical fertilizer (263 kg/ha through urea), significant increase in N_2O emission was observed compared to other treatments. Here availability of substrate for activity of nitrifiers and denitrifiers may be larger than other treatments. Also, N uptake may be lower for wheat crop grown under the second date of sowing, therefore providing rich substrate for nitrification and denitrification. Such favourable environment stimulates the activity of relevant microorganisms and is thus conductive to N_2O generation.

Treatment combinations associated with 100% organic nutrient (143 kg vermicompost/ha) resulted in minimum or negative N_2O flux. For each wheat season, we obtained average seasonal N_2O flux rate as negative from a few treatment combinations. Application of vermicompost (143 kg/ha) lowered the N_2O emission. The higher amount of organic carbon in such soils may be the reason for lowering of the N_2O emission rates. Negative N_2O flux denotes that the initial concentration of N_2O in the atmosphere may be more compared to emitted N_2O from crops within the chamber. With increasing chamber temperature, concentration of N_2O may decrease with time. A similar negative trend of N_2O flux has been reported by Gomes *et al.*[10] in the black oat/maize rotation crop, which was –20.2 ± 1.9 μg N/m²/h.

Soil moisture content ranged from 11% to 60% and 12% to 54% during 2013–14 and from 11% to 24% and 12% to 25% during 2012–13 at 15 and 25 cm soil depth respectively (Figure 3). However, we observed less variation in soil temperature in both the years. It was remained between 12°C to 25°C throughout the wheat growth cycle (Figure 4). Moisture content and soil temperature depend on precipitation, irrigation and crop phenophases (irrigation was applied according to soil moisture status).

Scheduled management practices had an important influence on N_2O emission during various phenological phases (Table 1). Among three different nutritional

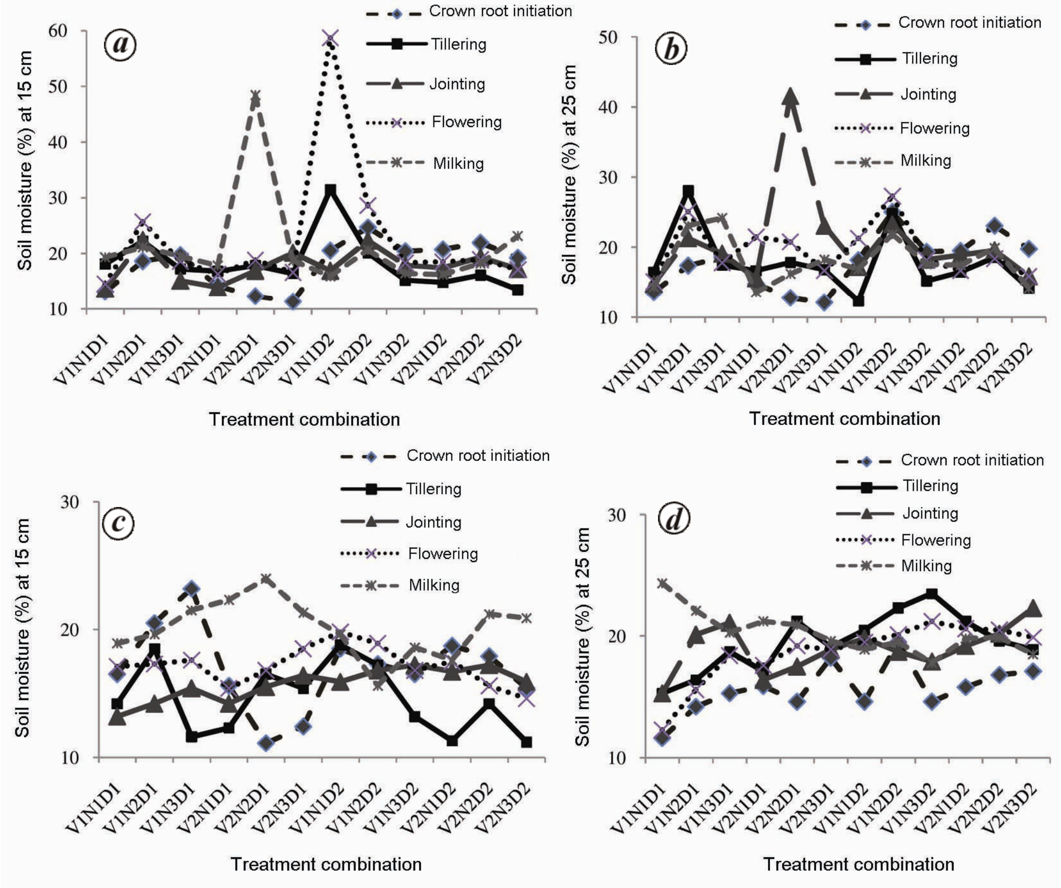

Figure 3. Variation of soil moisture at 15 and 25 cm depth for wheat growth phases during 2013–14 (***a*** and ***b***) and 2012–13 (***c*** and ***d***).

approaches, maximum N_2O (4.623 mg/m^2/day) was emitted from N2 (50% organic + 50% inorganic, where nitrogen is applied as 131.5 kg urea/ha with 71.5 kg vermicompost/ha) followed by N1 (100% inorganic; 263 kg urea/ha) as 3.728 mg/m^2/day during flowering phase only. N_2O emission (4.45 mg/m^2/day) was also observed at tillering stage under N1.

N_2O emission is negatively correlated with soil organic C, total N and C : N. Mineralization and immobilization of N and available N present in the soil are directly linked with the C cycle. So C and N should determine the N_2O emission under different nutrient schedules. In our study nitrogen was applied in two halves – as basal (60%) during land preparation and top dressing (40%) was done after three weeks of sowing when the crop was near tillering stage. Thus available nitrogen for microbial activity remains confined in the soil leading to major N_2O emission at tillering stage.

At each phenophase application of vermicompost (143 kg/ha) consistently emitted lower N_2O from wheat crop. Maximum variation was observed during flowering stage, which may be due to drastic changes in the soil C : N ratio. Moisture status along with fertilizer type play an important role in N_2O emission. Soil fertilized with urea under available moisture showed higher emission than with vermicompost where moisture played a favourable role for nitrification. Our recent study has shown that use of 50% synthetic + 50% organic fertilizer results in higher N_2O emission than application of 100% synthetic fertilizer at flowering stage of winter wheat[11]. Application of manure plays an important role in nitrous oxide emission by adding N and organic carbon required for microbes. Incorporation of organic material creates a pool of readily available N and therefore often stimulates N_2O emissions[12,13]. The application of manure fertilizer often improves soil structure, increases soil porosity, and decreases water filled pore space (WFPS), which reduces the denitrification rate and thus decreases N_2O emission[14].

In case of dates of sowing, peak N_2O emission was noticed (4.019 mg/m^2/day) for the 30 November sown crop. Major variation due to dates of sowing was also noticed during flowering stage. Depending on dates of sowing duration to attain different growth phases was different. Various phenological phases may be responsible for altering the microclimate leading to changes in soil environment which have a pivotal role in N_2O emission.

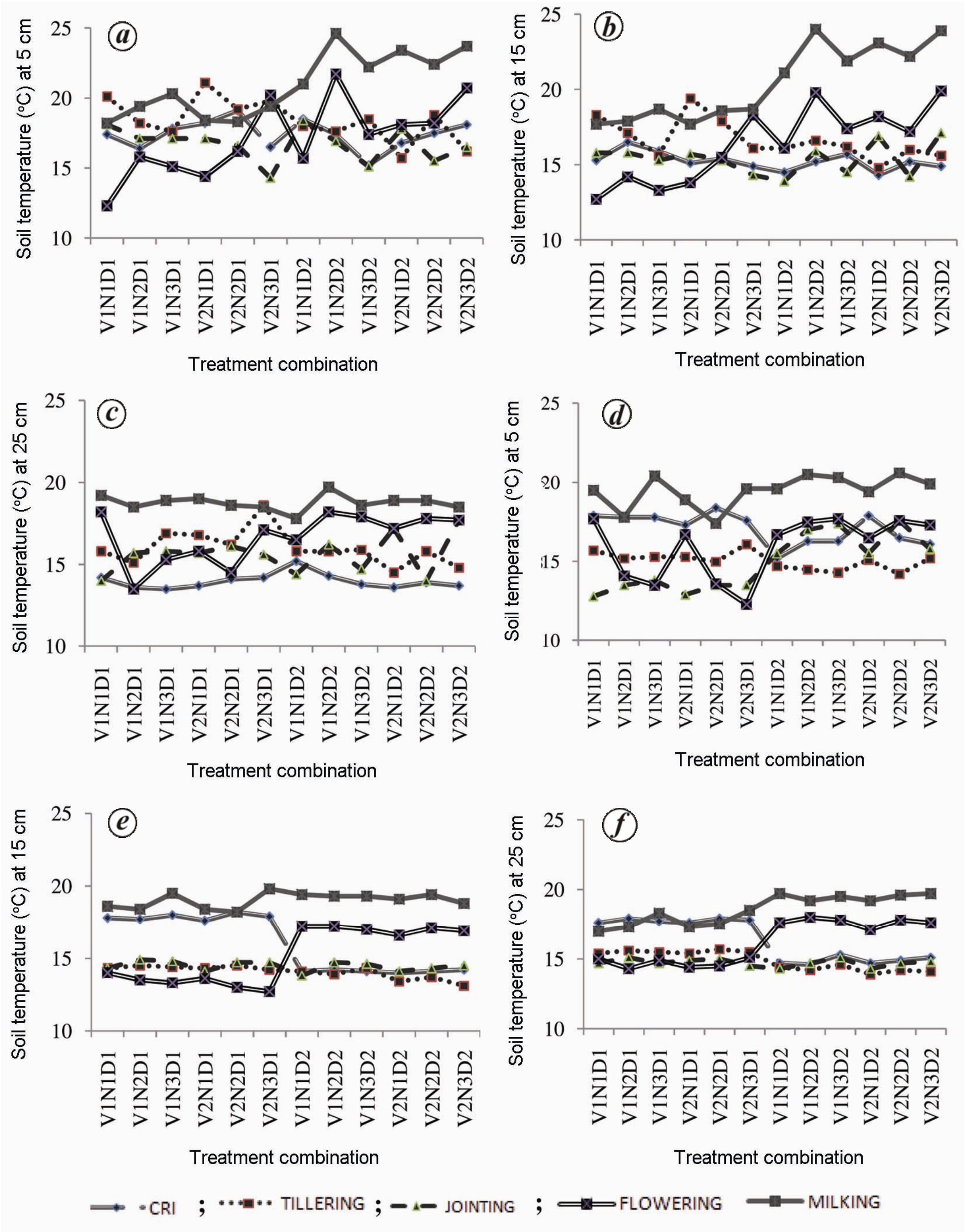

Figure 4. Temporal variation of soil temperature at 5, 15 and 25 cm depth during wheat growing seasons of 2012–13 (***a–c***) and 2013–14 (***d–f***).

Flowering stage seemed to be most important as maximum N_2O emission occurred as 3.095 and 1.900 mg/m^2/day for V2 (HD 2733) and Y1 (2012–13) respectively. In the present study, during flowering stage soil moisture content was between 20% and 27% at 15 and 25 cm soil depth during both years along with soil temperature ranging from 17°C to 21°C (Figures 3 and 4). Also at this time the crop had a well-distributed canopy cover which affects the soil environment. This type of soil condition may promote the N_2O emissions rates.

It has been reported that the rate of N_2O emission from wheat increases sharply after panicle initiation and at crop ripening stage and after the fertilization during the winter wheat maturity stage due to the acute alteration of soil moisture[15,16]. However, during the second year at this flowering stage soil moisture content was 60% due to sudden rainfall, leading to lowering of N_2O flux (0.36 mg/m^2/day) compared to the first year (1.9 mg/m^2/day). The results of Liu *et al.*[17] support our result that N_2O emissions initially increase and then decrease with

Table 1. Influence of individual and interactive parameters on N_2O emission ($mg/m^2/day$) from wheat during important phenophases

Experimental factors		Crown root initiation	Tillering	Jointing	Flowering	Milking
N1 (100% inorganic)		0.920	4.450	1.521	3.728	2.558
N2 (50% organic + 50% inorganic)		0.738	0.529	2.089	4.623	–0.495
N3 (100% organic)		0.637	–1.509	–2.009	–4.954	0.235
SEm (±)		0.135	0.749	0.342	0.791	0.576
CD (at 5%)		NS	2.148	0.980	2.269	1.652
D1 (15 November)		0.442	1.085	–1.164	–1.755	–0.696
D2 (30 November)		1.088	1.228	2.231	4.019	2.228
SEm (±)		0.269	1.498	0.683	1.582	1.152
CD (at 5%)		0.772	NS	1.960	4.538	3.304
V1 (K0307)		0.727	–0.525	0.993	–0.830	3.986
V2 (HD 2733)		0.803	2.838	0.075	3.095	–2.454
SEm (±)		0.110	0.611	0.279	0.646	0.470
CD (at 5%)		NS	1.753	0.800	1.853	1.349
Y1 (2012–13)		1.236	1.712	1.027	1.900	1.371
Y2 (2013–14)		0.294	0.602	0.041	0.365	0.161
SEm (±)		0.110	0.611	0.279	0.646	0.470
CD (at 5%)		0.315	NS	0.800	NS	NS
N × Y	SEm (±)	0.190	1.059	0.483	1.119	0.815
	CD (at 5%)	0.546	3.037	1.386	3.209	2.336
N × V	SEm (±)	0.190	1.059	0.483	1.119	0.815
	CD (at 5%)	0.546	3.037	1.386	3.209	2.336
N × D	SEm (±)	0.190	1.059	0.483	1.119	0.815
	CD (at 5%)	0.546	3.037	NS	3.209	2.336
Y × V	SEm (±)	0.155	0.865	0.395	0.914	0.665
	CD (at 5%)	0.446	NS	1.131	NS	1.908
Y × D	SEm (±)	0.155	0.865	0.395	0.914	0.665
	CD (at 5%)	NS	NS	1.131	NS	1.908
D × V	SEm (±)	0.155	0.865	0.395	0.914	0.665
	CD (at 5%)	0.446	2.480	1.131	2.620	NS
Y × N × V × D	SEm (±)	0.381	2.118	0.966	2.238	1.629
	CD (at 5%)	1.092	NS	2.772	6.418	4.673

Table 2. Association between N_2O and soil temperature at different depths

		R^2 value					
Soil temperature at		5 cm		15 cm		25 cm	
Treatment	Phenophase	2012–13	2013–14	2012–13	2013–14	2012–13	2013–14
V1	Flowering	0.111	0.057	0.180	0.507	0.039	0.376
V2	Flowering	0.200	0.120	0.196	0.003	0.804	0.094
N1	Tillering	0.826	0.017	0.700	0.948	0.799	0.611
	Jointing	0.347	0.358	0.976	0.004	0.416	0.653
N2	Tillering	0.007	0.146	0.530	0.080	0.229	0.061
	Jointing	0.518	0.235	0.340	0.881	0.315	0.222
	Milking	0.833	0.500	0.728	0.531	0.942	0.322
N3	Tillering	0.024	0.683	0.185	0.097	0.381	0.105
	Jointing	0.522	0.322	0.00	0.302	0.006	0.350
	Flowering	0.073	0.983	0.0	0.991	0.195	0.945
D1	Flowering	0.212	0.038	0.186	0.002	0.195	0.717
D2	Tillering	0.345	0.400	0.686	0.424	0.449	0.815
	Flowering	0.447	0.279	0.416	0.171	0.694	0.009

increasing soil moisture. It has also been reported that the synergistic effect of appropriate soil temperature (15.5°C) and WFPS (78%) promoted the higher N_2O emission in the wheat season under favourable soil microenvironment for denitrification[18,19].

Crop growth pattern varied with varietal differences. Thus there are differences in soil moisture content during phenological phases. This difference resulted in variation in N_2O emission from different wheat varieties. Cultivar differences in N_2O emissions have been reported earlier

Table 3. Association between N_2O and soil moisture at different depths

		R^2 Value			
Soil moisture at		15 cm		25 cm	
Treatments	Phenophase	2012–13	2013–14	2012–13	2013–14
D2	Flowering	0.502	0.928	0.298	0.035
V1	Flowering	0.536	0.808	0.498	0.249
V2	Flowering	0.027	0.044	0.041	0.601
N1	Tillering	0.200	0.214	0.544	0.087
	Flowering	0.367	0.357	0.621	0.947
N2	Tillering	0.212	0.562	0.354	0.695
	Jointing	0.967	0.400	0.033	6E-05
	Milking	0.843	0.981	0.466	0.783
N3	Tillering	0.028	0.301	0.824	0.146
	Milking	0.839	0.009	0.343	0.467

Table 4. Influence of individual and interactive factors on the yield (g/m^2) of wheat

Experimental factors	Yield (g/m^2)	Experimental factors	Yield (g/m^2)	Experimental factors		Yield (g/m^2)
N1 (100% inorganic)	320.00	V1 (K0307)	312.08	N × Y	SEm (±)	12.26
					CD (at 5%)	35.15
N2 (50% organic + 50% inorganic)	285.94	V2 (HD2733)	271.88	N × V	SEm (±)	12.26
					CD (at 5%)	35.15
N3 (100% organic)	270.00	SEm (±)	7.08	N × D	SEm (±)	12.26
					CD (at 5%)	35.15
SEm (±)	8.67	CD (at 5%)	20.29	Y × V	SEm (±)	10.01
					CD (at 5%)	NS
CD (at 5%)	24.86	Y1 (2012–13)	298.54	Y × D	SEm (±)	10.01
					CD (at 5%)	NS
D1 (15 November)	293.54	Y2 (2013–14)	285.42	D × V	SEm (±)	10.01
					CD (at 5%)	NS
D2 (30 November)	290.42	SEm (±)	7.08	D × V × Y × N	SEm (±)	24.51
					CD (at 5%)	NS
SEm (±)	17.33	CD (at 5%)	NS			
CD (at 5%)	NS					

from a legume–cereal intercropping[20]. Our recent study[11] also showed that the wheat variety K0307 was responsible for maximum amount of N_2O flux than the variety KRL 288. According to Gogoi *et al.*[21], N_2O emission rates from wheat crop increased gradually from 18 DAS onwards and at 39 DAS, N_2O flux of 273 μg N_2O-N/m^2/h was observed for wheat cultivar HUW 234 compared to others.

There were very less yearly variations in N_2O fluxes during wheat growth phases, except crown root initiation and jointing stage. Ambient temperature was same during both the years, approximately 21°C (Figure 1), due to which there were no significant inter-annual variations as meteorological conditions also affect soil environment followed by microbial activity. Considering the nearly identical N-fertilization rates and similar irrigation operations in each year in the study of Zhang *et al.*[18], the inter-annual variation of N_2O emissions was mainly ascribed to the changes of meteorological condition that affected the soil temperature and moisture.

Significant variation in N_2O emission rates was also found in case of interactions, viz. N × Y, N × V, N × D and D × V during flowering stage. However, combined effects of Y × V and Y × D on N_2O emission showed less significant variation during specific phenophases of wheat crop. Otherwise, it was found to be non-significant. Available moisture present in the soil (precipitation) with optimum soil temperature during flowering stage was responsible for this type of relationship. Whereas, four factor combinations resulted in significant variation in N_2O emission from wheat during flowering stage. Also at other growth stages less variation was noticed, except tillering stage. Individual factors maintained their identity in this case.

Our study indicated that there is a strong linear relationship between soil environment, viz. soil moisture and soil temperature, and N_2O emission rates. Significant correlation coefficient has been noticed between soil environment and N_2O flux at specific phenological phases during both the years (Tables 2 and 3). Results suggest that N_2O emission decreases with increasing soil temperature. Whereas increasing soil moisture promotes the emission of N_2O. The results of Tian *et al.*[22] agree with our findings that higher soil moisture greatly increases N_2O emissions from wheat field. However in different experimental sites, N_2O flux is often related to increased soil temperature[23,24]. The study by Wei *et al.*[25] in the Shaanxi Province, China indicated that N_2O fluxes in the winter wheat fields of the study area were somewhat temperature and water-dependent.

In our study, wheat crop yield was significantly affected by nutrient, variety, N × Y (nutrient × year), N × V (nutrient × variety) and N × D (nutrient × date of sowing) with *F* ratio of 8.686, 16.143, 8.507, 9.981 and 11.807 respectively (according to ANOVA study). Maximum yield (412.5 g/m^2) was obtained from N1 (100% inorganic fertilizer), V1 (K0307), D1 (15 November), Y1 (2012–13) (Table 4).

Results also indicated that wheat production component is not highly associated with N_2O emission potentiality under various management schedule ($R_2 = 0.039$ and 0.169 during 2012–13 and 2013–14 respectively). This finding was supported by Huang *et al.*[26]. They reported that there is no significant relationship between aboveground biomass and N_2O emission.

Finally, in conclusion, we can recommend to farmers that to reduce N_2O emission from wheat crop with sustaining productivity the following practice as use of wheat variety K0307 sown on 15th November under 100% organic nutrient may be adopted.

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ACKNOWLEDGEMENTS. We acknowledge the support of Principal Investigator, RKVY sponsored project on climate change, Department of Agricultural Meteorology and Physics, BCKV, Mohanpur, Nadia, and Department of Environmental Science, University of Kalyani, Kalyani, Nadia, West Bengal.

Received 27 April 2015; accepted 21 May 2015