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N_2O emissions in a long-term soil fertility experiment under maize–wheat cropping system in Northern India

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ABSTRACT

The agriculture sector is a major contributor towards global N_2O (nitrous oxide) emissions. Amongst various factors controlling N_2O emissions from cultivated fields, application of fertilizers and manures is the key factor. The effect of 42 years of continuous application of inorganic fertilizers and farmyard manure (FYM) on N_2O emissions in loamy sand soil was studied via closed chambers and gas chromatography. Daily N_2O fluxes from five treatments: 100% NPK (T_1), 150% NPK (T_2), 100% N (T_3), 100% NPK + FYM (T_4) and Control (T_5), of an onging experiment under maize-wheat cropping system on Typic Ustochrept in Northern India, were measured during maize and wheat crop seasons. The average N_2O fluxes in T_1, T_2, T_3, T_4 and T_5 treatments during maize crop season were 56.2, 60.8, 58.5, 59.2 and 24.6 N_2O-N g ha^{-1} day^{-1}, respectively and in the wheat crop season 17.1, 19.7, 17.2, 19.4 and 11.5 N_2O-N g ha^{-1} day^{-1}, respectively. Total N_2O emissions in long-term fertilizer or manure treatments were approximately 100 and 50% higher than control in the maize and wheat crop seasons, respectively. Various long-term treatments had significant effect on status of various soils C and N forms, which in-turn influenced N_2O emissions. Regression analysis revealed that water-input either from rainfall or irrigation controlled nearly 50% of the seasonal variations in N_2O fluxes in the control treatment and about 20% variations in fertilizer and manure treatments. This suggested that in addition to irrigation or rainfall, fertilizer application also played an important role in N_2O emissions. Although carbon-equivalent emissions were higher from balanced fertilization or FYM application treatments, yield-scaled global warming potentials (GWP) were lower due to higher maize and wheat grain yields in these treatments. Long-term maize-wheat cropping without any nutrient application or imbalanced fertilization resulted in higher yield-scaled GWP. The findings suggested that to achieve food security and curtail N_2O emissions, balanced fertilization or integrated nutrient management may be adopted.

1. Introduction

Amongst the three greenhouse gases (GHG) emitted by agricultural soils, radiative forcing of nitrous oxide (N_2O) is approximately 12 times larger than methane (CH_4) and 298 times of carbon dioxide (CO_2) over a 100-year time horizon. As per IPCC estimates, annual emissions of N_2O from agriculture are 2.8 $GtCO_2$-eq yr.$^{-1}$ and this constitutes around 60% of global N_2O emissions from all sources (Smith et al., 2007). Intensively irrigated and fertilized wheat, maize, and other upland crops are primarily a source of N_2O emissions, and their levels are largely driven by the amount of nitrogen (N) fertilizer applied (van Groenigen et al., 2010). Linquist et al. (2012) estimated that 0.68%, 1.21%, and 1.06% of applied nitrogen (N) is emitted as N_2O in rice, wheat and maize crops, respectively. There is strong evidence that biogenic fluxes of CO_2, CH_4 and N_2O are altered by N addition to ecosystems due to changes in the physiology of soil microbes and vegetation (Dalal et al., 2003; Bodelier and Laanbroek, 2004; Mosier et al., 2006).

Long-term field experiments play an important role in understanding the complex interactions amongst plants, added inputs, management practices and climatic conditions. These experiments help in observing the changes that occur slowly and are not easily noticed in short-term studies (Edmeades, 2003; Brar et al., 2013; Rasool et al., 2008). Many long-term fertilizer experiments have shown that continuous application of fertilizers, manures or crop residues or their combinations result in the build-up of soil organic matter and higher biological activity in soils (Manjaiah and Singh, 2001; Rudrappa et al., 2005; Mandal et al., 2007; Brar et al., 2013). Furthermore, improvements in soil physical properties such as bulk density, porosity, hydraulic conductivity, water holding capacity along with soil aggregation has been reported with the continuous application of fertilizers and manures (Edmeades, 2003; Rasool et al., 2008). With the differential long-term application of inorganic fertilizers and organic amendments, variation in the status of various soil C and N forms has also been observed (Hao et al., 2008; Tong et al., 2009). Denitrification in agricultural

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soils has been found related to soil organic matter and C:N ratio (Aulakh et al., 2001; Klemedtsson et al., 2005). The long-term application of fertilizers and manures in a soils under similar crop and management practices may result in differences in N_2O emissions due to variations in microbial activity caused by differential status of soil C and N forms.

Although, N_2O emissions from agricultural fields under rice–wheat cropping system in Northern India have been reported from some short-term field studies, any information about N_2O emissions from soils under a long-term maize-wheat cropping system is lacking. Due to entirely different tillage practices in maize and rice cultivation, redox potential after the monsoon rains or irrigation, drops differently in soils under rice or maize cultivation. In the puddled rice soils conditions become conducive for methane production, but in the maize fields conditions favorable for N_2O production are created. The present study was undertaken to study N_2O emissions as affected by the application of inorganic fertilizers and FYM in a long-term experiment under maize-wheat cropping system. The impact of various long-term treatments on the status of various soils C and N forms was studied with respect to N_2O emissions. Further, relationships were worked out to study the effect of seasonal fluctuations in weather variables on the temporal variations in N_2O fluxes from different treatments. To identify the nutrient management practice for addressing the twin issues of global warming and food security, C-equivalent emissions and yield-scaled GWP for different treatments were also computed.

2. Materials and methods

2.1. Field experiment

To study the effect of long-term inorganic fertilizer and FYM application on soil N_2O emissions in Typic Ustochrepts during the maize and the wheat crop seasons, a field experiment under a maize-wheat cropping system at Research farm, Punjab Agricultural University, Ludhiana was selected. Differential amounts of inorganic fertilizers and FYM in different treatments have been applied continuously for the past 42 years. The experimental site was located at 75°47′09″E, 30°54′19″N at an altitude of about 247 m ASL and the climate is subtropical, semi arid, hot and monsoon type with cold winters and hot summers. The soil in the experimental field is a Typic Ustochrept with a loamy sand texture (88% sand, 5% silt and 7% clay). N_2O fluxes in the five treatments: 100% NPK (T_1), 150% NPK (T_2), 100% N (T_3), 100% NPK + FYM (T_4), and Control (T_5); were measured during the maize and the wheat crop seasons (Table 1). 100% NPK refers to nitrogen (N), phosphorus (P) and potassium (K) fertilizer application at recommended level of 120 kg N + 26.2 kg P + 25.0 kg K ha^{-1} to each of the maize and wheat crops. Details of the annual application of inorganic fertilizers and FYM along with the status of soil organic carbon (SOC), P and K in experimental soil at the beginning of the experiment in 1971 and their status in the year of study (2013) are given in Table 1. Urea, single superphosphate (SSP) and muriate of potash (MOP) were used to supply N, P and K to maize and wheat crops. Application of FYM at 10 Mg ha^{-1} approximately supplied 3700 kg C, 90 N, 140 kg P and 150 K ha^{-1} annually. Maize hybrid PMH 1 was sown at the end of May 2013. Full dose of P and K fertilizers and one-third of total N was applied at sowing in T_1, T_2, T_3 and T_4 treatments, while remaining fertilizer-N was applied in two equal split doses at 20 and 52 days after sowing (DAS), and no fertilizer was applied in control (T_5). In addition to pre-sowing irrigation, three additional irrigations were given and other practices were followed as per the package of practices of Punjab Agricultural University, Ludhiana. Wheat crop (variety PBW 621) was sown on 21 November 2013 with a seed-cum-fertilizer drill and full dose of P and K fertilizers was applied at sowing. In T_1, T_2, T_3 and T_4 treatments, half of N-fertilizer was applied at sowing, while remaining half dose of fertilizer-N was applied after one month; no fertilizer was applied in T_5. In addition to a pre-sowing irrigation, another irrigation was applied 28 DAS. At maturity, the crops were harvested from three random spots of 1 m^2 in each treatment and fresh weights of grain and straw were recorded. Further, the samples were dried in oven at 60 °C for 24 h and weight of both straw and grain were again recorded after drying. The final yield was adjusted for 14 and 10% moisture for maize and wheat, respectively.

Table 1
Annual application of N, P and K fertilizers in different treatments under maize-wheat cropping system along with the initial status of pH, SOC, N, P and K at the start of the experiment in 1971 and after 42 years of cropping.

	Treatment	Total annual application ($kg\ ha^{-1}$)			pH	SOC[a] ($g\ kg^{-1}$)	Avl. P[b] ($g\ kg^{-1}$)	Avl. K[c] ($g\ kg^{-1}$)
					Initial status[d]			
					8.20	2.20	6.10	58.7
		N	P	K	Present status[e]			
T_1	100% NPK[f]	240	52.4	50.0	7.40 b	4.10b	55.13 b	70.6 a
T_2	150% NPK	360	78.6	75.0	7.00 c	4.10b	54.6 b	80.0 a
T_3	100% N	240	0	0	7.20 c	3.31c	8.61 c	44.3 b
T_4	100% NPK + FYM[g]	240	52.4	50.0	7.20 c	5.18a	60.6 a	82.1 a
T_5	Control	0	0	0	7.70 a	3.03c	9.13 c	44.8 b

[a] SOC = soil organic carbon.
[b] Avl. P = available P.
[c] Avl. K = available K.
[d] Initial status at the beginning of the experiment in 1971.
[e] Status in 2013 after 42 years of maize-wheat cropping.
[f] 100% NPK refers to nitrogen (N), phosphorus (P) and potassium (K) fertilizers application at recommended level.
[g] 10 Mg ha^{-1} of FYM was applied once annually before maize sowing.

2.2. Flux measurement

To measure N_2O fluxes, closed (static) chambers made of polymethyl methacrylate with 10 cm internal radius and 15 cm height were deployed in the fields. The chambers were equipped with a battery-operated fan for mixing the air in the head space, a vent tube for pressure equilibration, and a rubber septum for the collection of gas samples, based on the guidelines given by Parkin and Venterea (2010). Chamber collars made of polyvinyl chloride (PVC) were installed between the rows at sowing and left in the field undisturbed till the harvesting of crops. Air samples in triplicate (within a minute) were collected using a 10-ml syringe fitted with a hypodermic needle at 0, 15 and 30 min after chamber closure. The samples were immediately stored in 5-ml pre-evacuated glass vials equipped with a butyl rubber septum. The collected samples were taken to laboratory on the same day and N_2O concentration in the samples was determined via a gas chromatograph (model 2100 Shimadzu Inc., Kyoto, Japan) equipped with a packed column and an electron capture detector (ECD).Gas sampling was continued throughout the maize and wheat crop seasons. The N_2O flux ($mg\ N_2O\ ha^{-1}\ d^{-1}$) was calculated from linear temporal increase in the N_2O mixing ratio in the chamber head space as described by Parkin et al. (2012). Total seasonal N_2O emission for the whole season was calculated by linear interpolation of daily fluxes between two successive measurements. Based on the IPCC, 2007 guidelines, C-equivalent N_2O emissions ($Mg\ CO_2\text{-eq}\ ha^{-1}$) for seasonal total N_2O emissions were calculated by taking global warming potential of N_2O as 298 over a 100-year time horizon. Further, yield-scaled GWP was calculated by dividing the total C-equivalent emissions for each treatment by their respective grain yields and expressed as $Mg\ CO_2\text{-eq}\ Mg^{-1}$.

2.3. Soil sampling and analysis

Surface soil (0–15 cm) samples were collected from all treatments before sowing of maize and wheat crops for the determination of various soil C and N forms. Soil organic carbon (SOC) was determined using the Walkley and Black (1934) rapid titration method. Total carbon (TC) and total nitrogen (TN) were determined using a CHN analyzer (Vario EL III, Elementar Analysensysteme GmbH, Germany). Water soluble carbon (WSC) was estimated by extraction with distilled