Assessment of Greenhouse Gases Emission in Maize-Wheat Cropping System Under Varied N Fertilizer Application Using Cool Farm Tool

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In recent decades, climate change induced by enhanced global warming is one of the biggest challenges at the global level. Agriculture sectors significantly contribute to total anthropogenic greenhouse gas emission to the atmosphere. Wheat and maize, cultivated globally, and consumed in different forms, are considered as crucial staple cereal for ensuring food security to global population. The management practices involving land preparation, sowing, fertilizer application, irrigation, pest management, etc. significantly influence the emission of carbon dioxide (CO_2) and nitrous oxide (N_2O) from agricultural soil. In this study, CO_2 and N_2O emission were assessed from maize and wheat crops at four different levels of N fertilizer using cool farm tool model. Emissions of CO_2 per hectare varied from 331.4 to 1,088.3 $kgCO_2$ in maize and ranged from 292.3 to 765.3 $kgCO_2$ in wheat on application of different doses of N. The total GHG emission in maize crops ranged from 859.5 to 3,003.4 $kgCO_2$ eq per hectare with the application of nitrogen at varying levels (0–240 kg N per hectare). The highest N_2O efflux (0.368 kg per ton) was observed at 240 kg N per hectare under wheat crop. The total on-farm emissions, through fertilizer production, account for about 33.7%, and emission of N_2O contributes only 65.9%, whereas pesticides account merely 0.4% under maize-wheat cropping. This study confirms that the direct emission of N_2O was totally dependent on N fertilizers application rate; however, the indirect emission was controlled by the fuels and energy consumption.

Keywords: maize, wheat, carbon dioxide, greenhouse gases, nitrous oxide, nitrogen fertilizer

INTRODUCTION

The production of food grains (maize, rice, wheat, etc.) is being adversely affected by climate change, and agricultural activities leading to emission of methane (CH_4), carbon di-oxide (CO_2), and nitrous oxide (N_2O) (Malyan et al., 2021) serve as a major contributing factor to future climate change. The main anthropogenic source of CH_4 (77%) and N_2O (60%) emissions contributes in Indian Agriculture (Sharma et al., 2021). Methane emissions are confined to rice and enteric fermentation (Kumar et al., 2020b), while CO_2 and N_2O are uniformly released from all agricultural crops as consequences of crop raising activities such as soil manipulation and fertilizer applications (Kumar et al., 2016a; Kumar et al., 2016b; Bhattacharyya et al., 2018; Sapkota et al., 2021). The addition of nitrogen to agricultural soil changes GHG fluxes. Since

1960, consumption of nitrogen fertilizer has increased 66 times (Fagodiya et al., 2020a). In India, the use of irrational nutrient applications has resulted in low input use efficiency, lower income, and enhanced pollution (Pampolino et al., 2012). In India, fertilizer recommendation is based on response of a crop over a broad geographical area which could not concede the spatial variation in soil nutrient supplying ability (Majumdar et al., 2013). It is a well known fact that aeration, soil temperature, soil moisture, organic carbon (OC) supplies, fertilization, pH, and other environmental factors like production and transport influence N_2O and CO_2 emission in soil (Kumar and Sharma, 2017a; Kumar et al., 2020a; Fagodiya et al., 2020a).

In general, nitrogen is the most critical and limiting nutrient in agricultural production. The global consumption of nitrogen fertilizer has increased from 12 Tg (1960) to 113 Tg (2010) (Fagodiya et al., 2017). Moreover, the main components of nitrogen cycle are nitrification, assimilation, ammonification, and denitrification (Kumar et al., 2016b; Kumar and Sharma, 2017a; Kumar and Sharma, 2017b). Several compounds like NH_3, NOx, NO, N_2O, NO_3 etc. could be released into the atmosphere during the nitrogen cycle, influencing the climate system. The reactive nitrogen (Nr) plays direct and indirect roles on N_2O emissions in soil. N_2O emissions are of major concern because of their extensive atmospheric lifespan (approx. 116 years), maximum potential of global warming (310 times that of CO_2), and high global climate change potential (290 on a100–year basis) (Fagodiya et al., 2020a). N_2O emissions can occur both directly and indirectly from fertilizer N input to the soil. Additional fertilizer N application to the same soil is referred as direct emissions (Holka and Bienkowski, 2020). Indirect N_2O emissions are those that occur from the different sources except soil that should not be limited, like N_2O generated through waters and leaching of NO_3 to the soil (IPCC, 2006). Farms and horticultural enterprises account for just about 8% CO_2 emission. N_2O and CH_4 are important GHG which contribute 57% and 35%, respectively, to global warming (FAS, 2014). N_2O is a potent GHG that contributes directly to global warming. For a period of 100 years, N_2O emissions were more sensitive than other GHG because of its long atmospheric habitation (114 years), global climate change potential (290 times higher than CO_2), and global warming potential (265 times higher than CO_2). All these gases contribute as the third most abundant GHG after CO_2 and CH_4. Approx. 18.09% of total GHG and 73.29% of total N_2O were emitted from the agricultural sector in India during 2014. The use of nitrogen fertilizer fulfills the demand of food production considering the growing population, resulting in higher N_2O emissions from the country's agriculture.

Maize is an aerobic crop and unlike rice, puddling or submergence is not required for its cultivation. As a result, less energy is needed for tillage operation as well as less water is required for maize, resulting in fewer CH_4 emissions in comparison to rice fields. Hence, maize is a better option for minimizing ground water depletion, soil degradation, and CH_4 emissions from the Eastern plateau region of India. Maize, the third most important cereal crop, contributes 78.2 million tons to world total food grain production with an area of about 150 million hectares (McCann, 2007; Parihar et al., 2011). India is

producing 30.41 million tons from 9.1 million hectares (mha) area with a productivity of 2,771 kgha^{-1} (USDA, 2019). Maize-wheat cropping system ranked third after rice-wheat and rice-rice cropping systems (Jat et al., 2014). Consequently, wheat can be grown in a variety of climates around the world, covering more than 200 mha. The estimated production of the world crossed 750 million metric tons in 2016–17. India contributed 87 million metric tons from 30.22 mha area in 2016–17, core production of wheat (98.5 million ton) was registered from 30.72 mha in 2017–18, and a forecast of reduction in production in 2018–19 was estimated to 94 million metric ton (USDA, 2018) suggesting a degree of uncertainty in production level. Being less CH_4 gas emitter, maize-wheat is appealing as an alternative cropping system compared to rice-wheat system. Most of the studies conducted on mitigation of GHG emission in eastern plateau region of India are mainly based on rice-wheat cropping system. The N_2O emissions from MWR have rarely been reported. The GHG emissions associated with the manufacture of synthetic N fertilizers were estimated to be 41.44 and 59.71 Mt CO_2-eq year^{-1} for wheat and maize in China, respectively. And the direct N_2O emissions derived from synthetic N fertilization were estimated to be 35.82 and 69.44 Gg N_2O year^{-1} for wheat and maize, respectively (Chai et al., 2019). The carbon sequestration under maize-wheat cropping system provides promising prospects for reducing GHG emission. GHG emission can be measured with the help of Cool Farm Tool (Hillier et al., 2011) which has been defined as an empirical GHG quantification model into a single tool. Cool farm tool (CFT) enables the user to make choices appropriate to existing practices. The CFT is open-source software integrating several globally determined empirical models into a GHG emission calculator. At farm level, the tool identifies context-specific factors like pedo-climatic characteristics, output inputs, and other management activities that affect GHG emission. The Cool Farm Tool (CFT) calculates the total emission of GHG in terms of "per unit area" as well as "per unit product." The key objective of this study is to estimate the CO_2 and N_2O emission under maize-wheat cropping system at four different levels of N fertilizer application and three modes of application, by using the CFT model as the direct measurement to GHG emission.

MATERIALS AND METHODS

Description of Research Site

The research programme was carried out during 2015–16 and 2016–17 at the research farm of Ranchi Agriculture College under Birsa Agricultural University, Ranchi, under Maize-Wheat cropping system (**Figure 1**). The research field was located at 23°19' N and 83°17' E, at altitude of 625 m above mean sea level (MASL) in the Chhotanagpur Plateau, which comes under the eastern section of the Deccan plateau and situated under Agro-climatic Zone V.

The climate of state is falling under tropical and sub-tropical. During the summer season temperatures varied from 18 to 40°C, while during the winter, temperatures ranged from 0 to 22°C. The lowest temperature was recorded in the months of December and January; in some areas of Kanke sometimes the temperature
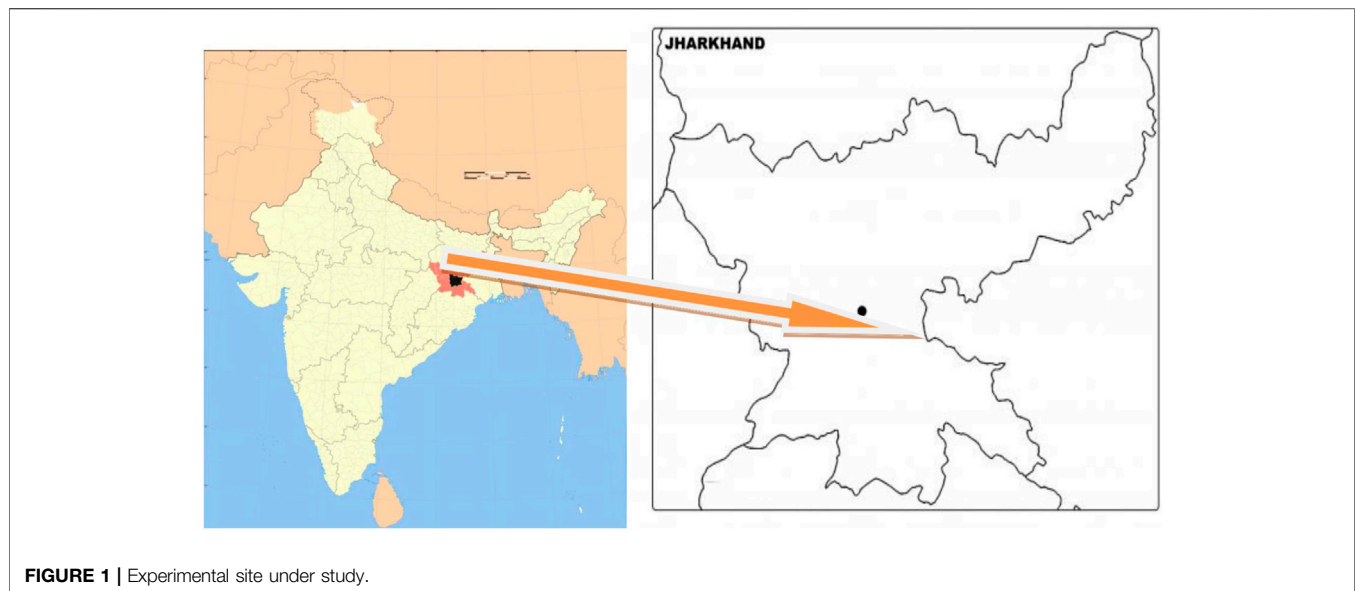
FIGURE 1 | Experimental site under study.

TABLE 1 | Treatments details of maize and wheat crop.

Treatments	Treatments details for maize/wheat	Application schedule for maize	Application schedule for wheat
N1	0/0 kg N	S1 (33/33/33 at basal, V4 and V10)	S1 (33/33/33 at basal, Crown root initiation) Stage (CRI), Panicle Initiation stage (PI)
N2	80/50 kg N (33-33-33)	S2 (33/33/33 (LCC)at basal, V4 and V10)	S2 (33/33/33 LCC) At basal, CRI and PI stage)
N3	160/100 kg N (33-33-33)	S3 (50-0-50 at basal and V10)	S3 (50-50 at basal and CR I stage)
N4	240/150 kg N (33-33-33)		
N5	0/0 kg N		
N6	80/50 kg N (33-33-33 LCC)		
N7	160/100 kg N (33-33-33 LCC)		
N8	240/150 kg N (33-33- 33LCC)		
N9	0/0 kg N		
N10	80/50 kg N (50-0-50)		
N11	160/100 kg N (50-0-50)		
N12	240/150 kg N (50-0-50)		

Note: LCC-Leaf Color Chart and CRI-Crown Root Initiation and PI-Panicle Initiation stage.

dipping down to the freezing point. The annual total rainfall received by the experimental areas is about 1,430 mm (56.34 inches) and 78–91% rainfall is received during the peak period of monsoon through South West Monsoon (from June to September). The rest is received in different seasonal spells like North East Monsoon (6.5% with amount 92.4 mm) from October to December. In the winter season, it received 3.74% with amount 52.4 mm (January to February) and summer 7.5% with the amount 104.7 mm with thunderstorm showers. During the maize growing season, total rainfall was about 528 mm, with average temperatures ranging from 20.3 to 30.80°C; however, rainfall was around 47 mm, with temperatures ranging from 3.10 to 39.50°C during the wheat cropping season. From the second week of February to the first week of March 2016, the highest average morning relative humidity was 87%, and the lowest average evening relative humidity was 31% in the third week of March.

Treatments and Cropping Systems

This experiment consisted four levels of nitrogen application (0, 80, 160, 240 kg Nha^{-1} for maize and 0, 50, 100, 150 kg Nha^{-1} for wheat) with three different modes of application. Methods of application of nitrogen were two splits (50-0–50 kg ha^{-1}) at basal and V10 stages, three splits (33-33-33 kgha^{-1}) at basal, V4, and V10 stage and (33-33-33 on the basis of LCC), in case of wheat apply as basal, and at CRI stage (50-0-50), basal, CRI, and PI stage (33-33-33). The phosphatic (single super phosphate) and potassic fertilizer (Murate of Potash) at the rate of 100 kgP2O5 and 100 kg K$_2$O^{-1}ha were applied as basal irrespective of treatments as shown in **Table 1**. The date of sowing of maize was 26/June 25, 2015/16 and date of harvesting was 05/October 6, 2015/16. However, the phosphatic and potassic fertilizer at 90 kgP2O5 and 80 kgK$_2$Oha^{-1} were applied as basal to all the treatment, and date of sowing were 10/December 11, 2015/16 and date of harvesting 12/April 13, 2016/17 respectively.

Methods Used for Calculating CO_2 Emission From Farm Operation

The emission of CO_2 from on farm and off farm through various activities like irrigation, tillage, fertilizer, and pesticide production are calculated from various published emission factors.

Irrigation

The emission of CO_2 after irrigation was calculated at 30% electric pump efficiency (Nelson et al., 2009; Gupta et al., 2015) and 19% electric power transmission and distribution losses in India (World Bank, 2014) by the following formula:

$$CO_2 - C\,(irrigation)\,(kgC/ha) =$$
$$[amount\ of\ irrigation\ water\ applied\,(m^3/ha)] \times [2.724/1000]$$
$$\times [Groung\ water\ depth\,(m)] \times [100/pump\ efficiency\,(\%)]$$
$$\times [100/power\ loss\ in\ transmission\,(\%)]\ ^*0.4062$$

(1)

where 2.724 is energy (kWh) needed to lift 1,000 m^3 of water from 1 m depth without any loss in pump efficiency and 0.4062 is carbon density (kgC per kWh) of coal-based electricity generation (Nelson et al., 2009).

Tillage and Sowing

Two tillage operations were conducted and CO_2 emission was calculated as per Gupta et al. (2015).

$$CO_2 - C\,(tillage)\,(kgc/ha) = duration\ of\ tractor\ operation\,(hour/ha)$$
$$\times diesel\ consumption\ rate\,(liter/hour) \times 0.728 \quad (2)$$

where 0.728 is CO_2-C emissions (kg) from consumption of 1 L diesel (EPA 2005).

Pesticide Production and Transportation

The CO_2 emission from pesticide production and transportation was calculated from the following equation

$$CO_2 - C\,(kgC/ha) = Herbicide\,(kg/ha) \times 6.3 + Insecticide\,(kg/ha)$$
$$\times 5.1 + fungicide\,(kg/ha) \times 3.9$$

(3)

where 6.3, 5.1, and 3.9 is amount of CO_2-C emitted from production and transportation of 1 kg of herbicide, insecticide, and fungicide respectively (Lal, 2004).

Fertilizer Production and Transportation

The CO_2 emission from fertilizer production and transportation was calculated from the following equation

$$CO_2 - C\,(kg/ha) = Amount\ of\ N\ applied\ by\ urea\,(kg/ha) \times 2.02$$
$$+ Amount\ of\ N\ applied\ by\ DAP\,(kg/ha) \times 1.84$$
$$+ Amount\ of\ P_2O_5\ applied\ by\ SSP\,(kg/ha) \times 0.06$$
$$+ Amount\ of\ K_2O\ applied\ by\ MOP\,(kg/ha) \times 0.25$$

(4)

where 2.02, 1.84, 0.06, and 0.25 is CO_2-C emission (kg) from the production and transport of 1 kg of N (urea), N (DAP), P2O5(SSP), and K2O (MOP) adopted from Kool et al., 2012.

RESULTS AND DISCUSSION

Carbon Dioxide Emission

CO_2 emitted by maize grown during the wet season emission ranged from 331.4 to 1,088.1 kg ha^{-1}, while in wheat (winter season) it varied from 292.3 to 765.3 kg ha^{-1} depending on the application rates of nitrogen fertilizer (**Table 2**). The mean value of emitted CO_2 was 1,088.1 $kgha^{-1}$, when maize received 240 kg N ha^{-1}, while 836.0 kg CO_2 ha^{-1} was released at 160 kg N ha^{-1}. However, the emission of CO_2 was lowest at a level of 0 kg N (331.4 kg CO_2 ha^{-1}). During the winter season, the highest CO_2 emission (765.3 kg CO_2 ha^{-1}) was recorded at 150 kg N ha^{-1}, followed by 100 kg N ha^{-1} (613.7 kg $CO_2 ha^{-1}$). At 50 kg level of N fertilizer application, the emission was 456.0 kg $CO_2 ha^{-1}$, that was 35.9% higher than that of the emission noted at 0 kg level (292.3 kg $CO_2 ha^{-1}$). Soil manipulation like tillage triggers CO_2 emission through biological decomposition of soil organic matter (SOM) acts as the primary source of CO_2 from agriculture field. Disintegration of soil aggregates through ploughing increases oxygen availability and facilitates organic matter (OM) decomposition of exposed organic material (Bhattacharyya et al., 2018). Other sources of CO_2 emissions include the fuel used for various agricultural activities and the burning of crop residues (Gupta et al., 2015). Carbon dioxide production at the time of manufacturing of fertilizers and pesticides is an off-site source (Pathak et al., 2010; Pathak et al., 2016).

Nitrous Oxide Emission

Emission of N_2O from the soil occurs as a result of additional nitrogenous fertilizer application to the soil (within a defined boundary of producer's field) referred as direct emissions (Sharma, 2020). N_2O gas emission emitted off-site (beyond the boundary) are referred as indirect emissions, which do not include N_2O gas produced through receiving runoff water and NO3 leaching in soil (Fagodiya et al., 2019). Nutrient management strategies had a significant impact on the amount of N_2O gas released per hectare and per ton of crop yield. Different rates of nitrogen application showed a major impact during the estimation of N_2O emission per hectare in both crops (maize and wheat). In maize, application of 160 kg N ha^{-1} estimated higher N_2O emission (4.3 kg N_2O ha^{-1}) compared to 80 kg N ha^{-1} (2.8 kg N_2O ha^{-1}). However, calculated N_2O emission was highest with N at 240 kg N ha^{-1} (6.5 kg N_2O ha^{-1}) and lowest value of 1.8 kg N_2O ha^{-1} at 0 kg N ha^{-1} (**Table 2**). The same pattern of emission was not followed in case of emissions per ton of maize yield than per hectare. That might be directly associated to the crop yield, while per hectare value is preferably reliant on yield, fertilizer doses, and other factors influencing crop production. The calculated value of nitrous oxide emission per ton of maize yield was lower (0.27 kg $tonne^{-1}$) at application of 160 kg N than that of 240 kg N ha^{-1} applied plot (0.37 $kgton^{-1}$). The highest value was observed with the produce recorded at N omitted plot (0.94 kg ton^{-1}). The calculated N_2O emission per tone was 0.28 kg ton^{-1} at 80 kg N ha^{-1} that was marginally higher than the 160 kg N ha^{-1} applied plot (0.27 kg $tonne^{-1}$) (**Table 2**). This has been found and reported that N inputs gradient in

TABLE 2 | Response of various doses of nitrogen treatments on GHG emission (maize–wheat cropping system).

Dose of nitrogen (kg ha^{-1})	Maize							Wheat					
	CO$_2$ (kg ha^{-1})	CH$_4$ (kg ha^{-1})	N$_2$O (kg ha^{-1})	N$_2$O (kg ton^{-1})	Total emission (kg CO$_2$ eq ha^{-1})	Total emission (kg CO$_2$ eq ton^{-1})		CO$_2$ (kg ha^{-1})	CH$_4$ (k gha^{-1})	N$_2$O (kg ha^{-1})	N$_2$O (kg ton^{-1})	Total emission (kg CO$_2$ eq ha^{-1})	Total emission (kg CO2 eq ton^{-1})
N1 (0/0 kg N)	331.4	0	1.8	0.94	859.5	450.0		292.3	0	1.8	0.63	820.4	287.5
N2 (80/50 kg N)	583.7	0	2.8	0.28	1,417.1	143.9		456.0	0	2.7	0.29	1,243.7	135.6
N3 (160/100 kg N)	836.0	0	4.3	0.27	2109.1	132.5		613.7	0	3.5	0.28	1,650.2	133.7
N4 (240/150 kg N)	1,088.3	0	6.5	0.37	3003.4	170.3		765.3	0	4.1	0.31	1974.1	148.0

row-crop agriculture directly dependent to the emissions of N$_2$O with different rate of nitrogenous fertilizer (Halvorson et al., 2008; Hoben et al., 2010; Millar et al., 2010). Application of increased nitrogen dose to the soil enhanced N$_2$O emissions in both of crops. The latest IPCC (2006) greenhouse gas inventory calculations are based on many factors, like heat, structure, water holding capacity, and organic matter content of the soil, and these are directly responsible for the rise in N$_2$O emissions. In general, management of crop residues and fertilizer application are major responsible factors for theN$_2$O pollution in agro-ecosystems (Rochette et al., 2008). The estimated value of N$_2$O emission per hectare in the case of wheat grown with 150 kg N ha^{-1} during winter season was maximum 4.1 kg ha^{-1}, followed by 100 kg N ha^{-1} (3.5 kg N$_2$O ha^{-1}). The lowest value (1.8 kg N$_2$O ha^{-1}) was recorded with the omission of nitrogenous fertilizer. On the other hand, in terms of N$_2$O emission per ton in wheat was highest (0.63 kg tonne^{-1}) under the N-omitted plot (0 kg N ha^{-1}), followed by the application of 150 kg N ha^{-1} (0.31 kg ton^{-1}), and the lowest value (0.28 kg tonne^{-1}) was recorded with the application of 100 kg N ha^{-1}. It may be concluded that the variation in NO2 emission per ton is due to the variation in yield and urea application. Jain et al. (2016) recorded that factor of N$_2$O emission varied from 0.48 to 0.58% and 0.40–0.46% in wheat and maize crops, respectively whereas, Bhatia et al. (2005) noted emission factor of 0.58–0.62% with the application of N fertilizers. Moreover, as per IPCC (2014) the default coefficient factor of nitrous oxide emission for N fertilizers was 1%.

Methane Emission

With removal of crop residues from the field at the time of tillage operation before sowing of maize and wheat, no methane gas emission was observed by using the CFT model. Soil CH$_4$ production is reliant on a limited supply of oxygen (anaerobic condition), which is regulated by moisture content of soil. Sowing of wheat in dry soil during winter (devoid of submerged condition) may be one of the key factors which suppressed the methane gas emission (Aryal et al., 2015).

Total Greenhouse Gas Emission
Maize

Global warming potential (GWP) per hectare for total GHG emission and CO$_2$-equivalent (CO$_2$-eq) per ton of crop yield positively varied at various level of nitrogen application (**Table 2**). The extent of total GHG emissions in maize contributed from 859.5 to 3,004 kg CO$_2$ eq ha^{-1}, depending on the doses of N fertilizers at 0 kg N ha^{-1}–240 kg N ha^{-1}. Emissions of gases increased with the escalating amount of nitrogen fertilizer. The application of 240 kg N ha^{-1} resulted in the highest GHG emission, followed by 160 kg N ha^{-1} (2,109.1 kg CO$_2$eq ha^{-1}) and at 0 kg N ha^{-1} resulted the lowest emission (859.5 kg CO$_2$eq ha^{-1}). While the emission of gases at the rate of 80 kg N ha^{-1} was 1,417.1 kg CO$_2$ eq ha^{-1}, it was marginally inferior to the use of 160 kg Nha^{-1}. The availability of mineral affected the enormity of N$_2$O emissions throughout the crop growth. Under the control scenario, the overall predictable GHG emission in terms of CO$_2$eqton^{-1} of product was considerably higher compared to the supplementary

TABLE 3 | Response of various level of nitrogen application on GHG emission (kg ha^{-1}) from various sources of farm (maize-wheat cropping system).

Dose of nitrogen (kg ha^{-1})	Fertilizer production (kg ha^{-1})	Direct and indirect N2 production (kg ha^{-1})	Pesticides production (kg ha^{-1})	Fertilizer production (kg ha^{-1})	Direct and indirect N2 production (kg ha^{-1})	Pesticides production (kg ha^{-1})
N1 (0/0 kg N)	1,392	528	21	1,253	850	20.5
N2 (80/50 kg N)	1,669	1,661	21	1,426	1720	20.5
N3 (160/100 kg N)	1946	3914	21	1,599	3083	20.5
N4 (240/150 kg N)	2223	8920	21	1772	5316	20.5

TABLE 4 | Correlation among yield, total GHG emission, and various soil properties (maize).

	Yield (qha^{-1})	GHG (kg CO$_2$ eqha^{-1})	pH	Org. C (g kg^{-1})	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
GHG (kg CO2 eq ha^{-1})	0.832**	—	—	—	—	—	—
pH	−0.192^{NS}	−0.319^{NS}	—	—	—	—	—
Org. C (g kg^{-1})	0.052^{NS}	0.025^{NS}	0.506^{NS}	—	—	—	—
Av. N (kg ha^{-1})	−0.017^{NS}	−0.064^{NS}	−0.417^{NS}	−0.551^{NS}	—	—	—
Av.P (kg ha^{-1})	−0.779**	−0.610*	−0.129^{NS}	−0.499^{NS}	0.234^{NS}	—	—
Av.K (kg ha^{-1})	−0.940**	−0.749**	0.193^{NS}	−0.002^{NS}	−0.094^{NS}	0.739**	—

TABLE 5 | Correlation among yield, total GHG emission, and various soil properties (wheat).

	Yield (q ha^{-1})	GHG (kg CO$_2$ eq ha^{-1})	pH	Org.C (g kg^{-1})	Av.N (kg ha^{-1})	Av.P (kg ha^{-1})	Av.K (kg ha^{-1})
GHG (kg CO2 eq ha^{-1})	0.889**	—	—	—	—	—	—
pH	−0.860**	−0.868**	—	—	—	—	—
Org. C (g kg^{-1})	0.262^{NS}	0.128^{NS}	−0.180^{NS}	—	—	—	—
Av. N (kg ha^{-1})	0.271^{NS}	0.197^{NS}	−0.207^{NS}	0.016^{NS}	—	—	—
Av. P (kg ha^{-1})	−0.739**	−0.730**	0.710*	−0.151^{NS}	−0.264^{NS}	—	—
Av. K (kg ha^{-1})	−0.649*	−0.770**	0.799**	0.038^{NS}	−0.395^{NS}	0.780**	—

TABLE 6 | Regression equation among different parameters (yield of maize and wheat with GHG emission, available P and K in soil, and various doses of nitrogen to GHG emission).

Crop	Parameters	Regression equation	R^2
Maize Grain yield	GHG emission	y = 104.79x + 505.71	0.7099**
	Available P	y = −0.611x + 115.73	0.609**
	Available K	y = −0.6536x + 154.82	0.8813**
Maize Nrate	GHG emission	y = 37.745x + 1054.1	0.9215**
	Grain Yield	y = 0.3032x + 12.072	0.9197**
Wheat Grain yield	GHG emission	y = 116.39x + 634.25	0.8053**
	Available P	y = −1.5956x + 178.3	0.5482**
	Available K	y = −1.0646x + 185.34	0.4243**
Wheat Nrate	GHG emission	y = = 32.677x + 1742.5	0.9319**
	Grain Yield	y = 0.2512x + 11.809	0.9267**

treatments. Application of different doses of nitrogen (0, 80, 160, and 240 kg N ha^{-1}) in maize emits 450.0, 143.9, 132.5, and 170.3 kg CO$_2$ eqton^{-1}, respectively.

Wheat

The amount of produced total GHG followed the same trend per ha and per tons maize, with a lower magnitude. The application of nitrogen at150 kg ha^{-1} had the highest GHG emission per ha (1974.1 kg CO$_2$ eq), subsequently with the addition of 100 kg N ha-1 released 1,650.2 kg CO$_2$ eq per hectare and omission of N fertilizer (0 kg N) showed 820.2 kg CO$_2$ eq per hectare (**Table 2**). Because of variation in wheat yield, the total anticipated GHG emission with respect to CO$_2$eq ton-1 of produce was lowest at the rate of 100 kg N ha-1 (133.7 kg CO$_2$ eq ton-1) and the highest value 287.5 kg CO$_2$ eq ton-1 was at 0 kg N ha^{-1}. Total GHG emission varied marginally between the application of nitrogen at the rate of 100 kg ha-1 (133.5 kg CO$_2$ eq ton-1) and at 50 kg N per hectare (135.6 kg CO$_2$ eq ton-1), while the higher value 1,545 kg CO$_2$ eq ton-1 was found at the rate of 150 kg N ha^{-1}. The yield, biological produce, and rate of N application all affected the value of total emission of GHGs by using CFT. The findings showed that when a greater amount of input was used, the total emission was higher than that at lesser amount of input. Among various emission sources, manufacture and use of synthetic fertilizers was found to be the most important source of pollution at the farm level. Pesticides account for just 0.50% of total on-farm emissions in maize, while synthesis of fertilizer and emissions of nitrous oxide account for 32 and 67% as whole farm emissions, respectively. Whereas, in case of wheat, fertilizer production and nitrous oxide emissions showed 35 and 64% of emissions, respectively, and pesticides account for only 0.6 percent. GHG emission by the use of nitrogenous fertilizer was split into two categories as intended towards N$_2$O emissions and GHG emission from fertilizer synthesizer unit. Nitrous oxide emissions

TABLE 7 | Response of various doses and time of nitrogen application on yield (q ha^{-1}) and harvest index.

Nitrogen rate (kg ha^{-1})	Maize			Wheat		
	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
N1(0 kg N)	5.80	13.37	31.90	9.04	19.50	31.53
N2(80/50 kg N)	40.20	58.26	40.68	28.18	63.55	30.85
N3(160/100 kg N)	71.69	87.39	45.20	41.97	81.44	34.01
N4 (240/150 kg N)	76.08	100.30	43.09	45.92	87.46	34.60
CD (0.05)	4.929	8.154	6.57	3.97	7.53	NS
Napplication Timing						
S1 (33/33/33)	48.30	63.10	40.48	31.70	61.09	33.60
S2 (33/33/33LCC)	49.09	67.16	39.47	31.61	68.21	31.45
S3 (50-0-50)	47.98	64.37	40.72	30.52	59.66	33.19
CD (0.05)	NS	NS	NS	NS	6.52	NS
CV%	10.35	12.78	16.61	12.91	12.14	9.75

could occur from microbial activities in soils too (**Table 3**). In agriculture, the mineralization process of nitrogen (ammonium to nitrates and the reduction of nitrate to gaseous form of nitrogen) plays an important role for N_2O production (Granli and Bockman 1994). N_2O emission is accounting for approximately 57% of total annual global GHG emission (IPCC, 2006). During synthesis of chemical fertilizers such as ammonia, phosphoric acid, and nitric acid, all emit greenhouse gases (Kongshaug, 1998). In maize and wheat, the regression analysis for yield and fertilizer doses indicated substantial variation in yield with respect to fertilizer doses (R2 value of 0.91 and 0.92, respectively).

Correlation Matrix
Maize

Correlation coefficient(r) among yield, total GHG emission, and various soil properties were presented in **Table 4**. Yield was positively correlated with GHG emission ($r = 0.832^{**}$) and negatively correlated with available P and K (-0.779^{**} and -0.940^{**}, respectively). Available P content in soil had negative relationship with GHG emission ($r = -0.610^*$) while positively correlated with yield ($r = 0.739^{**}$). Available K was significantly and negatively correlated with GHG emissions (-0.749^{**}) and yield (-0.940^{**}).

Wheat

Coefficient (r) values in wheat were illustrated in **Table 5**, with respect to produce and different variables. It was observed that yield had significant and positive association with GHG emission ($r = 0.889^{**}$). Available P and available K showed significant and negatively correlation with yield ($r = -0.739^{**}$ and -0.649^*) and GHG (-0.730^{**} and -0.770^{**}). The correlation coefficient among soil pH, yield ($r = -0.860^{**}$), and GHG emission ($r = -0.868^{**}$) was calculated and observed to be a significant and negative correlation, thus it could be stated that increased amounts of N application increases the amount of yield and GHG emission. Similarly, soil's available P registered a significant and negative correlation with GHG emission ($r = -0.730^{**}$), which had a positive "r" value with pH ($r = 0.710^*$). Soil available K was found to have a negative relation with GHG emission ($r = -0.770^{**}$), and positively correlated with available P ($r = 0.780^{**}$) and pH ($r = 0.799^{**}$).

The fertilizer recommendation and GHG emission mitigation for the entire cropping system may be given by using the prediction equation with soil test value estimated after harvesting of crops and GHG emission. In derived equations, the relationships are among GHG emission, soil properties after harvest, applied fertilizer quantity, and yield of maize and wheat (**Table 6**). These equations yielded R^2 values significant at 5% of important parameters. Such can be used for prediction of GHG emission, yield of crop, and status of available P and K after crop harvest can be predicted using regression equations and accordingly, optimum fertilizer recommendation can be made with the perspective of environment (Verma and Singh, 1991; Bera et al., 2006). **Table 7** stated that split application of N at 160 kg ha^{-1} to maize (basal, knee high, and tasseling stage) along with 100 kg P2O5 + 100 kg K2O ha^{-1} as basal and split application of N at 100 kg ha^{-1} to wheat (basal, crown root initiation, and panicle initiation stage) along with 90 kg P2O5 + 80 kg K2O ha^{-1} as basal could be the most effective in terms of yield (71.76 and 41.97 qha^{-1}, respectively, **Table 7**), GHG emission (2,109.1 and 1,650.2 kgCO$_2$ eq ha^{-1}, respectively), economic benefit, and available nutrient status of soil.

CONCLUSION

Direct measurement of the GHG is comparatively costlier. The GHG measurement through modeling provides not only the economic options, but variation of the key controlling factors can also be used to trap the minute changes in the GHG effluxes. Therefore, the present investigation is an attempt to utilize the Cool Farm Tool to optimize the N fertilizers and its subsequent effect on the GHG effluxes. In this study, greenhouse data (2015-16 and 2016-17) under maize-wheat cropping system was used to estimate CO_2 and N_2O emission from maize and wheat crops at four different levels of N fertilizer using cool farm tool model. Results stated that emissions of CO_2 per hectare varied from 331.4 to 1,088.3 kg in maize and 292.3–765.3 kg in wheat on application of different doses of N. The total GHG emission in maize crops ranged from 859.5 to 3,003.4 kg CO_2 eq per hectare with the application of nitrogen at varying levels (0–240 kg N per hectare). The highest N_2O efflux (0.368 kg per ton) was observed at 240 kg N per hectare under wheat crop. The total on-farm emissions, through fertilizer production, account for about

33.7%, and emission of N_2O contributes only 65.9%, whereas pesticides account for merely 0.4% under maize-wheat cropping. This study confirms that the direct emission of N_2O was totally dependent on N fertilizers application rate; however, the indirect emission was controlled by the fuels and energy consumption. This study establishes the efficacy of nutrient expert (N-management) rather make a prediction in implementing of site-specific nutrient management to smallholder production systems to enhance the crop yields and improve the increment of farmers' income considering to minimize GHG emission.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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AUTHOR CONTRIBUTIONS

RK carried out the study and organized the field experiment wrote the first draft of the manuscript. SK performed statistical analysis in collaboration with AM and JS. RK compiled the raw data. AbK provided consultation on statistical analysis of N_2O emission data with consultation ArK. All authors are taken keen interest during the preparation of the manuscript.

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