भारत में शुद्ध ग्लोबल वार्मिंग में नत्रजन उर्वरक उपयोग का योगदान और मक्का-गेहूं प्रणाली में उसके शमन के लिए उपाय

CONTRIBUTION OF FERTILIZER N USE IN INDIA TO NET GLOBAL WARMING AND ITS MITIGATION IN MAIZE-WHEAT SYSTEM

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CONTRIBUTION OF FERTILIZER N USE IN INDIA TO NET GLOBAL WARMING AND ITS MITIGATION IN MAIZE-WHEAT SYSTEM

By

RAM KISHOR FAGODIYA

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This is to certify that the thesis entitled **"Contribution of fertilizer N use in India to net global warming and its mitigation in maize-wheat system"** submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi in partial fulfillment of the requirements for the award of **Doctor of Philosophy** degree in **Environmental Sciences** embodies the result of a bona fide research work carried out by **Mr. Ram Kishor Fagodiya, Roll No. 9970** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that all the assistance and help availed during the course of investigation as well as all sources of information have been duly acknowledged by him.

Date: 26.12.2016
Place: New Delhi

(Himanshu Pathak)
Chairperson Advisory Committee

DEDICATED
TO

To
Farming community who feed the nation

To my mother
A strong and gentle soul who taught me
patience and perseverance

To my father
Whose past memories and enthusiasm still
encourage me to believe in myself

To my brother and Bhabi
For supporting me all the way and for fulfilling my
life with little-little surprises

To my wife and son
Whose friendship, love care, and humor gave me
strength and made me believe that "tough times
don`t last but tough people do."

To my sister
Whose silent support always motivates me

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LIST OF ABBREVIATION

CD	:	Critical Difference
AFOLU	:	Agriculture, Forestry and Other Land Use
CEE	:	Carbon Equivalent Emissions
CER	:	Carbon Efficiency Ratio
CFC	:	Chloroflorocarbons
CH_4	:	Methane
CO_2	:	Carbon dioxide
^oC	:	Degree Celsius
DAS	:	Days After Sowing
DCD	:	Dicyandiamide
EC	:	Electrical Conductivity
ECD	:	Electron Capture Detector
FID	:	Flame Ionization Detector
FST	:	Fortran Simulation Translator
FYM	:	Farm Yard Mannure
GC	:	Gas Chromatography
GHGs	:	Green House Gases
GTP	:	Global Temprature ChangePotential
GWP	:	Global Warming Potential
IGP	:	Indo Gangetic Plain
INCCA	:	Indian Network on Climate Change Assessment
IPCC	:	Inter Governmental Panel on Climate Change
kg.	:	Kilogram
g.	:	Gram
LAI	:	Leaf Area Index
LCC	:	Leaf Colour Chart
LTEs	:	Long Term Experiments

Max.	:	Maximum
Min.	:	Minimum
NCR	:	National Capital Region
NCU	:	Neem Coated Urea
NI	:	Nitrification Inhibitor
NUE	:	Nitrogen Use Efficiency
MOB	:	Methane Oxidizing Bacteria
MMOs	:	Methane Mono Oxygenases
NH_3	:	Ammonia
Nr	:	Reactive Nitrogen
N_2O	:	Nitrous Oxide
NO_x	:	Oxide of Nitrogen
O_3	:	Ozone
ppb	:	Parts Per Billion
ppm	:	Parts Per Million
RBD	:	Randomized Block Design
SEd	:	Standard Errors of Difference
SOC	:	Soil Organic Carbon
TDM	:	Total Dry Matter
Tg	:	Teragram

CHAPTER 1

INTRODUCTION

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major greenhouse gases (GHGs) contributing 87% of total radiative forcing (IPCC, 2013). Concentrations of these gases in atmosphere have surpassed the pre-industrial levels by 40, 150 and 20%, respectively due to anthropogenic activities resulting in global warming (IPCC, 2013). Agriculture, Forestry and Other Land Use (AFOLU) sector globally account for about 24% to total anthropogenic emissions of GHGs, mainly CH_4 and N_2O (IPCC, 2014).

Agriculture sector contributes about 18% to the total GHG emissions in India (Bur, 2015), while the global contribution from agriculture is 13.5% (IPCC 2007). The emissions from agriculture are mainly due to emission of CH_4 from rice field & enteric fermentation, and N_2O from application of organic manure and chemical fertilizers to agricultural soils. Methane is mainly produced under anaerobic condition in soil during microbial decomposition of organic matter. Carbon dioxide (CO_2) is largely emitted from microbial decomposition or burning of crop residue, and soil organic matter, tillage operations, production of farm inputs and then transportation of inputs and output. Nitrogen (N) fertilizer input into agricultural systems is considered the major source of N_2O emissions from agricultural soils. In soil N_2O is mainly produced by the microbial processes of nitrification and denitrification after fertilizer application. Nitrous oxide is an important GHG contributing 5% of the enhanced greenhouse effect. Agriculture and associated sectors produce about 78% of the total anthropogenic N_2O emission (Carlo *et al.,* 2007). With its current concentration of 324 ppbv, N_2O is also responsible for the destruction of the ozone (O_3) in lower stratosphere (Rodhe, 1990; Zaman et *al.,* 2012). The concern of emission of N_2O is greater than the other GHGs emission from soils because of its long atmospheric lifetime (116 years), higher global warming potential i.e., 310 (IPCC, 2014). N_2O emission from soils represents a loss of nitrogen from soil system decreasing N use efficiency (Pathak *et al.,* 2010). Global annual emission of nitrous oxide is 6.7 Tg yr^{-1}, which includes direct emission from soils through loss of N to atmosphere and aquatic system (IPCC, 2007). Soil is considered as one of the major source of N_2O emission contributing 65% to the total global N_2O emission (Ehhalt *et al.,* 2001). Biologically fixed nitrogen and Synthetic N fertilizer application in agricultural soils contribute to emission of N_2O during the nitrification and denitrification process. In 2010 synthetic N fertilizer, animal and green manure, soil mineralization, and crop residues, contributes 77, 13, 9 and 1%, respectively, to the total nitrous oxide emission from Indian agricultural soils (Pathak *et al.,* 2010). In India agriculture is the major contributor with 70% of total N_2O emission. The emission from Indian agriculture is likely to increase significantly in future due to our need to increase food production, which will need more application of N fertilizer. Fertilizer consumption in India has increased about 17 times from less than 1 million tons (Mt) in mid 1960s to almost 17 Mt today. The fertilizer consumption intensity varies highly from region to region, from 40.5 kg ha^{-1} in Rajasthan to 184 kg ha^{-1} in Punjab (INDIASTAT, 2012-13). Urea accounts for 82% of total nitrogen consumption.

Wheat is an important cereals crop in India. As regards to area and production, wheat ranks second among the cereals after rice with a production of 92.46 Mt from 29.65 million hectare (Mha) with a productivity of 3118 kg ha^{-1} (INDIASTAT, 2012-13). The major wheat producing states in the country are Uttar Pradesh, Punjab, Gujarat, Madhya Pradesh and Rajasthan. In India, maize is grown in 8.71 Mha with a production of 22.23 Mt and a productivity of 2552 kg ha^{-1} (INDIASTAT, 2012-13). Major maize producing states are Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Rajasthan, Bihar, and Uttar Pradesh. For maize, *kharif* season is the main growing season in northern India but it is also grown in Rabi season in large areas of Bihar and Andhra Pradesh. The maize-wheat cropping (MWCS) system is one of important system in India and its ranked 3rd after rice-wheat and rice-rice cropping systems. It is mainly concentrated in the rainfed ecosystem in Trans Gangetic Plains, Central plateau & hills region and Gujrat plains and hills having considerable amount of area i.e. 1.8 M ha (Jat *et al.,* 2014) which contributes about 3% to the nation food production.

A model is a simplified representation of a system. Crop modeling is defined as the science and art of mimicking the growth and development of the crop. Crop models are useful in defining research priorities, technology transfer, yield estimation, as well as for predicting the effects of climate change and climatic variability. A well validated crop simulation model can simulate crop growth, development and yield with reasonable accuracy and serve as a viable tool for optimizing crop production. The use of modeling tool is gaining importance day by day due to increasing resource crunch and its capability to supplement field experimentation. Simulation is the building of mathematical model and the study of their behavior in reference to that of the system they represent. Among the several crop growth simulation models developed during last few decades InfoCrop and DSSAT are important. However, many models are not able to meet fully for the requirement of the integrated information on impacts of global change, emission of GHG, soil nitrogen and carbon dynamics while simulating the regional variations. InfoCrop is a generic crop simulation model which developed to meet such specific requirements (Aggarwal *et al*., 2006). InfoCrop is written in fortran simulation translator (FST) language which simulate the effects of soils, weather, agronomic management (namely irrigation, nitrogen, residue, planting), and major insects pests on crop yield and its associated environmental impacts. The model is able to simulate the effect of daily changes in weather (caused by climate change also) for any specific location on crop growth and yield. The model requires easily available inputs, user-friendly, and it is targeted to increase its applications in research and development. Robust modeling for simulating the Contribution of fertilizer N use in India to net global warming and its mitigation in maize-wheat system will be highly useful for developing the adaptation strategies at regional level.

The global nitrogen (N) cycle has accelerated sharply due to anthropogenic activities to supply food to the rapid growing human population. The N cycle involves five steps i.e., N fixation ($N_2 \rightarrow NH_3/NH_4^+$), nitrification ($NH_3/NH_4^+ \rightarrow NO_3^-$), assimilation (uptake of NH_4^+ and NO_3^- into plant tissues), ammonification (organic N $\rightarrow NH_3$) and denitrification ($NO_3^- \rightarrow N_2$) (Pathak *et al.,* 2016). During the N cycle several reduced (NH_3) and oxidised N compounds (NOx, NO, N_2O, NO_3^-) are emitted to the atmosphere affecting the climate system (Galloway *et al.,* 2003). A catastrophe of the nitrogen cycle is affecting the emission of the three major GHGs (N_2O, CO_2 and CH_4) from agriculture thereby has impacts on climate (Velthof *et al.,* 2009; De Vries *et al.,* 2010). Inversely, due to the limitation of reactive N (Nr) i.e., all N compounds except N_2, in agriculture system, increased Nr application and deposition usually increases ecosystem productivity there by increasing the fixation of atmospheric CO_2 by crops and plants (Hungate *et al.,* 2003), which results in enhanced carbon (C) sequestration in agricultural soils due to increased crop residue production and reduced organic matter decomposition (Janssens *et al.,* 2010). Further Nr use can also decrease the oxidation capacity of atmospheric CH_4 in to the soils, thereby decreasing the total CH_4 uptake (Steudler, 1989). Therefore, both direct and indirect N_2O emissions from agricultural soils induced by the application of Nr are probably set off by carbon sequestration. Both model based global estimates (Zaehle *et al.,* 2010) and meta-data analysis (Liu and Greaver, 2009) results indicating that nitrogen driven carbon sequestration offsets the reduced CH_4 uptake and N_2O emission.

Keeping in view of the importance of N fertilizers in Indian agriculture, food security and projected increase of N use in future it is necessary to quantify the global warming and cooling impacts i.e., net impact of N fertilizers to global warming potential. Such quantification based on field experiments can also be incorporated into the simulation models for carrying out the impact assessment at local, regional and national scales. The present study was carried out with the following objectives.

1. To quantify the emission of greenhouse gases in a maize-wheat system and assess the magnitude and cost of mitigation with suitable technologies in the upper Indo-Gangetic Plains (IGP).
2. To simulate the impact of N fertilizer use on global warming potential and yield of a maize-wheat system.
3. To quantify the net global warming potential of N fertilizer use in Indian agriculture.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Greenhouse gases

Greenhouse gases (GHGs) are the gaseous (natural and anthropogenic) constituents of lower atmosphere absorbing and emitting radiation of specific wavelengths within the thermal infrared spectrum. Only those gases, which absorb infrared radiation, followed by molecular vibration and subsequent change in dipole moment of the molecule can act as a GHG. This property is not shown by homo-nuclear diatomic gases such as nitrogen (N_2) and oxygen (O_2), hence they are not GHGs. The property is mainly sown by gaseous molecules consisting of three or more atoms like CO_2, CH_4 and N_2O. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHG in the earth`s atmosphere.

The concept of influence of atmospheric gases on earth's temperature was first given by Nobel Laureate, Svante Arrhenius, Swedish chemist in 1903 by posing it as the first question "Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere?" (Arrhenius, 1896). It was recognized as a pioneering contribution to the science of climate change as the first published research to attempt to quantify the role of CO_2 as a GHG. The potential of GHG for warming effect are defined by radiative forcing, which changes the earth's atmospheric energy balance; typically expressed as watts per square meter (Wm^{-2}) (IPCC, 2007). The effectiveness of GHG is measured in terms of global warming potential (GWP). The GWP is a function of radiative forcing, mean lifetime of gas in the atmosphere and its atmospheric concentration. The GWP of different GHG are calculated in respect to GWP of CO_2. Atmospheric water vapour is not considered as potent GHG due to its short atmospheric life-time. However, many GHG (CO_2, CH_4, and N_2O) are long-lived in the atmosphere and are the major contributors to global warming (IPCC, 2007). The GWP of each of these gases can be expressed in CO_2 equivalents. The CH_4 and N_2O have 21 and 310 times higher GWP then CO_2 (IPCC, 2014).

Anthropogenic GHG emissions of CO_2, CH_4 and N_2O have increased since the pre-industrial era largely driven by industrial development and population growth (IPCC, 2014). Concentrations of CO_2, CH_4 and N_2O have increased by about 40, 150 and 20%, respectively since 1750. The CO_2 is the major GHG contributing 76% of total anthropogenic GHG emissions in 2010. On the other hand CH_4 and N_2O contributed 16 and 6.2% respectively. Energy generation, industry, agriculture, forestry and other land use system (AFOLU), transport and building are the major sources of GHG. They contributed 35%, 24%, 21%, 14% and 6.4% respectively of the total GHG globally in 2010 (IPCC, 2014). In India, GHG emissions from energy, agriculture, Industrial Processes and Product Use (IPPU) and waste sectors constituted 71%, 18%, 8% and 3% of the net CO_2 eq. emissions, respectively in 2010 (BUR, 2015).

2.2 Greenhouse gas emission from agriculture

Agricultural soils are among the important sources of GHG. In 2012, the agricultural forestry and other land use (AFOLU) sector accounted for about 1/4th of total enhanced GHG emissions mainly from emissions from agricultural soils, deforestation, nutrient management and livestock (IPCC, 2014). Global emissions of CH_4 and N_2O from agriculture have increased by about 17% from 1990 to 2005, with an average increase of about 60 Mt CO_2-eq. yr^{-1} annually. In 2005, agriculture accounted about 60% of N_2O and 50% of CH_4 emission. A CO_2 emission from electricity and fuel use in agriculture is about 0.04 Gt CO_2 yr^{-1} (IPCC, 2014)

Indian agricultural sector emitted 390.16 million tons (Mt) of CO_2 eq. in 2010, which accounted 18% of country's total GHG emission (BUR, 2015). Enteric fermentation in livestock, agricultural soils, rice cultivation, field burning of crop residue and manure management are the sources of GHG from agriculture. Among different agricultural sources, enteric fermentation in livestock accounted highest (58%) of total GHG emissions from agriculture followed by agricultural soils (21%), rice cultivation (18%), field burning of crop residue (2%) and manure management (1%). The agriculture sector alone contributed more about 75% (0.27 Mt) of the total N_2O emission from the country.

The N_2O are mainly emitted from soils of wheat and maize crops field as results of nitrogen fertilizer application. Both the crops are generally grown in well drained, aerobic soil condition hence, emission of CH_4 is very less or may be in negative, normally known as CH_4 uptake. In both the crops the major GHG is N_2O that is emitted in short-term pulses after fertilization, heavy rainfall and irrigation events.

2.3 Mechanism of nitrous oxide production and emission from soils

Nitrous oxide (N_2O) is a GHG with a GWP of 310 as compare to CO_2 (IPCC, 2014). About 70% of the total N_2O emitted into the atmosphere from biotic process is derived from soils (Bouwman, 1996). Nitrous oxide can be produced through the nitrification, incomplete nitrification and denitrification process, as well as during reduction of nitrate (NO_3^-) to ammonium (NH_4^+) (Kool *et al*., 2010). However, major process of N_2O production following the application of N fertilizers occurs because of nitrification and denitrification process (Wrage *et al.,* 2001; Snyder *et al.,* 2009). N_2O Production through nitrification and denitrification process occurs simultaneously, but the dominant process depends on the type and availability of substrates, and levels of soil moisture and aeration (Khalil *et al.,* 2004). The substrate N for these processes can be all possible sources likely native soil nitrogen, atmospheric deposition, crop residues, manure, nitrogen fixation and nitrogen fertilization; however fertilizer application is dominant source from agricultural field (Mosier, 1998 and Verge *et al.,* 2007, Davidson 2009). Major processes of N_2O formation are described below.

Denitrification

In wet soils under anaerobic condition, where oxygen is limited, denitrification is the main source of N_2O production (Smith, 1990). According to Firestone (1982) and Robertson and Groffman (2007), denitrification is the anaerobic microbial process of reduction of nitrate (NO_3^-) to nitrite (NO_2^-) and then to other gases *viz* NO, N_2O and N_2 as described by following pathway

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The conversion of NO_3^- to N_2 can be complete, but a small and variable portion of the N is often emitted as N_2O gas (Poth and Focht, 1985). This may occur where water hindered the diffusion of O_2 (Pathak, 1999). Denitrification process in soils may also consume nitrous oxide through the reduction of N_2O to N_2 (Firestone *et al.,* 1989;

Saggar *et al.,* 2013). Hence denitrification process may serve as a both source and sink for N_2O.

Nitrification

Nitrification also contributes to N_2O emissions. Nitrification is the aerobic conversion of NH_3 into nitrite (NO_2^-) and NO_3^- by nitrifying bacteria (Arezoo Taghizadeh-Toosi *et al.,* 2011). Nitrification is the process of oxidation of ammonium ion (NH_4^+) to nitrite (NO_2^-) by bacteria such as *Nitrosomonas sp.* which is further oxidized into NO_3^- by *Nitrobacter sp.* and *Nitrospira sp.* bacteria (Norton, 2008). N_2O and NO are emitted as minor by-products during this transformation under oxygen-limited conditions (Yoshida and Alexander, 1970). It has been reported that, emissions of N_2O during nitrification of N fertilizers may be dominant under aerobic (yet moist) condition, when ammonium (NH_4) is available and N_2O emissions from nitrification of ammonium-based fertilizers can be substantial (Bremner and Blackmer, 1978; Duxbury and Mc Connaughey, 1986). Nitrification rates tend to increase linearly with increasing soil NH_4^+ concentrations and microbial nutrient supply such as phosphorus (P) (White and Reddy, 2003; Kirk and Kronzucker, 2005), and decrease under low (moisture stress) and high (less oxygen availability) soil moisture contents due to their effects on biological activity. The relative importance of either of nitrification and denitrification processes in emission of N_2O from agricultural soils is very difficult to assess and this is likely to vary remarkable with the type of nitrogenous fertilizer, land and manure management, climate and other factors affecting soil conditions.

Chemical formation of N_2O

The chemical reactions can also produced N_2O when NO_2^- or NH_2OH are decomposed into N_2O in acid soils.

$$NH_2OH + HNO_2 \rightarrow N_2O + 2\ H_2O$$

Since there was not significant increase in the N_2O production rate by this chemical process, hence the formation of N_2O by this reaction does not seem to be important in soils (Pathak, 1999).

2.4 Mechanism of carbon dioxide production and emission from soils

Carbon dioxide (CO_2) is mainly produced in soil during autotrophic i.e. roots and associated mycorrhizae and heterotrophic i.e. soil macro- and micro-fauna, respiration. Heterotrophic respiration is the microbial decomposition of organic matter in the upper surface of soil where crop residue accumulates (Hanson, *et al.* 2000; Rastogi *et al.,* 2002).

Organic matter → $CO_2 + H_2O$ + Energy

Soil micro-organism contributes 99% of total CO_2 emission as a results of soil organic matter decomposition, while root respiration account for 30-50% of total CO_2 emission from soil (Rochette, *et al.,* 1999; Curtin, *et al.,* 2000; Rastogi *et al.,* 2002). The photosynthetes (carbohydrate) and their translocation from leaves to root serve as substrate for root respiration, while litter fall, plant residue and FYM are the substrates for microbial respiration. In comparison to CH_4 and N_2O, carbon dioxide is recycled in large amounts through the process of photosynthesis in agricultural crops to make food, feed, fibre, and fuel. The fossil fuel (diesel) used for various farm operations also results in carbon dioxide emission (Dyer and Desjardins, 2003) from agriculture. In comparison to CO_2 recycling in agriculture, net emission of CO_2 from agriculture is small, and CO_2 is mostly emitted from the use of fossil fuel for various farm operations and during the manufacture and transport of farm input and farm products (IPCC, 2007). There are several factors including soil organic matter (SOM), soil temperature, soil physical parameters, soil moisture regime (aeration), tillage and residue management which control soil microbial respiration and emission of CO_2 from soil (Huifang, *et al.,* 2014).

2.5 Factors affecting production and emission of GHG from soils

Several factors influence the production and emission of GHG from soil. According to Snyder *et al.* (2009) the important factors influencing N_2O emission are grouped into two category as (i) chemical and physical properties of soil namely soil organic matter (SOM), soil mineral nitrogen (NH_4^+ and NO_3^-), soil pH, soil texture, drainage status, soil temperature, soil moisture content, soil aeration (O_2 status), porosity and microbial activity, (ii) crop management factors, including rate of N application, type of fertilizer, fertilizer application method, timing, tillage, irrigation, application of farm yard manure (FYM), crop residues incorporation and type of crop. Many of among these factors can also affect CH_4 and CO_2 production and emissions from agricultural soils. Concentration of nitrate, labile and non-labile C, soil temperature, water-filled pore space (WFPS) and soil compaction are six important factors which effects the GHG emission from soils (García-Marco *et al.,* 2014). The addition of NO_3^- and WFPS are affecting N_2O fluxes, on the other hand carbohydrate, NO_3^- and soil temperature are affecting CO_2 emission flux from the soil.

2.5.1 Soil physical properties

The soil physical factors that control GHG emissions from soil include soil temperature, soil moisture and oxygen status, bulk density and soil texture (Ussiri and Lal, 2009).

Soil temperature

Soil temperature is of great importance for regulating microbial activities therefore it plays a great role in GHG emissions. Soil temperature and moisture have not only strong influence on GHG production but also in its diffusion from soil to the atmosphere (Davidson and Swank 1986). Generally the microbial activity increases up to threshold level with increase in soil temperature. According to García-Marco *et al.,* (2014) there is 2.8, 1.6 and 1.7 times increase in N_2O, CO_2 and CH_4 emission, respectively with 10 °C increase in normal soil temperature. Under low temperatures, nitrogen conversion rate is small and it increases with increase in temperature (Akiyama *et al.,* 2000; Hao *et al.* 2001). However, in a wider range, N_2O emission increases exponentially with increase in soil temperatures (0-50ºC) (Liu *et al.,* 2011). There is a close relationship between the temperature and seasonal variation of N_2O flux (Wolf and Brumme, 2002; Zhang and Han, 2008). Impacts of soil temperature and moisture on GHG emissions were analysed by Jarecki and Lal (2006) and it is found that CO_2 fluxes shows positive correlation with temperature, and negative correlation with soil moisture content.

Soil moisture and oxygen

Soil moisture can influence GHG directly and indirectly by restricting oxygen supply, C and N substrates and providing diffusion medium thereby altering suitable conditions for microbial growth and activity. According to Ruser *et al.,* (2006) increase in soil moisture about 60% WFPS (below saturation) Sharpen nitrification and contributes to N_2O and CO_2 emissions. García-Marco *et al.,* (2014) reported that in order to reduce N_2O emission, the percentage of WFPS should be maintained below 80%. Meixner and Yang (2006) and Schaufler *et al.* (2010) also found the similar results. Water can produce anaerobic condition by reducing O_2 level in the air-water interfacial area which further effects N_2O production in soils (Pathak, 1999). Both nitrification and denitrification can proceed at a relatively high rate due to relatively high soil Eh under alternate irrigation and drainage conditions. Soil water content is a key factor in controlling of continuous aerobic condition results in small amounts of N_2O production, whereas alternate aerobic and anaerobic conditions significantly increased the emission of N_2O by many time. Drying of soils increases the denitrifying capacity of soil by increasing the amount of readily available organic carbon. Whereas, flooded soil has both an aerobic and anaerobic subsurface layer. Therefore two distinct layers of soil in close proximity favours both nitrification and denitrification simultaneously (Saggar *et al.,* 2013). It has been reported that practice of intermittent irrigation and midseason drying in rice field reduces significant amount of CH_4 emission but it also leads to emission of substantial amount of N_2O (Pathak *et al.,* 2002). In general, increase in soil moisture condition results in higher N_2O emission (Baggs *et al.,* 2000, Giacomini *et al.,* 2006), because soil moisture affects the both nitrification and denitrification processes. Successive moist and dry periods alters the moisture levels which results in the increase in N_2O emission (Brentrup *et al.,* 2000).

Denitrifying activity mainly occurs in anaerobic conditions, and oxygen have inhibitory effects on denitrifying enzymes, however, critical limit of O_2 differs among different denitrifying bacterial species (Pathak, 1999). The N_2O production during nitrification activity is inversely correlated with the dissolved O_2 concentration. The Expression of genes encoding the enzymes that produce and consume N_2O is regulated by environmental condition in particular by low concentrations of oxygen (Thomson *et al.,* 2012).

Bulk density

Bulk density (ρb) is another important property of soil that can affect GHG emissions. Generally high ρb associated with soil compaction and in moist soil condition tillage implements and tractor can reduce aeration. According to Mosquera *et al.*, (2007) compaction of soil can reduce CH_4 oxidising ability of soils by as much as 30 to 90%. Slight compaction of soil results in 20% higher N_2O emissions while severe compaction results in double the N_2O emissions. Yamulki (2002) observed that emission of N_2O and CH_4 emissions was increased by 3.5 and 4.4 times respectively under soil compaction condition compared with emissions from un-compacted plots.

Soil texture

Soil texture may also influence the N_2O emission flux emitted from soils (Stevens and Laughlin 1998). Sandy soils tends to shows lower N_2O emissions in comparison to clayey soils (Brentrup *et al.,* 2000), and generally N management increase the N_2O emission, particularly in soils of fine texture (Chen *et al.,* 2008; Tan *et al.,* 2009). The N_2O flux from coarse-textured soil was higher than that from fine-textured soil (Hua *et al.,* 1997).

2.5.2 Soil chemical properties

Soil chemical properties mainly soil pH and quality and quantity of soil organic carbon (SOC) may also influence the gaseous emissions. The growth and development of soil flora and fauna are highly dependent on soil pH and SOC. In general at neutral soil pH growth and development of soil flora and fauna is high as compared to adverse low and high pH.

Soil pH has effects on net N_2O (Simek and Hopkins, 1999) by affecting ammonia oxidizer (Nicol *et al.,* 2008) and denitrifier populations (Enwall *et al.,* 2005) in to soils. Generally, higher pH values decrease the N_2O emissions from acidic soils when denitrification is the main source of N_2O production, on the other hand it enhanced the N_2O production if nitrification is the main process of N_2O production

(Granli and Bockman, 1994; Signor and Cerri, 2013). According to Bremner (1997), in incubated soils the production of N_2O by denitrification process is favoured by low pH and high concentrations of NO_3^-. The emission of N_2O would be greater, under low pH values, due to small amount of conversion of nitrate to N_2 (Chapuis-Lardy *et al.,* 2007). Knowles (1998) also reported that in acidic soils with pH of 4.0 or below, N_2O is the main product of denitrification. The per unit increase in soil pH may cause decrease 0.2 units in the N_2O emission (Stevens and Laughlin 1998). Thus, the continuing acidification of agricultural soils through excessive application of nitrogenous fertilizers could drastically enhance N_2O emissions; on the other hand the careful management of soil pH by lime application would results in N_2O emissions (Thomson *et al.,* 2012). The nitrification process in aerobic soils conditions tends to reduce the soil pH, while the denitrification process under anaerobic soil condition can increase the soil pH (Khalil *et al.,* 2004).

Soil pH below and above pH 7 is adversely affect soil respiration and subsequent emission of CO_2. According to Rao and Pathak (1996) at pH 8.7 and 10, CO_2 emission get reduced by 18% and 83% respectively as compared to emission at pH 7.0. Sitaula *et al.* (1995) also reported 2-12 fold decrease in CO_2 emission at pH 3 than at pH 4 from different soils.

The quality and availability of soil carbon affects GHG emission. The labile carbon source are easily used by methanogenic bacteria to produce CH_4 and by other microorganisms producing CO_2 while slow decomposing source had a small effect on emission of CH_4 and CO_2 fluxes (García-Marco *et al.,* 2014).

2.5.3 Soil management factors

Fertilizer application

Greenhouse gas emission is also affected by fertilizers application in particular nitrogenous (N) fertilizers. Global N_2O emission from agricultural land is estimated 3.5 Tg N yr^{-1}, about half of this is from synthetic N fertilizer (Hirsch *et al.,* 2006). The use of N fertilizer directly influence the availability of substrate NO_3^- or NH_4^+ for denitrification and nitrification process (Lloyd and Sheaffe, 1973) and causes larger flux of N_2O followed by N fertilizer application, however it also depends on fertilizer type, soil moisture and aeration. The higher the amount of substrate (NH_4^+-N) in the N fertilizer, the higher will be the nitrification process (Mosier, 2001; Khalil *et al.,* 2004; Liu *et al.,* 2005). When NO_3^- in the soil is high, N_2O emissions will also be greater (Carmo *et al.,* 2006; Ruser *et al*., 2006; Zanatta *et al*., 2010). The N_2O emissions will decrease with decrease in the availability of NO_3^-, (Hellebrand *et al.,* 2008). On the other hand, there is higher plant biomass and crop residue production due to N fertilization application, which would be available as carbon source in the soil, which could increase the emission of N_2O for a longer period, after the N fertilizer application (Hellebrand *et al.,* 2008).

Blackmer *et al.,* (1980) found that the emission of N_2O will be higher from plots treated with ammonium sulphate {$(NH_4)_2SO_4$} or urea significantly exceeded N_2O emission from those from plots which receiving same amount of N as calcium nitrate {$Ca\ (NO_3)_2$}. The higher emissions of N_2O are also found from soils fertilized with anhydrous NH_3 than those of N fertilizers sources having higher NO_3 and NH_4 concentration (Duxbury *et al.,* 1982). Urea, widely used N fertilizer in the country contribute to maximum amount of N_2O emission followed by ammonium sulphate {$(NH_4)_2SO_4$}, ammonium chloride (NH_4CL) and potassium nitrate (KNO_3) from alluvial soil at submerged and field capacity moisture regimes (Majumdar *et al.,* 2000) and observed there were no dependence of N_2O emissions on N fertilizer application that was applied in ammonium form.

Besides the type of N fertilizer used, N_2O emission also depends on the mode of fertilizer application. Incorporation of urea @250 Kg N ha^{-1} in the plough layer results in less (0.15%) N_2O-N emission than the band application of lower rate of urea application (0.27%) (Yan *et al.,* 2001). In some situation addition of phosphorous (P) nutrients and liming materials ($CaCO_3$) can also affect N_2O emissions from soils. Lindau *et al*., (1990) reported that P or $CaCO_3$ application increased N_2O emissions under aerobic soils conditions. However, P induced emissions were larger than those obtained with $CaCO_3$. It has been also reported that $CaCO_3$ addition increased emissions but P addition had no effect (Lindau *et al.,* 1990).

N fertilizer application also affects CO_2 emission indirectly by influencing soil pH and microbial respiration. Sitaula *et al.* (1995) reported that about 30-40% reduction in emission of CO_2 after application of NH_4NO_3 fertilizer, because it decreased soil pH after application of fertilizers subsequently reduced soil microbial respiration. Wilson and Al-Kaisi (2008) reported 23% less CO_2 emissions from the soil fertilized with 270 kg N ha^{-1} than the soil fertilized with 0 and 135 kg N ha^{-1} under continuous corn and corn-soybean rotation.

Amendment with organic manure

With increasing interest of organic manure (FYM, crop residue, green manure) for remediating soils, it is important to investigate their interactive effects on greenhouse gas emissions, particularly nitrous oxide (N_2O) and carbon dioxide (CO_2). Organic manure are source of substrate (C and N) in the soils and thus strongly effect GHG emission. Denitrifiers (mainly bacteria) use organic C compounds as electron donors for energy synthesis. Aulakh (1991) reported higher rates of denitrification as results of application of farmyard manure, green manure and plant residue. However, emission of N_2O and plant residues mineralization are dependent on C:N ratio of the crop residues (Huang *et al.,* 2004). A C:N ratio of 25 generally do not cause net mineralization or immobilization, while lower and higher ratio than 25 caused net N-mineralization and immobilization, respectively (Paul and Clark, 1989). During the first few days after the application of low C:N organic manure, increased N_2O flux has been reported (Christensen and Tiedje, 1990; Comfort *et al.,* 1990). These emissions are results of rapid nitrification and denitrification processes induced by organic manure, because they contain considerable amounts of readily available organic carbon and ammonium (Granli and Bockman, 1994).

However incorporation of crop residues having C:N ratio higher than 25 has been reported to net immobilization of N which limits the availability of substrate (N) for nitrification and denitrification process (Jensen *et al.*, 1996; Singh *et al.,* 2010) and thus reduce emission of N_2O emission. Huang *et al.,* (2004) found that the greater the C:N ratio of plant residue the lower will be cumulative N_2O emission and it was negatively correlated with the C:N ratio in plant residues.

In general application of organic matter i.e. FYM, crop residue and green manure, in soil leads to increased CO_2 emission (Moore and Dalva, 1993; Rao and Pathak, 1996). The soluble organic carbon is the immediate source of carbon for microorganisms and it enhances CO_2 emission (McGill *et al.,* 1981). Al-Kaisi and Yin (2005) reported 24% less cumulative emission of CO_2 from no-tillage with corn residue than without residue in corn-soybean fields, while Huifang *et al.,* (2014) reported significantly higher (26%) soil CO_2-C emission under no tillage summer maize with surface application of wheat straw than no tillage without wheat straw.

Tillage

Tillage practices influence the fluxes of GHG (N_2O, CO_2 and CH_4). Tillage strongly affects the flux of CO_2 from the agricultural soils. Tillage caused physical disturbance of soil, increased mineralization of SOM by improving soil aeration, increased contact of crop residue and soil, enhanced plant nutrient availability, breaking down soil macro-aggregates and exposed protected carbon to microbial processes (Ball *et al.*, 1999; Sainju *et al.,* 2006). The strong correlation has been reported between CO_2 emission and intensity of soil disruption and volume of soil disrupted by the implements used for soil tillage practices (Dao, 1998; La Scala, *et al.,* 2006; Reicosky and Archer, 2007). Lower CO_2 emission has been widely reported under zero tillage (ZT), (Chatskikh and Olesen, 2007; Alluvione *et al.*, 2009; Silva-Olaya *et al.*, 2013; Huifang *et al.* 2014). However, Hendrix *et al.* (1988) reported the contrasting result. Some other authors also reported insignificant differences in CO_2 emissions between ZT and conventional tillage (CT) (Nouchi and Yonemura, 2008; Elder and Lal, 2008).

The major source of N_2O emission from soils is denitrification, which is more prevalent in no tillage (NT) soils as compared to CT soils, which is mainly due to higher bulk density and soil moisture content (Palma *et al.,* 1997). The GWP of N_2O is 310 times more than CO_2, hence the benefits of adopting NT on atmospheric carbon sequestration could be offset by increased emission of N_2O (Li *et al.,* 2005). Various studies (Ball *et al.,* 1999; Rochette, 2008; Bhatia *et al.,* 2010) reported high variation in N_2O emission as influenced by zero/reduced tillage. While, other have reported lower N_2O emissions in zero tillage soils condition in comparison to conventionally tillage soils condition (Chatskikh and Olesen, 2007; Gregorich *et al.,* 2008; Pandey *et al.,* 2012).

Climate, soil aeration and time since conversion to no tillage may also affect N_2O emission. According to Rochette (2008) in poor soil aeration condition no tillage generally increases N_2O emissions; on the other hand in good and medium soil aeration N_2O emission has been neutral. Under no tillage conversion initially N_2O emissions increased but over the time this impact decreased and this is higher in arid area as compared to humid area (Six *et al.,* 2004).

Crops and varieties

Plants can affect the emissions of GHG directly and indirectly by influencing partial pressure, carbon and nitrogen content of soil. Uptake and assimilation of nitrogen by plants from soils, reduced availability of nitrate hence make it unavailable for denitrification, which results in low N_2O emission. Plants roots added organic matter to soil. This supply of organic matter through root and root respiration directly affect CH_4 and CO_2 emission from soils. Another indirect effect is that some plants e.g. rice have ability to supply O_2 at the rhizosphere zone, which can increase the nitrate content by promoting nitrification and oxidise CH_4.

Several plant species differ in their effects on N uptake from soils and subsequent denitrification of nitrate substrate. The denitrification rates are generally higher in soils grown with a legume as compared to soil grown with cereals plant (Bertelson and Jensen, 1992). These differences on N_2O emissions by crops species may contribute significantly to higher uncertainties in the current estimates of N_2O emissions form cultivated soils (agricultural land).

Kaiser *et al.,* (1998) reported the significantly higher N_2O emission from sugar beet crop than from wheat crop, although under higher N fertilizer doses in wheat crop. Mahmood *et al.*, (1998) also measured emission of N_2O from wheat and irrigated maize crop grown in sandy loam soil and reported strong correlation of N_2O emission with denitrification and NO_3^- content under maize while in wheat strong correlation was among NH_4^+, NO_3^- and temperature. It has reported that early maturing crop variety generally had lower emission than the late maturing variety (Lu *et al.,* 2000). The presence of crops also influences the production and emission of CO_2 from soil. Under crop filled condition 2-3 times higher CO_2 emission has reported as compared to bare field (Russell, 1973).

2.6 Mitigation of GHG emission

There are some effective technologies for GHG mitigation from wheat and maize crops.

2.6.1 Mitigation of nitrous oxide

Soil moisture/aeation) and temperature, are two most important factors for N_2O production that affect nitrification and denitrification processes, however, under homogenous or similar temperature and precipitation conditions at the regional level, the agricultural management factors become the dominant factor determining N_2O emissions (Guo and Zhou, 2007). Therefore, both type and growth stage of crops, fertilizers type, amount, time and methods of application and irrigation are major factors to consider for GHG mitigation. Both wheat and maize crops are generally grown in well drained, aerobic soil condition hence, the major GHG from wheat and maize crop field is N_2O, mainly emitted in short-term pulses after fertilization, heavy rainfall and irrigation events.

N_2O is produced as result of nitrification and denitrification process and has been mainly linked with the application of nitrogenous fertilizers; hence the efficient use of fertilizer can reduce N_2O emission from wheat-maize system. The peak of N_2O emissions are mainly occurred 3-4 days after fertilization. The control of process of nitrification and denitrification has been suggested as one of most important strategy to reduce N_2O emission from aerobic soils. The use of nitrification inhibitors (NIs), slow release fertilizers and application of fertilizers when needed have been reported to be highly efficient in reducing emission of N_2O from wheat as well as maize crop. Some of these reported technologies are given below.

Application of nitrification inhibitors and slow-release fertilizers

The Nitrification inhibitors (NIs) slowed down the process of nitrification i.e. conversion of NH_4-N into NO_3–N, but did not stop the process completely because NI changes concentration of NH_4^+ and ($NO_2^- + NO_3^-$) (Luo *et al.,* 2010). On the other hand slow release fertilizer limit the conversion of NH_4-N into NO_3–N, thereby reducing emissions of N_2O via nitrification directly (Prasad and Power, 1995). Therefore, the management of nitrification process by the application of NIs is a well-proven strategy to improve N use efficiency (NUE), and for reducing GHG emission (Malla *et al.,* 2005; Prasad, 2009). Nitrification inhibitors have great potential to decrease emission of N_2O from fertilized soil in the wider range of nitrogen level and moisture conditions (Signor *et al.,* 2013).

Several chemicals namely N-serve (nitrapyrin), dicyandiamide (DCD), AM (2-amino-4 chloro-6 methyl pyrimidine), sodium chlorate and sodium azide are capable of inhibition of urea hydrolysis. However, many of these NIs have limitations to their usefulness, and have been restricted to the experimental stage only because of the cost effectiveness, limiting availability and having adverse impacts on beneficial soil microorganisms. Nirapyrin the most commonly used NI is often effective because of hydrolysis and loss by volatilization. DMPP (3, 4 - Dimethyl pyrazole phosphate), reduced NO_3 leaching without being liable to leaching itself unlike DCD. In fertilized plots treated with DMPP and DCD, DMPP reduced N_2O emission by 26% only in comparison to DCD, whereas it decreased the release of N_2O by 49% (Weiske *et al.,* 2001). Besides these farmers are lacking of knowledge about the use of NIs. Natural nitrification inhibitors viz. neem and karanj products which are eco-friendly and biodegradable therefore hold considerable promise (Upadhyay *et al.,* 2011).

Bremner and Yeomans (1986) studied the impacts of 28 nitrification inhibitors on the emissions of N_2O in well-aerated soil conditions. The application of wax coated calcium carbide has been reported to reduce the rate of nitrification hence, the emission of N_2O, while no significant difference in the rates of N_2O emission between control and another nitrification inhibitor. Burzaco *et al.,* (2013) observed overall 22% lower N_2O–N emission in nitrapyrin application than without the nitrapyrin.

Majumdar *et al.,* (2002) evaluated the role of neem products (namely neem and nimin coated urea), dicyandiamide (DCD) and thiosulphate on emission of N_2O from irrigated wheat under field conditions in Delhi. The N_2O–N emission flux was significantly lowered when neem product and NIs were used with urea. The highest N_2O–N flux was reported from the soil fertilized with urea alone, while the application of all the nitrification inhibitors results significantly lower N_2O-N emission flux in comparison to soil fertilised with urea alone. The application of Nimin coated urea, urea + DCD, urea + thiosulphate and neem coated urea application results in 63, 49, 35 and

9%, lower N_2O-N emission, respectively, as compared to urea alone. This means coating of urea by neem product was found effective in reducing N_2O emission from wheat field.

Malla *et al.* (2005) also evaluated efficiency of five nitrification inhibitors viz. neem cake, thiosulphate, coated calcium carbide, NOCU and DCD and hydroquinone a urease inhibitor in mitigating N_2O and CH_4 emissions from soil in wheat as well as rice in the Indo-Gangetic plains. They found that N_2O emission ranged 7-29% with lowest in hydroquinone and highest in DCD in wheat crop. Coating of urea with neem cake and neem oil also results in 10-20% reduction in N_2O emission from rice as well as wheat fields. Datta and Adhya (2014) studied the effects of urea + Nimin, urea + Karanjin and DCD on CH_4 and N_2O emission from tropical rice paddy. They found that N_2O emission was inhibited by 69-85% in the Nimin applied soils.

Aulakh *et al.* (2001) reported that when DCD was applied with urea it reduced N_2O-N emission by 11%, whereas thiosulphate reduced the same by 9% when applied with urea. The N_2O–N emission was reduced by 29% when urea–ammonium nitrate (UAN) was applied with both urease and nitrification inhibitors (Halvorson *et al.*, 2010). In another experiment, Halvorson and Del Grosso (2013) found 50% reduction in N_2O emissions compared to UAN with and without both urease and nitrification inhibitors.

Pathak and Nedwell (2001) studied the effect of seven NIs on N_2O emission in a laboratory experiment. They found that the N_2O emission was reduced by 12, 24 and 63% in the presence of nitrapyrin, AM, and DCD, respectively whereas, thiourea, sodium thiosulphate, acetylene and sulphur, had no effect on N_2O emission. In submerged condition none of these inhibitors reduced the emission. Type of fertilizer and soil moisture status play important roles in N_2O emission. At submergence nitrate-containing fertilizers emitted higher amount of nitrous oxide. At field capacity, soil fertilized with urea, ammonium sulphate, or ammonium nitrate showed higher emissions than with potassium nitrate due to nitrification of ammonium-N.

Optimization of irrigation practices and the selection of right kind of fertilizer could help in reducing the N_2O emission (Pathak and Nedwell, 2001). Malla *et al.,* (2005) reported the reduction in N_2O emission as a result of application of neem cake, thiosulphate, coated Ca carbide and DCD in wheat. Weerden and Styles (2012) also reported high effectiveness of DCD, in reducing emission of N_2O from animal urine patches in four different soils in New Zealand. N_2O emissions from the compacted soil with urine were significantly greater than from compacted soil without urine, with 3.2% of the urine-n being lost as N_2O (Weerden and Styles (2012).

Verma *et al.* (2007) reported that there is reduction in both average and peak N_2O emissions with increasing concentration of DCD from 6 to 12% of nitrogen applied in the form of urea. DCD was also effective in inhibiting nitrification in late autumn-winter-early spring grazed pasture soils in most parts of New Zealand (Di and Cameron, 2004). 3, 4-dimethylpyrazole (DMPP) @ 0.5-1.5 kg ha^{-1} was sufficient to achieve optimal nitrification inhibition in agricultural fields (Zerulla *et al.,* 2001*).* Majumdar *et al.,* (2001) reported that when Karanjin was used as an inhibitor to conserved ammonium in different soils the nitrate formation was effectively minimized at all stages. Nitrification inhibition by karanjin was ranged from 9-76%, it remained very high for initial period of about 6 weeks and then decreased with time.

The nitrification potential of S-benzylisothiouronium furoate, S-benzylisothiouronium butanoate, and propanoate was studied by Kumar *et al.,* (2004) and they found a better inhibition potential of these compound as compared to DCD even at 5% of dose up to 42nd day under laboratory condition. Bhatia *et al.,* (2010) reported that the- S-benzylisothiouronium butanoate, S-benzylisothiouronium furoate reduced GWP by 8.9–19.5% and increased yield of wheat, over urea treatment and this can be used to mitigate emissions of N_2O from agricultural soils.

Demand driven nitrogen application

More than 60% of total nitrogen applied is lost in many field conditions; due to lack of synchrony in N supply and plant N demand (Singh and Singh, 2003). Therefore, matching the plant N demand with supply has been found to increase agronomic nitrogen use efficiency (NUE). The site specific and leaf colour chart (LCC) chart based nitrogen application can enhance both NUE and crop yield (Wang *et al*., 2001).

Bhatia *et al*., (2012) studied the impact of conventional application of N and application of N based on LCC on the emissions of N_2O and CO_2 in a rice–wheat cropping system in the Indo-Gangetic Plains of India. They found that urea application based LCC reduced N_2O emission; however CO_2 emission was not affected. Application of 120 kg N ha^{-1} decreased N_2O emission by 16% and 18% in rice and wheat crop, respectively over conventional application of urea in rice-wheat system.

2.6.2 Mitigation and sequestration of carbon dioxide

Carbon dioxide (CO_2) emission from agriculture is mainly from three sources: farm machinery, production transport and application of fertilizers and pesticides, and oxidation of SOC as a result of soil disturbance. Even though agricultural soils emit all three GHG (CH_4, N_2O and CO_2), but agriculture is not a net source of CO_2 because it act as a sink also. Carbon dioxide is fixed by plants during photosynthesis for biomass production. According to IPCC (2007), global CO_2 emissions from agriculture are 0.04 Gt CO_2 y^{-1} mainly attributed to electricity and fuel consumption. Agricultural soil has been found to useful in mitigation of CO_2 by carbon sequestration through storage of C as soil organic matter when good management practices are adopted (Lal 2004; Hutchinson *et al.,* 2007; Pathak *et al.,* 2011a).

Extensive research shown that C in cropland soil can be increased by judicious nutrient management (Pathak *et al.,* 2011a) by adopting C-conserving practices, namely zero/minimum tillage, discarding summer fallow, and residue incorporation (Hutchinson *et al.,* 2007). The benefit of these practices highly differs among the regions, depending on soil taxonomy, texture and climatic conditions. However, Hutchinson *et al.,* (2007) found that C sequestration in soils contributes small (3–6%) to mitigation of greenhouse gas emissions. Some of management practices leading to CO_2 mitigation and C-sequestration in soil have been discussed below.

Judicious nutrient management

Judicious nutrient management is very important to C sequestration in soils. Generally adequate nutrients supply can increase biomass production and subsequent SOC content, therefore C sequestration in soils (Van Kessel and Hartley, 2000).

Analysis of 26 long-term experiments (LTEs) in different agro-climatic regions of India for the assessment of the C sequestration potential and its cost (Pathak *et al.* 2011a) showed that average SOC concentration was increased from 0.54% to 0.65% in NPK treatment and from 0.54% to 0.82% in NPK + FYM treatment in comparison to unfertilized treatment. In 17 out of 26 LTEs, the NPK + FYM treatment had higher SOC and subsequently leads to higher net return as compared to the NPK treatment. Therefore, long-term application of FYM along with NPK fertilizers has good potential for C sequestration.

Conservation agriculture

Conservation agriculture has great potential to enhance the SOC content and reduce CO_2 emissions. Zero/no tillage has found to serve dual purpose, firstly it increased SOC by reducing CO_2 emission and increasing carbon content (Diekow *et al.*, 2005; Fuentes *et al.*, 2009; Fuentes *et al.*, 2012) and secondly reduction in CO_2 emission due to low fuel consumption during farm operations as well as enhances farmer's income by low fuel consumption and higher crop yield (Koga *et al.,* 2003; Mileusnic *et al.,* 2010). However in many studies it is found that zero/no tillage has also increase N_2O emission, which might offset the positive impacts of C-sequestration (Ball *et al.,* 1999; Rochette 2008; Bhatia *et al.,* 2010).

Tillage increase the mineralization of SOM by improving soil aeration, increased soil and residue contact, increased nutrient availability and breakdown of soil macro-aggregates (Ball *et al.*, 1999). There is a strong correlation between emissions of CO_2 and disruption of soil by tillage operations (La Scala, *et al.,* 2006; Reicosky and Archer, 2007). The lower CO_2 emission under zero tillage wheat (ZTW) has been widely observed (Silva-Olaya *et al.*, 2013; Huifang *et al.,* 2014).

Huifang *et al.,* (2014) studied the long-term effect of residue retention and zero/no tillage on soil microbial respiration and soil organic carbon (SOC) in summer maize of north plain in china. The incorporation and mulching of chopped wheat straw in no tilled (NT) and conventionally tilled (CT) maize led to significant increase in SOC, 5.17% and 2.64% in the 40 cm soil profiles as compared to without straw treatments in both NT and CT. However, Hendrix *et al.* (1988) found the contrasting results.

The application of cereals crops residue generally enhances SOC; however it has been reported to influence N_2O and CH_4 emissions also. The lower emission of N_2O has reported due to immobilization effect of high C:N ratio of cereal crop residue. The N_2O

emission and mineralization of crop residue are negatively correlated with C:N ratio of residue (Huang *et al.,* 2004).

The CO_2, CH_4, and N_2O emissions in a rice-wheat cropping system with rapeseed cake and wheat straw application has been evaluated by Jianwen *et al.*, (2004). They found that the emissions of CO_2, CH_4, and N_2O enhanced by 12.3, 25.3 and 17.5%, respectively in the rice growing season by incorporation of rapeseed cake, while in the following wheat growing season there was no further effect. Wheat straw incorporation rice growing season reduced N_2O emission by 18.8%, while CO_2 and CH_4 emissions enhanced by 7.1 and 24.6%, respectively.

2.7 Nitrification inhibitors and yield

A meta-analysis carried out by Hu *et al.* (2014) to observed the effects of N-fertilizers with nitrification inhibitors on the yields of several agricultural crops viz. wheat, barley, rapeseed, potato and maize to compare the conventional N fertilization without NIs at a particular N rate in Germany. These experiments with NIs have been conducted with a large number of crops. Smith *et al.,* (1998) reported the effectiveness of the nitrification inhibitors dicyandiamide (DCD) and nitrapyrin on reducing N_2O emissions and slight increase in yield of crops. Bhatia *et al.,* (2010) also reported the increase in yield of wheat crop as results of use of nitrification inhibitors. Singh and Prasad, (1992) also conducted a field experiment on a sandy loam soil at New Delhi and they found that yield of maize crop with 80 kg ha^{-1} N plus DCD was higher than with 120 kg ha^{-1} N without DCD. However, application of DCD beyond 15% of N as DCD reduced wheat yield. Majumdar *et al.* (2002), also reported 4-12% increase in yield of wheat crop due to use of NIs at different places in Gujarat and these results are in line with different places in New Delhi (Bhatia *et al.,* 2010).

2.8 Simulation models

There are several tools of systems research related to computer and information technology now available, which can help in solving agricultural problems. One such tool is simulation model. These models integrate the effect of weather, soil, crop, pest and management factors on the crop growth and yield. These models need input data that mimic ‘genetics’ of a crop/variety. As the area of interest expands say to water, nutrient, pest limited or actual productivity, knowledge base of several additional disciplines are tapped and integrated into the model. Once the integration and its validation is successful, crop simulation models can help us in analyzing the effect of climatic factors on crop growth, yield and GHGs emissions taking interaction with edaphic, biotic and agronomic factors into account. Normally such type of analysis is not possible with field experimental methods. Hence, simulation model can reduce the need of time-consuming, laborious and expensive field experiments because model can extrapolate the results of research conducted at one location in one season to other seasons, locations, or management practices.

2.9 Modelling the impacts of N fertilizer on GHG emission and yield of maize-wheat system

Several approaches have been developed for estimating GHG emissions from crops field and different cropping systems. Conducting field experiment is a direct approach, which is more reliable but laborious, costly and required longer time period. Therefore, several indirect approaches viz. emission factors, and simulation model derived from field experiments are being popularly used. In recent period, simulation models have been used to estimate the emissions of GHG emissions from rice and wheat (Pathak and Wassmann 2007; Bhatia *et al.*, 2012b; Pathak *et al.,* 2012).

Several modelling approaches have been developed for quantification of GHG emissions from agricultural soils, i.e., DNDC (Li, 2000), DayCent (Del Grosso *et al.,* 2001), InfoCROP (Aggarwal *et al.,* 2004b) and WNMM (Li *et al.,* 2005), TechnoGAS (Pathak and Wassmann 2007), InfoRCT (Pathak *et al.*, 2011b). Some of these simulation models have successfully validated for GHG emission from rice fields in Asian countries viz. India (Pathak *et al.,* 2005; Saharawat *et al.*, 2012) and China (Cai *et al.,* 2003).

InfoCrop is a generic crop simulation model which meets all these specific requirements of weather, soil, crop, management and pest (Aggarwal *et al*., 2006). It is a Decision Support System (DSS) written in (FST) language and designed to simulate the effects of these specific requirement crop yield and its associated environmental impacts. The general structure of this is primarily based on SUCROS (Laar *et al*., 1997) and subsequently supported by MACROS (Penning de Vries *et al*., 1989), WTGROWS

(Aggarwal and Kalra, 1994), and ORYZAI (Kropff *et al*., 1996) models. The InfoCrop model requires easy available inputs, user friendly and it is targeted to enhanced its applications in research and development. InfoRCT (Information on use of Resource-Conserving Technologies) developed by Pathak *et al.* (2011b) is one such simulation models which has been successfully validated and used for estimation of GHG emission from rice-wheat cropping system (RWCS) in India (Pathak *et al.,* 2012; Saharawat *et al*., 2012). In present study we used InfoCrop model for simulating GHG emission from wheat and maize crop based on a field experiment conducted in IARI, New Delhi.

There are large spatial and temporal variability in the emission flux of N_2O from agricultural soils due to environmental factors, climatic factors (temperature and precipitation), farm management practices, source of N, and soil properties particularly SOM (Butterbach-Bahl *et al.,* 2011). Therefore, both empirical and process based models may use to extrapolate N_2O emission fluxes due to nitrogen input in agricultural soils over larger area from countries to continents. Empirical models could be very simple such as, IPCC approach, in which N_2O emission can be estimated using a emission factor (EF) of 1.0% of the total N input (IPCC, 2006), to more detailed models, such as the approach by Stehfest and Bouwman (2006) used in the IMAGE model (Bouwman *et al.,* 2002) and the approach by Lesschen, *et al.,* (2011) used in the INTEGRATOR model (de Vries *et al.,* 2011). In these detailed models the values of EF are calculated on basis of Source of nitrogen, its application rate, type of crop and its duration, environmental and climatic factors, soil type and its properties, such as SOC content, pH and texture. Similarly, the process based models also range from very simple (de Vries *et al*., 2005) to detailed model (DNDC or DayCent) models that can be applied on larger scales from nations to continental (Butterbach-Bahl *et al*., 2001). Using these process based model finally, several meta-models have been developed, such as the DNDC meta-model for agriculture (Britz and Leip, 2009). A systematic inter comparison of models at wider scale in Europe in respect to estimates of GHGs and total reactive nitrogen (Nr) emissions from agricultural soils have been done by de Vries *et al.,* (2011) and it is found that the data on Nr use to agricultural soils are more or less similar or quite comparable, due to similar data sources, N_2O fluxes show a relatively large scatter. The agricultural soils are pondered to very uncertain source of GHG emission in national GHG inventories of European nations submitted to the UNFCCC (Leip, 2010; Winiwarter and Muik, 2010). In general, simple empirical models and simple emission factors (EF) based models seem to give more robust results in comparison to inverse model (de Vries *et al.*, 2011; leap *et al.*, 2011).

In India the InfoCrop simulation model was evaluated by the Bhatia *et al.* (2012) to estimate the CH_4, N_2O and CO_2 emissions from soils in a rice and wheat crop. It is found that the 2.07, 0.02, and 72.9 Tg of CH_4-C, N_2O-N and CO_2-C, respectively emitted from the Indian rice fields having 42.21 Mha and global warming potential (GWP) of 88.5 Tg CO_2-C eq. On the other hand the annual emission of N_2O-N was 0.017 Tg and CO_2-C was 43.2 Tg, with a GWP of 44.6 Tg CO_2-C eq. from 28.08 Mha total wheat-growing areas. The alternate wetting and drying in rice crop results in reduction of methane emissions by about 40%. However, GWP was increased by 41% when farmyard manure (FYM) was applied in rice crop.

The Denitrification and Decomposition (DNDC) model was also evaluated by Pathak *et al.* (2005) for its calibre to simulate the GHG (N_2O, CH_4 and CO_2) emissions from rice growing areas in India with different management practices. Then this model was applied for GHG estimation from rice fields in India using a newly assed database of soil, climate and land use. This is found that continuous flooding of rice having area 2.25 Mha resulted in 1.07–1.10, 0.04–0.05 and 21.16–60.96 Tg annual net emissions of CH_4-C, N_2O-N and CO_2-C, respectively, having 130.93–272.83 Tg CO_2 equivalent global warming potential (GWP). The intermittent flooding of rice fields reduced annual net emissions of CH_4-C and CO_2-C emission to 0.12–0.13 and 16.66–48.80 Tg, respectively while it increased N_2O emission to 0.05–0.06 Tg N_2O-N. The net GWP, however, reduced by 22-30%.

2.10 Net global warming potential/global temperature change potential of Nr used in agricultural soils.

In parallel with increasing use of nitrogenous fertilizers both direct as well as indirect emissions of N_2O from agricultural soils have increased in reality from the last few decades. The N_2O emission from soils are likely to increase in near future, in parallel with increased use of nitrogenous fertilizers to fulfilment of food demand for ever increasing human population. According to Mosier *et al.*, (1998) total nitrogen emission from agricultural system (including animal production and indirect emission) are 6.3 Tg N y^{-1}. However, total direct emissions from agricultural soils are 2.1 (0.4-3.8) Tg N y^{-1} only.

The effects of N application to soils are both positive and negative, the positive effects are increased forest growth as result of N application which may lead to higher C sequestration in to soil (De Vries *et al.,* 2009; Liu and Greaver, 2009; Reay *et al*., 2008). Nitrogen fertilization enhanced the C sequestration in both tree and plant biomass as well as in soils too. Due to enhanced tree growth, the application of N fertilization results in an average of 20% more C in tree and plant biomass and 48% more C in soil compared to unfertilized site (Adams *et al*., 2005).

Application of N fertilizer also increased CH_4 emissions and SOC by 13%–66% and 21–94%, respectively but had no effect on CO_2 emissions in either year. This might be due to conversion of CO_2 into CH_4 under anaerobic soil conditions, subsequently leading to significant high CH_4 emissions rather than CO_2 emissions between fertilized and unfertilized treatment areas (Cheng *et al*., 2012).

The important CH_4 removal process in aerobic soils is oxidation of CH_4 i.e. CH_4 uptake by methane oxidizing bacteria (MOB). The highest CH_4 uptake rates exhibit in forest soils (Dutaur and Verchot, 2007). In fertilised field the applied N mainly ammonium ions (NH_4^+) have inhibitory effects on MOB. This is due to that methane mono oxygenases (MMOs), which oxidize methane to methanol, can also oxidize NH_4^+ in soil (Steudler *et al.,* 1989; Wang and Ineson, 2003). The inhibitory effect of CH_4 oxidation by nitrate ions (NO_3^-) have also been observed (Reay and Nedwell, 2004; Xu and Inubushi, 2004). The use of reactive nitrogen (Nr) also effect the CH_4 production and emission from ruminants (Beauchemin *et, al*. 2008) and may also decrease the methane uptake capacity of soils for atmospheric CH_4, which may led to the reduction in net CH_4 influx from atmosphere to biosphere (Steudler *et, al.* 1989).

Agriculture nitrogen emission are mainly dominated by NH_3 contribute 95% of total N emission from agriculture soils and only 3% of all NO_x emission in the EU (European Union) are due to agriculture (Leip *et al*., 2011). The subsequent formation of sulphur (S) containing aerosols having direct cooling effect and also responsible for increase in diffuse radiation which resulting higher ecosystem production, since higher efficiency of photosynthesis in diffuse light condition (Mercado *et al.,* 2009). Nr and S containing aerosols also regulate the atmospheric oxidation capacity due to increase in hydroxyl radical (OH) the main atmospheric oxidants, which determine the life time of CH_4 (Isaksen *et al.,* 2011).

Both the emissions of N_2O from aerobic soils and CH_4 emissions from livestock are generally compensated by the carbon sequestration in forests and grasslands due to effects of reforestation, CO_2 fertilization, temperature increase and Nr deposition. The result of balance of all the GHGs across terrestrial biosphere in Europe is almost neutral (De Vries *et al*., 2011).

The increase in N_2O emission after addition of nitrogenous fertilizers was observed in several experiments; because of it increased supply of substrate mainly ammonium and nitrate ions for nitrifying and denitrifying bacteria (Butterbach-Bahl *et al.,* 1998; Keller *et al.,* 2005). This is found that in tropical forest the N_2O emission from NO_3^- fertilization is five times higher than the NH_4^+ fertilization treatment in a tropical forest (Keller *et al.,* 1988). Lindau *et al*., (1994) also reported that the stimulation of N_2O emission by NO_3^- is much more than NH_4^+ addition in a forest wetland. This might be occurred due to small amount of added NH_4^+ was denitrified under severe limitation of nitrification in reduced soil conditions.

The meta data analysis results by Liu and Greaver (2009) showed that the application of nitrogen, ranged 10-562 kg N ha^{-1} yr^{-1}, resulted, 216% increased emission an average across all ecosystems. The mean N_2O emission increased in agricultural system, anaerobic agricultural system and non-agricultural ecosystems was 0.0072 ± 0.0012, 0.0127 ± 0.0031 and 0.0087 ± 0.0025 kg N_2O-N ha^{-1} yr^{-1}. On the other hand They also found that application of nitrogen ranging from 90 to 550 kg N ha^{-1} yr^{-1} into agricultural fields for 4-50 years result slightly increased SOC by an average of 2%. On an average, 24.5 ± 8.7 and 0.53 ± 0.10 kg CO_2-C ha^{-1} $year^{-1}$ was sequestrated for forest ecosystems and agricultural soil respectively for 1 kg N ha^{-1} yr^{-1} added to the ecosystems.

CH_4 is mainly produced during the decomposition of organic matter in the anaerobic soils by methanogenic bacteria, whereas CH_4 is mainly consumed by methanotrophic in aerobic soils through the process of methane oxidation (Le Mer and

Roger 2001). Le Mer and Roger (2001) found that the addition of nitrate (NO_3^-) ion can decrease CH_4 production due to increase in soil redox. Both CH_4 and NH_4^+ can be oxidized by methane mono oxygenase bacteria (MMO), hence NH_4^+ generally inhibits CH_4 production by competing MMO (King and Schnell, 1998; Bodelier and Laanbroek, 2004). Nitrification or denitrification processes also produced nitrite (NO_2^-), which have toxic effect and may also involve in the inhibition of CH_4 oxidation by N addition.

The Meta data analysis results of Liu and Greaver, (2009) showed that the CH_4 emission enhanced by an average of 95% when averaged across the grassland, wetland and anaerobic agricultural system due to addition of nitrogen, ranging from 30 to 400 kg N ha^{-1} yr^{-1}. The methane emission was increased by 0.008 ± 0.004 kg CH_4-C kg^{-1} N ha^{-1} yr^{-1} in anaerobic condition whereas, CH_4 uptake was reduced significantly under in aerobic condition and it reduced by an average of 38% under N addition, ranging from 10 to 560 kg N ha^{-1} yr^{-1}. Under aerobic agricultural condition CH_4 uptake decreased by 0.012 ± 0.006 kg CH_4-C ha^{-1} yr^{-1} and 0.016 ± 0.004 kg CH_4-C ha^{-1} yr^{-1} for non-agricultural ecosystems per 1 kg N ha^{-1} yr^{-1} added to the ecosystem.

Several experiments examine the effect of reactive nitrogen addition on fluxes of CO_2, CH_4 and N_2O separately; however few have also assessed the overall net balance of all the GHG fluxes under elevated nitrogen condition (Bowden *et al.* 2000; Butterbach-Bahl *et al.* 2002; Mosier *et al.*, 2006). The response of GHG fluxes to the addition of Nr may vary in both, magnitude and direction, across ecosystem types and environmental conditions (Neff *et al.* 1994; Gulledge and Schimel, 2000). The emission of different N species as a result of fertilizers N application, its impact on CH_4 and CO_2 fluxes and subsequent impacts on climate (global warming and cooling) are mentioned in Table 2.1.

Although lot of work have been done on quantification and mitigation of GHG emissions from agricultural soils and mostly focused on separate GHG either on nitrous oxide, methane and carbon dioxide emissions mainly from rice crop and rice based cropping system. There is still lacking data from other cropping system mainly from aerobic soils conditions. Warming of N_2O emission alone as results of nitrogenous fertilizers is considered in many studies, however the net balance of warming caused by application of reactive nitrogen in agriculture is lacking hence the present study was focused on contribution of fertilizer N use in India to net global warming and its mitigation in maize-wheat system.

Table 2.1 Gaseous emission process altered by reactive nitrogen, climate forcing elements, process of warming/ cooling and their overall impacts.

Gaseous emission process altered by reactive N	**Climate forcing element**	**Process of warming/cooling**	**Overall impacts**
N_2O	N_2O	Emitted from agricultural soils	Warming
NOx → ozone and CH_4	Ozone, CH_4	NO_x perturbs the chemical production and destruction of the greenhouse gases ozone and CH_4.	Cooling
NOx→ aerosol	Nitrate and ammonium aerosol	NO_x can enhance the formation of light-scattering aerosols.	Cooling
NH_3→ aerosol	Nitrate and ammonium aerosol	NH_3 enhances the formation of light-scattering aerosols.	Cooling
N fertilizer → CO_2 flux	CO_2	On croplands, nitrogen from fertilizer and manure may enhance the storage of CO_2.	Cooling
N fertilizer → CH_4 flux	CH_4	On croplands, N from fertilizer and manure may perturb uptake and emission of CH_4.	Warming

Modified from Pinder *et al.* (2012)

CHAPTER 3

MATERIALS AND METHODS

To achieve the objectives of the current study we, initially conducted field experiment growing wheat and maize crops during 2012-13 and 2013-14 at Indian Agricultural Research Institute, New Delhi, India with seven treatments followed by use of InfoCrop model for simulation of grain yield and GHG emission from maize-wheat system. Finally we estimated the net warming potential of fertilizers N used in Indian agriculture. The detail materials and methods are as follows

3.1 Field experiments

3.1.1 Location and weather conditions

A field experiment was conducted growing wheat and maize crops during 2012-13 and 2013-14 at farm (Genetic-G field) of Indian Agricultural Research Institute, New Delhi. Geographically the site is located in the Indo-Gangetic alluvial tract at 28°38′23″N and 77°09′27″E, at an altitude of 228.61 m above mean sea level. It has semi-arid, sub-humid and sub-tropical climate with hot dry summer and cold winter. Average annual rainfall of the area is about 700 mm, 80% of which occurs during June to September.

3.1.2 Soil properties

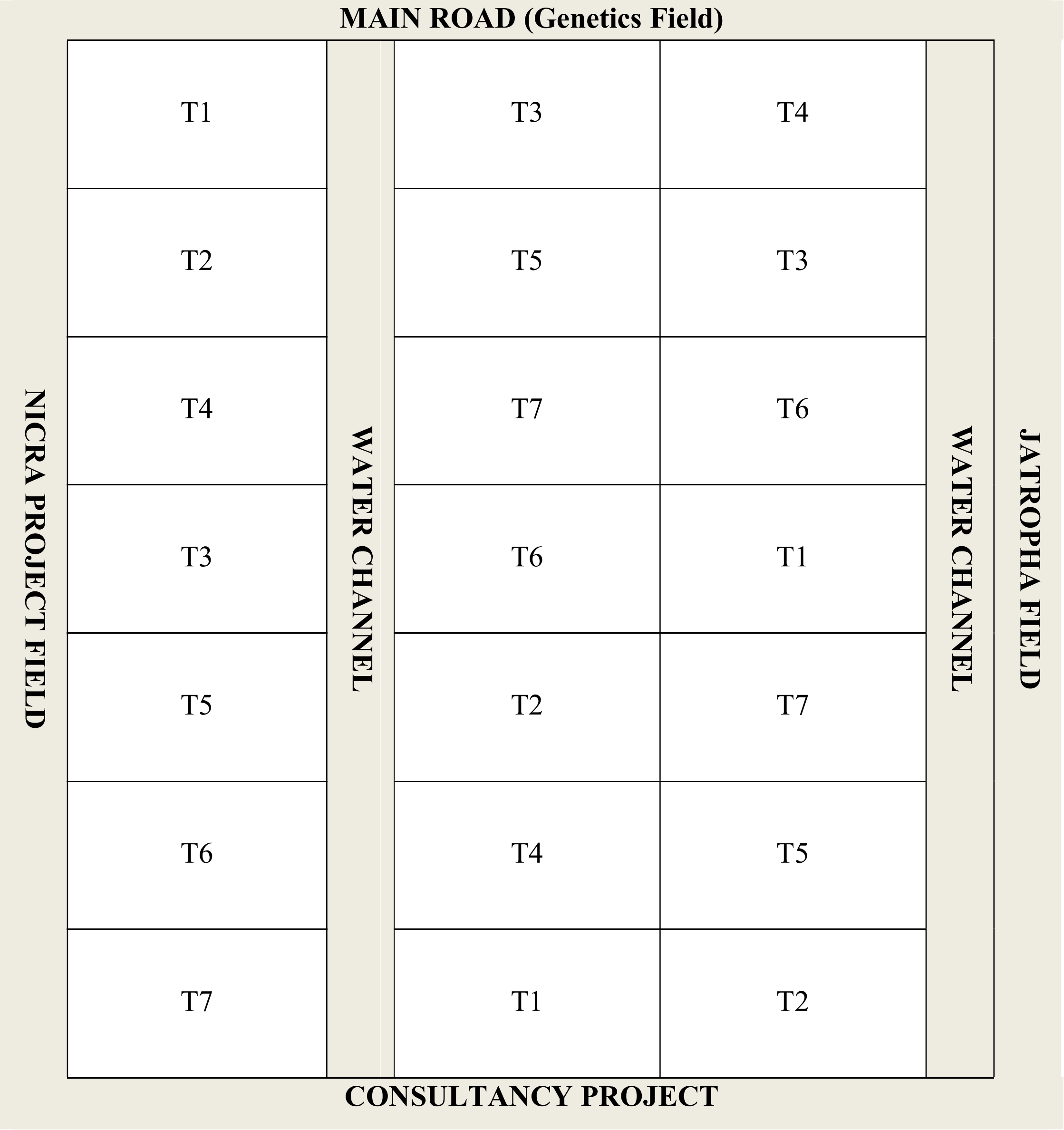
Composite soil samples from 0-15 cm soil layer at 3 locations in each treatment were collected using a core sampler before sowing of the crops. The samples were air-dried, sieved through a 2 mm screen, mixed and used to determine various physico-chemical properties using the standard procedures (Table 3.1).

Table 3.1 Methods of soil analysis

Parameters	Method	Reference
pH (1:2 :: Soil:Water)	Glass electrode	Jackson, 1973
EC (1:2 :: Soil: Water)	Conductivity bridge	Jackson, 1973
Soil texture	Hydrometer method	Bouyoucos, 1936
Soil organic carbon	Walkley and Black method	Walkley and Black, 1934
Soil available N (kg ha^{-1})	Alkaline permanganate method	Subbiah and Asija,1956
Soil available P (kg ha^{-1})	Olsen method	Olsen *et al.* (1954)
Soil available K (kg ha^{-1})	NH_4 OAC (pH 7.0)	Jackson (1967)

3.1.3 Details of the experiment

The field experiment was conducted growing with wheat (variety WR-544) and maize (variety PC-3) in maize-wheat cropping rotation. Wheat crop was grown in *rabi* season in 2012-13 and 2013-14, while maize crop was grown in *kharif* season in 2013 and 2014. The experiment was laid out in a randomized block design (RBD) (Plate 1 & 2) with seven different treatments of nitrogen. Each treatment was replicated three times.



T1	T3	T4
T2	T5	T3
T4	T7	T6
T3	T6	T1
T5	T2	T7
T6	T4	T5
T7	T1	T2

Plate 3.1 Experimental field layout

Plate 3.2 Experimental field layout

3.1.4 Varietal characteristics

Maize composite-3 (PC-3) has medium maturity, stay-green character and long ears with yellow-orange flint grains. It is tolerant to major foliar diseases and stalk borer and resistant to lodging. It matures in 85-90 days and its potential yield is about 4.0 t ha^{-1}. The wheat variety WR-544 (Pusa Gold) is an early maturing variety (fits well in intensive cropping system); possesses terminal heat tolerance, high level of resistance to leaf and stem rusts, and leaf blight. Potential yield is 3.7 t ha^{-1} and released for cultivation in NCR (National Capital Region).

3.1.5 Treatments and crop management

Treatments in both crops were designed as follows: (1) N0 (control-no N nutrient applied) (2) N120 (120 kg N ha^{-1} through urea) (3) NST (140 kg N ha^{-1} through urea on soil test basis (4) 50% urea + 50% FYM (120 kg N ha^{-1}, 50% N through urea and 50% N through FYM) (5) 100% FYM (120 kg N ha^{-1} through FYM) (6) Urea + NI (120 kg N ha^{-1}, 90% N through urea and 10% N through nitrification inhibitor-DCD) (7) NOCU (120 kg N $ha^{-1,}$ through NOCU) (Table 3.2).

Table 3.2 Details of the treatments

Treatments	Treatment details
T1 = N0	(Control) no nitrogen
T2 = N120	N @ 120 kg ha^{-1} through urea in three split doses
T3 = NST (N140)	N @ 140 kg ha^{-1} on basis of soil test value through urea in three split doses
T4 = 50% urea + 50% FYM	N @ 120 (50% N through Urea + 50% N through FYM). Urea applied in three split doses
T5 = 100% FYM	N @ 120 (100% N through FYM)
T6 = Urea + NI	N @ 120 (90% N through Urea + 10% N through nitrification inhibitor -Dicyandiamide) in three split doses
T7 = NOCU	N @ 120 (100% N through neem oil coated urea-NOCU) in three split doses

To achieve the desired plant population, maize seeds were sown in the rows spaced at 60 cm apart with plant to plant spacing of 20 cm at a depth of 5 cm. Wheat was sown at a spacing of 20 x 15 cm and at a depth 5 cm. In all the treatments P @ 60

P_2O_5 kg ha^{-1} through SSP and K @ 60 K_2O kg ha^{-1} through MOP were applied as a basal dose while nitrogen was applied in three splits: 50% as basal dose, 25% as first split dose around 30 DAS and 25% as second split dose around at 55 DAS. The farmyard manure (FYM) was incorporated in to soil at 10 days before sowing of the crops. Two-time manual weeding was done about at 25 DAS and 45 DAS in every crop. Irrigation was provided uniformly in each treatment whenever crops needed. Days to various field operation carried out in field experiments are mention in Table 3.3.

3.1.6 Greenhouse gas sampling and analysis

Closed chamber technique was used for the collection and sampling of GHG (Pathak *et al.,* 2002). Chambers of dimension 50 cm × 30 cm × 100 cm (length × width × height) made of 6 mm thick acrylic sheets and fitted with a battery operated fan, a thermometer and a three way stopcock at top were used for this purpose (Plate 3.3).

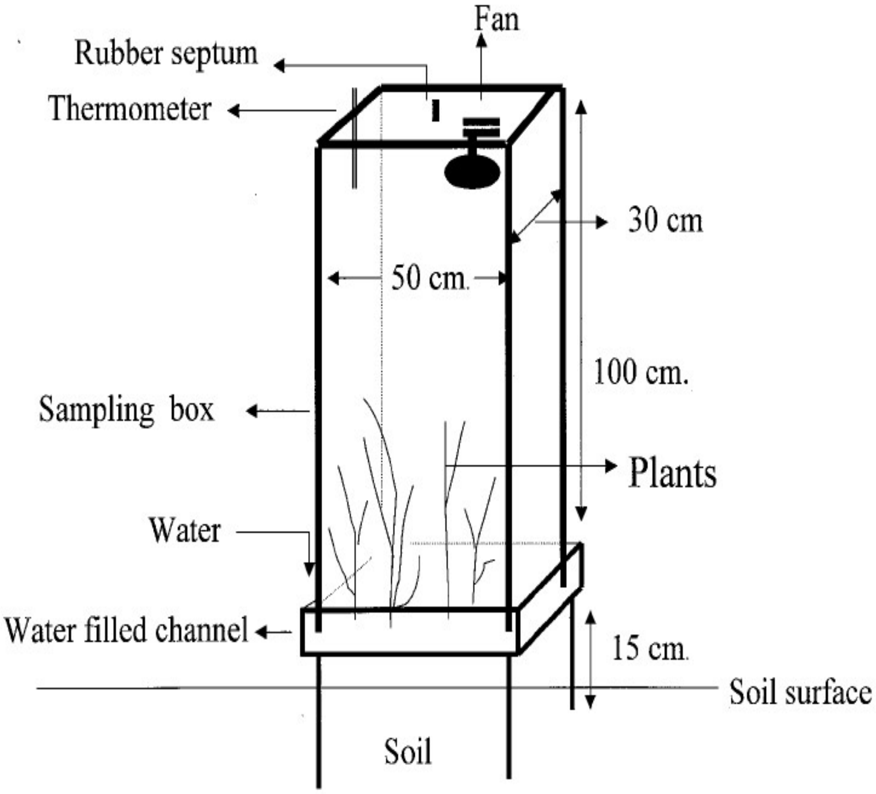


Plate 3.3 Closed chamber used for GHG sampling

Table 3.3 Days to various agronomic operations in the field experiments

Crop	Operation	Dates (DAS)
Wheat (I season)	Sowing	08-12-2012 (0)
	Fertilizers	08-12-12 (0), 03-01-13 (26), 07-02-13 (61),
	Irrigation	29-12-12 (21), 05-03-13 (88), 21-03-13 (104)
	Rainfall	18-01-13 (41), 19-01-13 (42), 5-02-13 (59), 06-02-13 (60), 16-02-13 (70), 23-02-13 (77), 29-03-13 (111)
	Weeding	25-12-12 (17), 12-01-13 (35)
	Harvesting	9-04-13 (122)
	GHG sampling	1, 2, 3, 10, 19, 27, 28, 30, 35, 44, 52, 62, 63, 64, 80, 86, 93, 102, 108, 121
Wheat (II season)	Sowing	07-12-2013 (0)
	Fertilizers	07-12-13 (0), 12-01-14 (36), 31-01-14 (56)
	Irrigation	10-12-13 (3), 07-01-14 (31), 30-01-14 (55), 26-02-14 (81)
	Rainfall	14-02-14 (67), 15-02-14 (68), 01-03-14 (84)
	Weeding	24-12-13 (17), 16-02-13 (40)
	Harvesting	09-04-14 (123)
	GHG sampling	1, 2, 3, 9, 17, 24, 30, 37, 38, 39, 47, 56, 57, 58, 68, 75, 80, 87, 96, 104, 111, 118
Maize (I season)	Sowing	26-7-2013 (0)
	Fertilizers	26-07-13 (0), 31-08-13 (37), 16-09-13 (52)
	Irrigation	13-09-13 (49)
	Rainfall	28-07-13 (3), 30-07-13 (5), 06-08-13 (11), 09-08-13 (14), 13-08-13 (18), 16-08-13 (21), 17-08-13 (22), 21-08-13 (26), 30-08-13 (35), 22-09-13 (58), 11-10-13 (77)
	Weeding	06-08-13 (12), 29-08-13 (35)
	Harvesting	23-10-13 (88)
	GHG sampling	1, 2, 3, 11, 18, 28, 37, 38, 39, 46, 53, 54, 55, 63, 71, 76, 86
Maize (II season)	Sowing	07-07-2014 (0)
	Fertilizers	07-07-14 (0), 11-08-14 (35), 01-09-14 (56)
	Irrigation	09-07-14 (3), 08-08-14 (32), 20-08-14 (44), 17-09-14 (72)
	Rainfall	18-07-14 (11), 23-07-14 (16), 31-07-14 (20), 11-08-14 (31), 30-08-14 (55), 01-09-14 (57), 02-09-14 (58), 05-09-14 (61), 06-09-14 (62)
	Weeding	07-08-14 (31)
	Harvesting	07-10-14 (91)
	GHG sampling	1, 2, 4, 9, 16, 23, 36, 37, 45, 57, 58, 59, 66, 73, 80, 90

An aluminium channel was placed in the field and used with each acrylic chamber. The aluminium channel was inserted 10 cm inside the soil and the channels were filled with water to make the system air-tight. Three channels were randomly fixed in each treatment plot to take gas samples in triplicate. Gas sampling was always carried out in morning between 9:00 and 10:30 A.M. from all the fields once in a week throughout the cropping season. Gas samples were drawn with 50 ml syringe with the help of a hypodermic needle at 0, 30, and 60 min and syringes were made air-tight with a three-way stopcock and analyzed for determination of N_2O and CO_2 concentration within 24 hour of sampling. Head space volume inside the box was recorded, which was used to calculate flux of GHG. Gas sample collected from both the crops were used to analyze N_2O and CO_2. In both the crops gas was collected from chambers fixed between the rows of crop plants (Plate 3.4). Concentrations of N_2O and CO_2 in the gas samples were analyzed using Gas Chromatographs (GC: Hewlett Packard 5890 Series II) fitted with electron capture detector (ECD), flame ionization detector (FID) and 6′× 1/8″ stainless steel column (Porapak N). The carrier gas was N_2 with a flow rate of 14 ml min^{-1}. N_2O concentration was estimated by GC-ECD with 50, 120, and 350 °C column, injector, and detector temperatures, respectively (Plate 3.5). Concentration CO_2 was estimated by passing gas sample through a methanizer followed by GC-FID with 60, 120, and 120 °C column, injector, and detector temperatures, respectively. The standards of GHG were obtained from Spectra Gases, USA. Estimation of total N_2O and CO_2 emission during the crop season were done by successive linear interpolation of average emissions of particular GHG on the sampling days assuming that GHG emissions followed a linear trend during the periods when no sample was taken.

Plate 3.4 Collection of gas samples by close chamber technique

Plate 3.5 Estimation of GHGs concentration in the gas samples collected from the field by gas chromatography.

3.1.7 Calculation of greenhouse gas flux

The following formula was used to calculate the flux

Cross sectional area of the chamber = A m^2
Headspace = H m
Volume of headspace = $AHm^3 = 1000 \times AH$ l
Concentration given GHG at 0 time = Co ppmv
Concentration given GHG after time t = C_t ppmv
Change in concentration in time t = $(C_t - C_o)$ ppmv
= $(C_t - C_o)$ µl l^{-1}
Volume of given GHG evolved in time t = $(C_t - C_o)$ µl $l^{-1} \times 1000$ AH L
= $(C_t - C_o) \times AH$ ml
When t is in hours, then flux = $(C_t - C_o) \times AH)/(A \times t)$ ml m^{-2} h^{-1}
= Y µl m^{-2} h^{-1}

Now 22.4 ml of CH_4 is 'M' mg at STP (M = molecular weight of given GHG)

So, Y µl of N_2O is (M ×Y/22.4) µg at STP

Therefore, Flux = Y × M/22.4 µg m^{-2} h^{-1}

Hence, Flux = $[(C_t - C_o)/t] \times H \times M/22.4$ µg m^{-2} h^{-1}

So, for one hectare/day given GHG

$$\text{Flux} = \frac{[(Ct - Co)/t] \times H \times 44/22.4 \times 10000 \times 24 \text{ mg}}{1000}$$

$$\text{GHG flux mg ha}^{-1}\text{ d}^{-1} = \frac{[(Ct - Co)/t] \times H \times M \times 240 \times 28 \text{ mg ha}^{-1}\text{ d}^{-1}}{22.4 \times 1000}$$

$$= [(Ct - Co)/t] \times 300 \text{ mg ha}^{-1}\text{ d}^{-1}$$

3.1.8 Global warming potential and green house gas intensity

Global warming potential (GWP) is an index defined as the cumulative radiative forcing between the present and some chosen later time 'horizon' caused by a unit mass of gas emitted now. It is used to compare the effectiveness of each greenhouse gas to trap heat in the atmosphere relative to some standard gas, by convention CO_2. The GWP for N_2O is 310 and for CO_2 is 1. The GWP of different treatments were calculated using the following equation (IPCC 2014).

$$\text{GWP (kg } CO_2 \text{ eq. ha}^{-1}) = CO_2 \text{ (kg ha}^{-1}) + N_2O \text{ (kg ha}^{-1}) \times 310$$

Based on a 100 year time frame, the GWP coefficients of N_2O is 310, when the GWP value for CO_2 is taken as one (IPCC, 2014). This shows that emission of 1 unit of N_2O is equivalent to emissions of 310 units of CO_2.

The greenhouse gas intensity (GHGi), which shows the GWP per unit production of economic yield i.e. grain yield of the different treatments were also calculated as

$$\text{GHGi} = \text{GWP/grain yield}$$

3.1.9 Observations on Crop phenology and grain yield estimation

Observations on crop phenology (days to 50% germination, days to 50% flowering and days to 50% physiological maturity were taken on plants in different treatments, while observations on grain and residue yield were also recorded.

3.1.9.1 Phenological observations

Days to 50% germination The number of days taken from the date of sowing to germination of 50% of the seeds in a plot was reported as days to 50% germination.

Days to 50% flowering The number of days taken from the date of sowing to flowering of 50% of the plants in a plot were reported as days to 50% flowering. In maize, this corresponded to days taken to silking of 50% of plants in a plot, while in wheat it corresponded to days taken of 50% of anthesis of the plants in a plot.

Days to 50% physiological maturity: In case of maize, time taken in days from sowing to 75% of cobs in 75% of plants in a plot became yellowish and noticeable formation of black tip on the grain was recorded as days to physiological maturity.

3.1.9.2 Grain and residue yield

Sampling were done from one m^2 area in each plot as ''sample plants'' for recording observations on 1000 grain weight and harvest index in wheat crop and 100 grain weight, shelling percentage and harvest index in maize crop. Grain and residue yields in both the crops were determined from the total plot area.

3.1.10 Cost-benefit analysis

The operational cost of cultivation of experiments in both the crops were calculated by considering costs of inputs i.e. seed, fertilizers, diesel, electricity and the hiring charges of services for various farm operations (land preparation, irrigation, fertilizer application and harvesting) using following formula

Total cost of cultivation (Rs ha^{-1}) = Inputs cost [Seed, Fertilizer and Energy (diesel and electricity)] + [Cost of hiring services (Human and machine)] + [miscellaneous cost (@ 10% of total cost)]

Where, All units of costs are in Rs ha^{-1} and

Cost of energy was calculated using following formula,

Cost of energy (Rs ha^{-1}) = Tractor operation cost [(Diesel consumed by tractor (l ha^{-1}) × total duration of tractor operation (hr ha^{-1}) × price of diesel (Rs l^{-1})] + irrigation cost [Electricity consumed by electric pump for irrigation (kW hr^{-1}) × total duration of pump operation (hr ha^{-1}) × electric charge (Rs kW hr^{-1})]

The current market price of all the inputs used, hired services during respective season of cultivation were taken in to accounts as mentioned in Table 3.4.

Table 3.4 Prices of farm inputs

Inputs	**Price**	
	2012-13	**2013-14**
Wheat seed (Rs kg $^{-1}$)	35	37
Maize seed (Rs kg $^{-1}$)	30	35
Urea (Rs kg $^{-1}$)	6.4	6.5
NOCU (Rs kg $^{-1}$)	8.1	8.2
SSP (Rs kg $^{-1}$)	8.4	8.8
MOP (Rs kg $^{-1}$)	19.6	21
NI (Rs kg $^{-1}$)	100	100
FYM (Rs kg $^{-1}$)	0.3	0.3
Labour wage (Rs man^{-1} day^{-1})	280	280
Tractor rent (Rs hr^{-1})	800	800
Electricity (Rs kW h^{-1})	0.5	0.55
Diesel (Rs l^{-1})	48	51
wheat grain (Rs kg $^{-1}$)	13.5	14
maize grain (Rs kg $^{-1}$)	13.1	13.5
wheat straw (Rs kg $^{-1}$)	0.5	0.5
maize straw (Rs kg $^{-1}$)	0.35	0.35

Gross income of the experiment was the minimum support price offered by the Government of India for wheat and maize crop in the respective year plus income from residue selling. The gross income was determined by following formula

Gross income (Rs ha^{-1}) = [Total grain yield (kg ha^{-1}) × Minimum support price of grain (Rs kg^{-1})] + [Total straw yield (kg ha^{-1}) × market price of straw (Rs ha^{-1})]

Net income of the experiments was calculated as the difference between gross income and total cost. Overall system productivity was also calculated for both the year by adding together grain yield of wheat and maize crops in each year and finally benefit cost ratio was determined by following formula

$$\text{Benefit cost ration (B:C)} = \frac{\text{Gross income (Rs)}}{\text{Total cost (Rs)}}$$

3.1.11 Statistical analysis

The data on various observations recorded during the course of investigation were tabulated and statistically analyzed using Randomized Block Design (RBD). The critical difference (C.D.) and standard errors of difference (SEd) was calculated at 5% level of significance for comparing the means.

3.2 InfoCrop a generic crop simulation model

In order to test the model performance in simulating the response of crop to simulate the impact of N fertilizer use on crop yield and global warming potential of maize-wheat system, InfoCrop model was used. InfoCrop model is a generic simulation model that describes daily phenological development and growth in response to the environmental factors i.e. soil, weather and management factor. The basic description of this dynamic simulation model is given in Aggarwal *et al*. 2006 (Fig 3.1).

The model is written in Fortran Simulation Translator programming language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands; van Kraalingen, 1995). The InfoCrop model considers the processes of growth and development, soil water, nitrogen and carbon, and crop pest interaction. The processes considered are as follows

- Crop growth: Phenology, leaf area, growth and senescence, photosynthesis, respiration, dry matter partitioning, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen, and effects of water, nitrogen, temperature, CO_2, flooding and frost stresses.

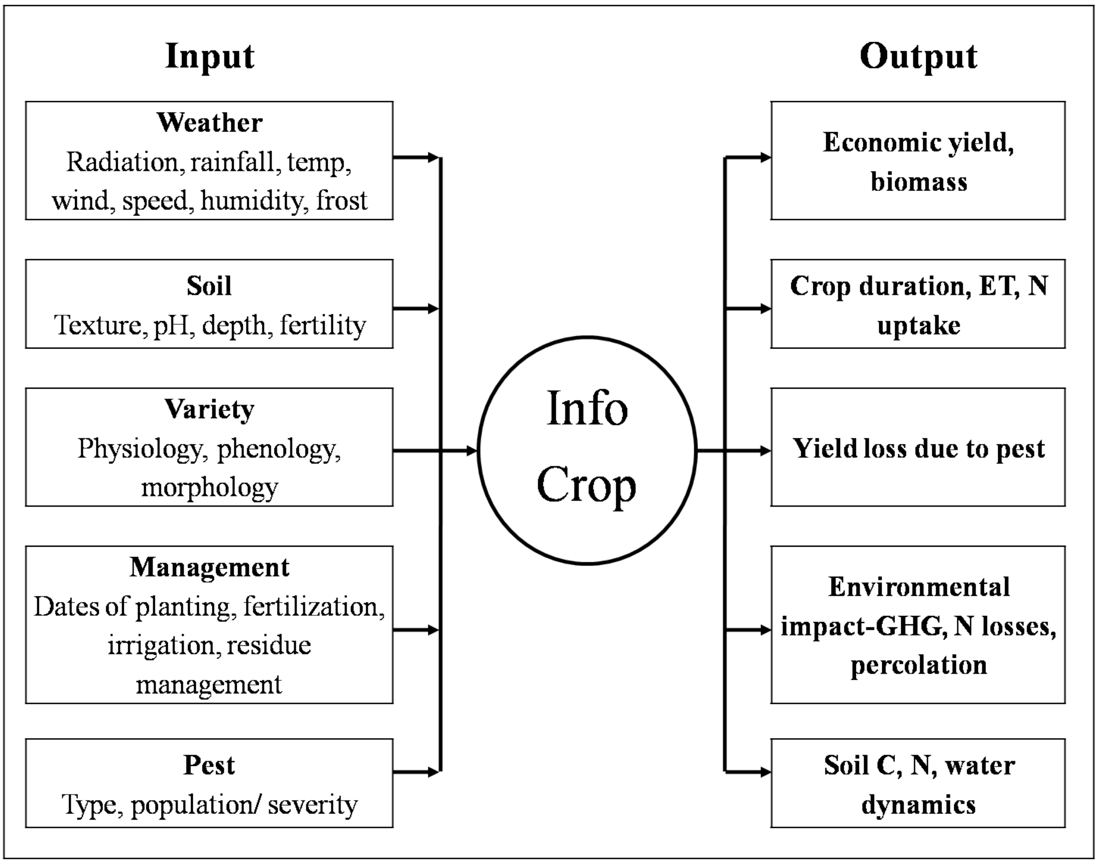


Figure 3.1 Key inputs and outputs of InfoCrop (Source: Aggarwal et al., 2006)

- Crop-pest Interactions: Damage by insects, diseases and weeds
- Soil water balance: Water uptake by roots, soil inter-layer movement, drainage, evaporation, runoff, ponding
- Soil nitrogen balance: Mineralization uptake, fixation, nitrification, volatilization, inter-layer movement, denitrification, leaching
- Soil organic carbon dynamics: Mineralization and immobilization

The input data used to calibrate the InfoCrop wheat and maize model are described in Table 3.5.

Table 3.5 Input data collected to calibrate the InfoCrop-Wheat and maize model

Sl. No.	Data required	Description
1	Weather	Daily value of maximum and minimum air temperature, rainfall and solar radiation of the respective growing season or year
2	Soil characteristics and fertility	Soil profile with its intrinsic properties including soil texture (clay, sand, silt), bulk density, moisture content at field capacity, permanent wilting point, soil organic carbon, soil available N, P_2O_5 and $K\ _2O$ and field slope.
2	Soil characteristics and fertility	Soil profile with its intrinsic properties including soil texture (clay, sand, silt), bulk density, moisture content at field capacity, permanent wilting point, soil organic carbon, soil available N, P_2O_5 and K_2O and field slope.
3	Crop management	Includes depth of planting, sowing dates, seed rate, fertilizer doses, frequency and time of fertilization, amount, time and frequency of irrigation, seed rate and application of organic matter
4	Pests	Population/severity of pests and their timing of presence
5	Variety	Thermal time from sowing to seedling emergence, thermal time from seedling emergence to anthesis, thermal time from anthesis to maturity, base temperature from sowing to seedling emergence, base temperature from seedling emergence to anthesis, base temperature from anthesis to maturity, optimal temperature, maximum temperature, photoperiod correction factor for the thermal time from seedling emergence to anthesis, specific leaf area and grain size.

Source: Aggarwal *et al.,* 2006

3.2.1 Phenology

The total development of a crop has been quantified based on development stages (DS), a dimension less variable having a value of 0 at sowing, 0.1 at seedling emergence, 1.0 at flowering and 2.0 at maturity (Seligman and Keulen, 1981). This was calculated by integrating the temperature-driven development rates of the phases from sowing to seedling emergence, seedling emergence to anthesis, and storage organ filling phase. In the model, phenological development of the crop is based on the accumulated daily thermal time ((Tmax + Tmin) /2) – Tbase)). The base temperature used for maize model is 10°C. In case of wheat model base temp used for germination is 3.6°C, for flowering 4.5°C and for physiological maturity 7.5°C.

3.2.2 Growth and dry matter production

The leaf and root weights at seedling emergence were initialized based on the user-specified seeding rate. A fraction of the seed weight was assumed to be lost in respiration during the seedling emergence phase; the balance was partitioned between roots and leaves depending upon the crop. For simulating further increase in dry matter, the crop has been treated as an intact unit, individual plant have not been simulated. Seed rate and the potential dry matter production are calculated based on as a function of Radiation Use Efficiency (RUE). WLVI is the initial leaf weight, FRLVWT is the fraction of seed that is in leaves at the seedling emergence stage, SEEDRT is the quality of seed sown, WRTI is the initial root weight, LAII is the initial leaf area index, and SLAVAR is cultivar-specific leaf area.

3.2.3 Dry matter partitioning

The dry matter produced is partitioned into root, leaves, stem and the storage organ. The portioning is a crop specific function of development stage. The partitioning function is described in the model for leaves (FLVTB), stem (FSTTB), and root (FRTTB). Final grain yield is the product of plant population, kernels per plant and weight of kernel. Pre-determined values of RUE were input in the model as a function of crop/cultivar (RUEMAX). Yield is influenced by the soil characters, weather, availability of nutrients and water.

3.2.4 Nitrogen Stresses

Nitrogen stress (NSTRES) was determined based on potential (ANCRPT) and current levels (ANCR) of N in different plants parts, analogous to actual/potential transpiration ratio used for determining water stress factor. N stress effect was assigned a value of zero (maximum N stress) when actual mobilizable nitrogen is zero, and linearly approached a value of 1.0 when actual nitrogen approached the maximum value (no N-stress).

3.2.5 Nitrous oxide emission

Denitrification and nitrification are the two most important mechanisms contributing to N_2O emission from soil. Nitrification contributes to N_2O emission following ammonium fertilization or ammonia forming fertilizer addition to soils during the oxidation of $NH4^+$ to NO_3^-. Denitrification occurs when nitrate is present in anaerobic sites. A range of soil, climate and management factors affect the nitrification and denitrification process, thereby emission of N_2O from soil. Amount of N_2O-N formed by the process of nitrification was calculated using first order kinetics as per equation

NHN2O = NH4 * (1-EXP (-N2NRAT)) * TFAC * AMIN1 (MFAC, PHFAC)

Where, NHN2O is N_2O formed due to nitrification, and N2NRAT is the rate constant of nitrification,

Amount of N_2O-N formed due to denitrification was calculated on the basis of amount of nitrate, temperature, pH and moisture status of soil.

N2ODEN = (NO31 * (1-EXP (-N2DRAT)) * AFGEN (MTABD, AWF1) * MBFAC * AMIN1 (TFAC, PHFAC)

Where, N2ODEN is N_2O formed due to denitrification, NO31 is the amount of nitrate in soil layer 1, and N2DRAT is the rate constant of denitrification.

3.2.6. Carbon dioxide emission

The amount of dissolved organic carbon left after emission of methane is emitted as CO_2. However, the entire CO_2 was not allowed to escape at the same time by considering a time coefficient (TCOEFF) for its release.

CO2EMS = AMAX1 (0., CDOC - CH4SUM / TCOEFF

CO2SUM = INTGRL (ZERO, CO2EMS)

3.2.7 Global warming potential

The global warming potential (GWP, kg CO_2 ha^{-1}) of a system was calculated by using GWP values for CO2 and N2O emissions as 1 and 310 respectively.

$$GWP = CO2EMS * 1 + N2OTOT * 310$$

3.2.8. Calibration and validation of InfoCrop model for simulating crop phenology, yield and nitrous oxide emission.

For this initial calibration of model, the experimental values pertaining to first season of both the crop wheat and maize were used. Initially, the model was calibrated for varietal performance using the varietal characteristics for N120 condition (N @120 kg ha^{-1}). For attaining the proper phenology, yield and N_2O emission several iterations were done and simulations runs were made. After satisfactory performance of model in N120 condition, the simulations were done for N140 (NST) (N @140 kg ha^{-1}) and control (N0) (N @ 0 kg ha^{-1}) and calibrations was repeated through less iteration so as to get proper simulation results in N140 and control (N0) conditions as well and finally model was calibrated for other treatment also in similar way. Thereafter, the model inputs were changed to suit the different N conditions and simulations were carried out. Simulation results on phenology, yield and GHG (N_2O) emission were compared with those from the field experiment.

3.2.9. Evaluation of model performance

Four statistical measures were applied to evaluate the model that included mean bias error (MBE) (Addiscott and Whitmore, 1987); root mean square error (RMSE) (Fox, 1981), index of agreement (IA) (Willmott, 1982) and modelling efficiency (ME) (Nash and Sutcliffe 1970).

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(Si - Oi) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Si - Oi)^2} \quad (2)$$

$$IA = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}\left(\left|Si - \overline{O}\right| + \left|Oi - \overline{O}\right|\right)^2} \tag{3}$$

$$ME = 1 - \frac{\sum_{i=1}^{n}(s_i - o_i)^2}{\sum_{i=1}^{n}\left(\left|O_i - \overline{O}\right|\right)^2} \tag{4}$$

Where n is the number of samples, S_i and O_i are the simulated and observed values, respectively, and $\bar{O}$ is the mean of the observed data. The MBE indicates bias of model error as it accounts for positive and negative deviations. The RMSE describes mean absolute deviation between simulated and observed values. Accuracy of simulation is characterized by lower RMSE. The IA, is an additional method for evaluation of model performance, which ranges between 0 and 1, the closer IA is to 1, the better the simulation. Another parameter, ME allows negative values and compares deviation between simulated and observed state variables with the variances of observed values of development, growth and yield.

3.3. Global warming and cooling impacts of N input used in Indian agriculture

3.3.1 Total nitrogen input used in Indian agriculture

To calculate the total reactive nitrogen used in Indian agriculture from synthetic fertilizers, animal manure, crop residues and atmospheric deposition equation (1) was used.

$$N_T \text{ (Tg)} = (N_{SN} + N_{AM} + N_{CR} + N_{DEP}) \tag{1}$$

Where,

N_T denotes the total N added to soil; N_{SN} denotes the annual amount of synthetic fertilizer N applied to soil; N_{AM} denotes the annual amount of animal manure nitrogen applied to soils; N_{CR} is the amount of N in crop residue returned to soil annually. Data on N_{SN}, N_{AM} and N_{CR} were obtained from FAOSTAT, 2016. N_{DEP} is the amount of N added by atmospheric wet and dry deposition and it was calculated using equation (2).

$$N_{DEP} = \text{Total agriculture area} \times \text{deposition factor} \tag{2}$$

Here data on total agriculture area was obtained from FAOSTAT whereas; data on deposition factor was obtained from Liu *et al.,* 2010.

3.3.2 Emission/uptake factors (EF)

The emission/uptake factors used in the study are mentioned in Table 3.6. According to IPCC (2006) the emission factor for N_2O-N emitted from the various nitrogen additions to the soil has a default value of 1%. In this study the EF 0.007 was used for direct N_2O-N emission and 0.005 was used for indirect N_2O-N emission from nitrate leaching (Bhatia *et al*. 2004). Emission factor for NO_3^- leaching, NH_3 and NOx emissions were used 0.1, 0.15 and 0.005 kg kg^{-1} N applied, respectively. Emissions of CH_4 from anaerobic and aerobic fields were taken as 0.008 and -0.012 kg CH_4-C kg kg^{-1} N applied. The factor for C sequestration was 0.053 kg CO_2-C kg kg^{-1} N applied.

Table 3.6 Coefficient used in the present study

Parameters	Emission Factor (EF)	Unit	Source
Direct N_2O-N	0.007	kg N_2O-N $ha^{-1}yr^{-1}kg^{-1}$N	Bhatia *et al*., (2004)
N_2O-N from nitrate leaching	0.005	kg N_2O-N $ha^{-1}yr^{-1}kg^{-1}$N	Bhatia *et al*., (2004)
Nitrate leaching	0.1	kg NO_3-N $ha^{-1}yr^{-1}kg^{-1}$N	Bhatia *et al*., (2004)
NH_3-N	0.15	kg NH_3-N $ha^{-1}yr^{-1}kg^{-1}$N	Aggarwal *et al.,* (1987); Sarkar *et al.,* (1991); Parashar *et al.,* (1998)
NOx-N	0.005	kg NH_3-N $ha^{-1}yr^{-1}kg^{-1}$N	Veldkamp *et al.,* (1997); Sharma *et al.,* (2008)
CH_4-C uptake (upland soil)	-0.012	kg CH_4-C $ha^{-1}yr^{-1}kg^{-1}$N	Liu and Greaver (2009)
CH_4-C emission (lowland soil)	0.008	kg CH_4-C $ha^{-1}yr^{-1}kg^{-1}$N	Liu and Greaver (2009)
CO_2-C	0.053	kg CO_2-C $ha^{-1}yr^{-1}kg^{-1}$N	Liu and Greaver (2009)

3.3.3 Emission/uptake fluxes

Application of N to cropland alters the flux of N_2O, NO_X, NO_3^- leaching, NH_3 , CH_4 and CO_2, hence using these above mention emission/uptake factors total emission/uptake fluxes of different species (N_2ON, $NO_X{-}N$, $NH_3{-}N$, $CH_4{-}C$ and $CO_2{-}C$) were calculated using equation (3).

$$F_T\,(Tg) = N_T\,(Tg) \times EF \tag{3}$$

Where,

N_T, is total amount of N (Tg) added to agricultural land and EF is the respective emission/uptake factor. In case of $CO_2{-}C$ flux it includes the enhanced plant growth, soil carbon accumulation and increase microbial activity.

N_2O flux from NO_3^- leaching was calculated using the equation (4).

$$N_2O \text{ emission from } NO_3^- \text{ leaching (Tg)} = NO_3^- \text{ leaching flux} \times EF \tag{4}$$

3.3.4. Global temperature change potential of N_2O, NO_X, NH_3, CH_4 and CO_2 fluxes

It included calculation

The GTP of N_2O, NO_x and NH_3 fluxes were calculated using the equation (5).

$$GTP_{Nt}\,(Tg\ CO_2e) = F_T\,(Tg) \times GTP_{txi} \tag{5}$$

Where, GTP_{Nt} is GTP at ‘t’ time-scale i.e., 20 or 100 years; F_T is flux of NO_x, NH_3 and N_2O emission (kg yr^{-1}), GTP_{txi} is GTP for ‘i’ kg of ‘x’ compound (N_2O, NOx, NH_3) at time-scale ‘t’. GTP_{20} and GTP_{100} used in the study are mentioned in Table 3.7.

Table 3.7 Global Temperature Change Potential (kg CO_2/kg N) used for different species and process altered

Species (process altered)	GTP_{20}	GTP_{100}	Source
N_2O	+260 to +290	+290 to +320	Shine *et al.,* 2005
NOx → ozone and CH_4	-55 to -37	-2.9 to -0.024	Fuglestvedt *et al.,* 2010
NOx → aerosol	-31 to -7	-0.0024 to 0	Shindell *et al.,* 2009
NH_3 → aerosol	-9.5 to -2.2	-0.022 to 0	Shindell *et al.,* 2009
N fertilizer → CH_4 flux	+37 to +77	+2.9 to +4.9	Boucher *et al.,* 2009
N fertilizer → CO_2 flux	1	1	IPCC, 2013

The equation (6) was used to calculate GTP of CH_4 and CO_2 emission/uptake (GTP_{Ct}).

$$GTP_{Ct}\ (Tg\ CO_2e) = F_T \times GTP_{txi} \tag{6}$$

Where GTP_{txi} is GTP for ‘i’ kg of ‘x’ compound (CH_4 and CO_2) at time-scale ‘t’.

Finally, the net GTP (GTP_T) of N addition to global agriculture was calculated using the equation (7).

$$GTP_T\ (Tg\ CO_2e) = GTP_{Nt}\ (Tg\ CO_2e) + GTP_{Ct}\ (Tg\ CO_2e) \tag{7}$$

CHAPTER-4

RESULTS

The field experiment growing maize and wheat crops during 2012-13 and 2013-14 under wheat-maize cropping system was aimed to quantify the emission of greenhouse gases in a maize-wheat system and assess the magnitude and cost of mitigation with suitable technologies in the upper Indo-Gangetic Plain (IGP) and further to simulate the impact of N fertilizer use on global warming potential and yield of a maize-wheat system.

4.1. Weather condition during the experimental crops growth seasons

The minimum and maximum temperature, rainfall and sunshine duration during crops growing seasons recorded at the meteorological observatory, Division of Agricultural Physics of Indian Agricultural Research Institute; New Delhi, India are given in figure 4.1 and 4.2. During the experimental wheat crop growth season first (from December, 2012 to April, 13), the total rainfall was 182.6 mm. The mean maximum and minimum temperature was 23.7°C and 9.6°C, respectively. The daily mean sun-shine duration was 5.5 hrs (Fig. 4.1A). While, during succeeding wheat crop growth season (from December, 2013 to April, 2014), the total rainfall was 152.4 mm. The mean maximum and minimum temperatures was 23°C and 9°C, respectively and daily mean sun-shine duration was 4.6 hrs (Fig. 4.1B). Temperature was little favorable but, sunshine duration was low during second season compare to first season.

During the first maize crop growth season, (from July to October, 2013), the total rainfall was 841 mm. The mean maximum temperature was 33.0°C while, mean minimum temperatures was 23.2°C. The daily mean sun-shine duration was 5.1 hrs (Fig. 4.2A). While, during succeeding season (from July to October, 2014), the total rainfall was 435.1 mm. The mean maximum and minimum temperature was 35.3°C and 25.1°C, respectively. The daily mean sun-shine duration was 5.8 hrs (Fig. 4.2B).

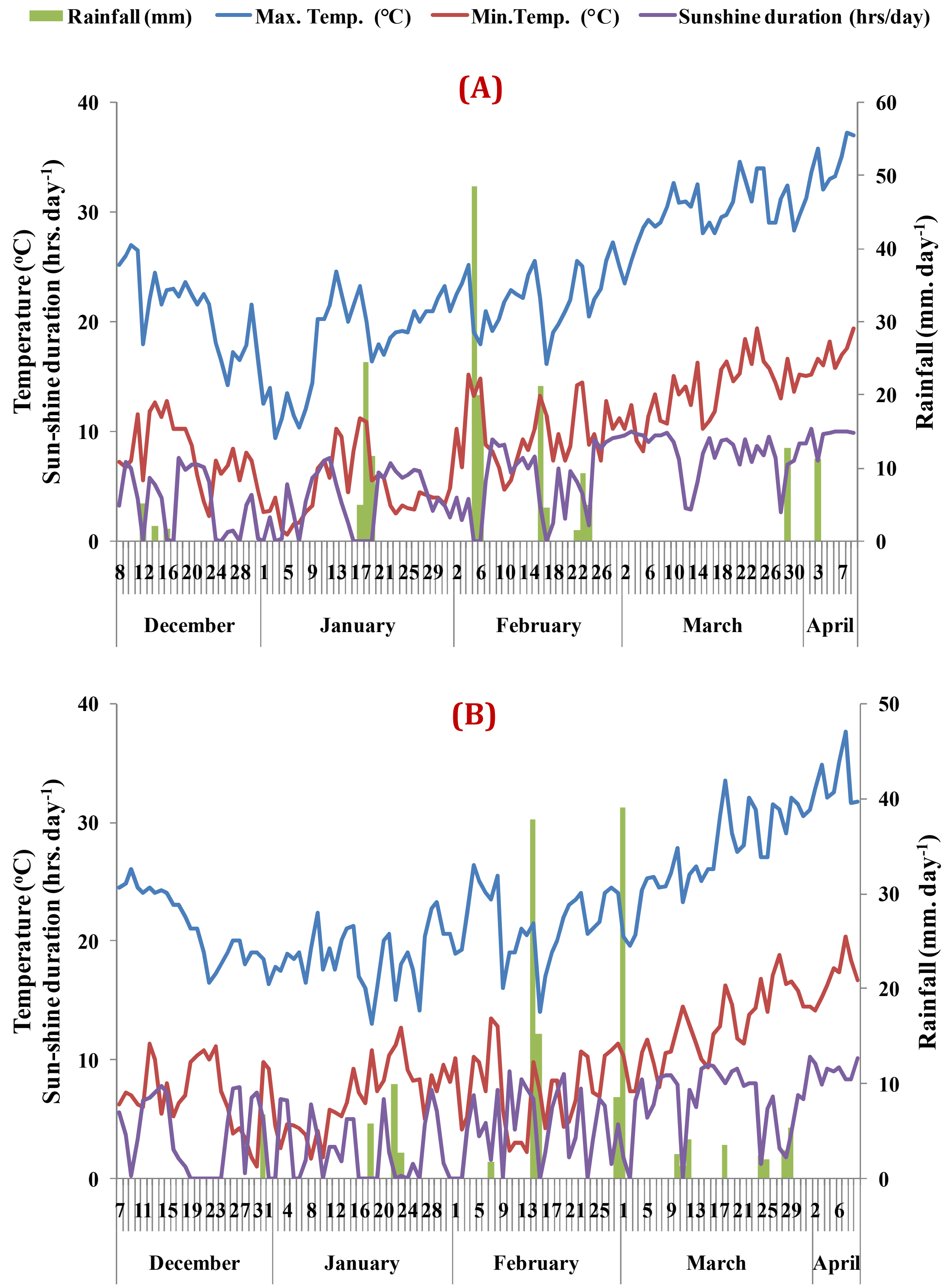


Figure 4.1 Daily weather during the experimental wheat crop growth: A) I-season and B) II-season

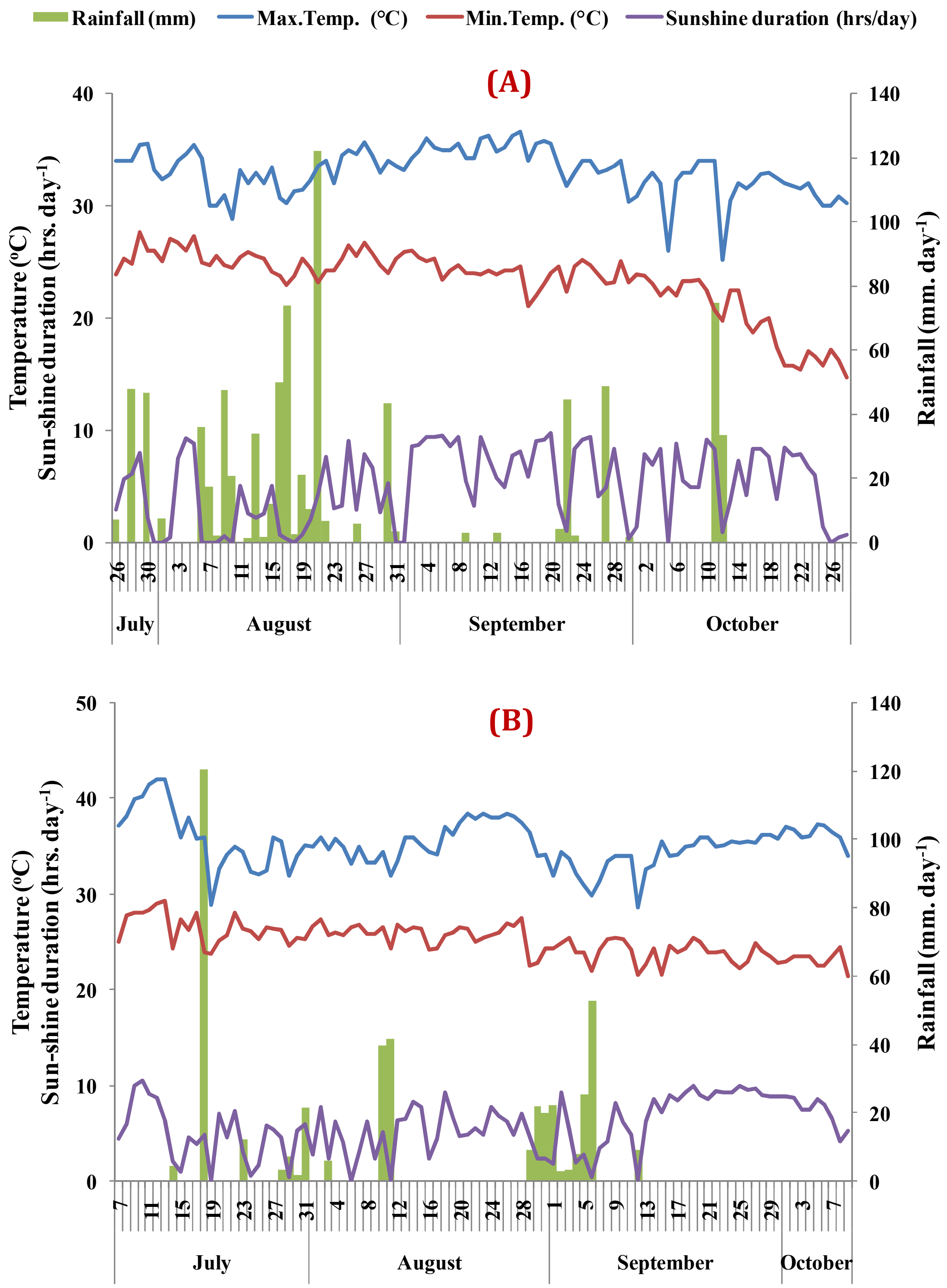


Figure 4.2 Daily weather during the experimental maize crop growth: A) I-season and B) II-season

4.2. Initial soil properties of experimental field

The soil of experimental site is slightly alkaline with low electrical conductivity. The soil was well drained. The Yamuna alluvial soil of the experimental site was Typic Haplustept with pH 8.16 and sandy loam in texture (46% sand, 25% silt and 29% clay). Soil was medium in organic carbon content and low in available nitrogen, medium in available potassium and available phosphorous (Table 4.1).

Table 4.1 Physical and chemical characteristics of the soil of the experimental field

Parameters	Values
Sand (%)	46
Silt (%)	25
Clay (%)	29
Texture class	Sandy clay loam
pH (1:2::Soil:Water)	8.16
Electrical conductivity (dS m^{-1})	0.295
Organic carbon (%)	0.48
Soil available N (kg ha^{-1})	221.6
Soil available P (kg ha^{-1})	23.4
Soil available K (kg ha^{-1})	285.8

4.3. Phenology of wheat and maize crops

It was observed that both crops took 5-6 days for germination in both season which shows that germination of wheat and maize crops were not affected significantly by the doses and sources of nitrogen through which nitrogen were added in different treatment. Both the days to flowering and days to physiological maturity are affected. Wheat crop took 85 to 89 days for anthesis in both the seasons which were 4-5 weeks latter compared to the time taken for tasseling of maize crop. Similarly, wheat matured about 4-5 week latter than the maize crop. It was due to the duration of crop varieties used.

In wheat crop, under N120 treatment, flowering delayed by about 4 to 5 days as compared to the control (N0) crop (Table 4.2). Coincidence of optimum nitrogen application during vegetative period delayed flowering. On the other hand, nitrogen stress caused early flowering. Similar results were also found in the succeeding wheat crops. Similarly maturity was also delayed by 3-5 days compared to control crop. Maturity was delayed by 5 days in the treatments of N120, NOCU and urea + NI. In case where full nitrogen was applied though FYM (100% FYM) and where 50% nitrogen was substitute by FYM (50% urea + 50% FYM) maturity were at par with control crops. Similar results were also observed in the succeeding wheat crop (Table 4.2).

Similarly in case of maize under adequate nitrogen regime (N120), silking delayed by 1 to 2 days as compared to that of control crop (N0), while the nitrogen stress advanced silking by 2 days as compared to that of adequate application of nitrogen (Table 4.2). Coincidence of vegetative period with nitrogen stress advanced silking while with adequate nitrogen it delayed. Similarly maturity was also delayed around 3-4 days in where nitrogen were applied though chemical fertilizer. Highest days to maturity were recorded in the N140 (NST) treatment. In case where N was applied trough NOCU maturity was at par with N140 (NST) treatment. Days to maturity were at par in control crops (N0) and 100% FYM treatment. It was observed that days to maturity were in between control and 50% urea + 50% FYM (Table 4.2).

Table 4.2 Phenology (days after sowing) of wheat and maize crop under different treatment

Treatments	**Wheat**			**Maize**		
	50% G	**50% A**	**50% PM**	**50% G**	**50% S**	**50% PM**
Season I						
N0	5	86	115	5	57	85
N120	6	89	119	5	58	87
N140 (NST)	6	89	119	6	58	88
50% urea+50%FYM	5	88	116	6	57	86
100% FYM	6	87	115	6	57	85
Urea + NI	5	88	117	5	57	87
NOCU	5	89	119	6	58	88
CD p=0.05	N/A	0.99	1.03	N/A	1.11	1.23
SE(d)	0.41	0.45	0.47	0.49	0.51	0.47
Season II						
N0	5	85	114	5	57	87
N120	5	89	119	6	58	89
N140 (NST)	6	90	119	6	59	90
50%urea+50%FYM	6	86	116	5	58	88
100% FYM	5	86	116	6	59	87
Urea + NI	6	88	118	5	58	88
NOCU	6	89	119	6	59	89
CD p=0.05	N/A	1.55	1.26	N/A	1.04	1.85
SE(d)	0.56	0.71	0.57	0.50	0.47	0.84

Where,
G=Germination; A= Anthesis; PM=Physiological maturity; S= Silking

4.4. Greenhouse gas emission from wheat and maize crops field experiments

A field experiment was conducted for two consecutive years at IARI farm to quantify the emission of greenhouse gases in a maize-wheat system and assess the magnitude and cost of mitigation with suitable technologies in the upper Indo-Gangetic Plain (IGP). We measured N_2O and CO_2 fluxes at weekly interval from sowing to harvesting in each treatments and quantify cumulative GHG emission by linear interpolation followed by global warming potential (GWP) and green house gas intensity (GHGi) for each treatments and maize-wheat systems. The obtained results are beneath.

4.4.1 Nitrous oxide emission

In both the seasons of experiments we have observed similar temporal trend of N_2O emission flux in all the treatments of wheat and maize crops however, the magnitude differed (Fig. 4.3 & 4.4). The flux of N_2O reached its peak value 2-3 days after application of fertilizers and subsequently declined. However, in case where 100% urea was substituted by FYM (100% FYM) showed that N_2O emission was higher in initial days and gradually decreased over the period (Fig. 4.3 and 4.4).

Nitrous oxide emission from wheat crop

The temporal N_2O emissions varied widely throughout the wheat crop growing seasons (Fig 4.3 A & B). Flux of N_2O–N ranged from 1.89 to 29.15 and 1.77 to 26.56 g ha^{-1} day^{-1} among different treatments in first and second season respectively. First peak flux of N_2O-N emission on 2nd day after sowing (DAS) varied from 5.28 to 29.15 and 6.15 to 26.56 g ha^{-1} day^{-1} among different treatments in first and second season respectively. Subsequently, there was lowering of the emission. Highest peak of N_2O–N emission in both the season was (29.15 g ha^{-1} day^{-1} in first season and 26.56 g ha^{-1} day^{-1} in second season) from N140 (NST) treatment and lowest (1.89 g ha^{-1} day^{-1} in first season and 1.77 g ha^{-1} day^{-1} in second season from control (N0) treatment. However, at the time of first peak, in 100% FYM and 50% urea + 50% FYM treatments, the peak of N_2O-N emission is lower and subsequently remain higher till next peak of N_2O-N occurs. After every dose of N fertilizer application N_2O-N flux increased due to availability of substrate for nitrification. Average daily emission of N_2O-N was more in treatments where nitrogen was applied through urea, while it was lower in the treatments where N was applied though NOCU and urea with nitrification inhibitor (urea + NI).

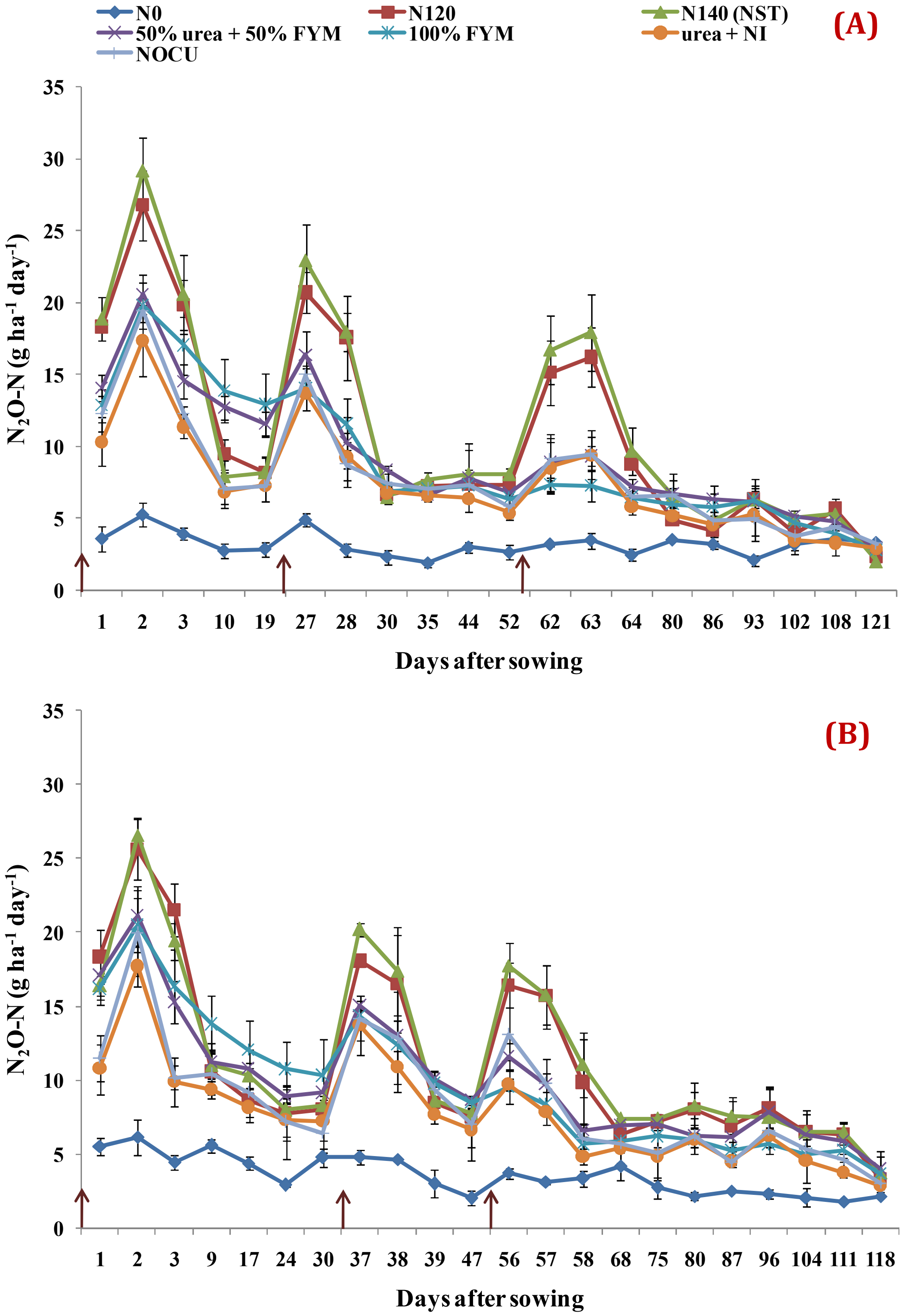


Figure 4.3 Temporal variation in N_2O-N emission flux from wheat crop under different treatments: (A) Season-I and (B) season-II. Arrow indicates date of fertilizers application

The cumulative emission of N_2O-N from wheat crop field is significantly affected by different treatments and it varied from 0.36 to 1.04 and 0.36 to 1.03 kg ha^{-1} in first and second season, respectively among different treatments (Table 4.3). The highest N_2O-N emission was from the N140 (NST) treatment while the lowest emission was from N0 treatment. The N_2O-N emission was significantly higher by 6.1 and 5.1% in first and second season, respectively under N140 (NST) treatment as compared to N120 treatment. All the other treatment showed the reduction in N_2O-N emission compared to N120 treatment (Table 4.3). Application of NOCU and nitrification inhibitor (urea + NI) caused significant reduction in emission. Average reduction in N_2O-N emission due to NOCU application was 17.3 and 19.4 % in first and second season, respectively. Reduction due to application of nitrification inhibitor was 23.5 and 25.5% in first and second seasons respectively. 50 and 100% substitution of urea by FYM also showed the reduction of N_2O-N emission compared to N120 treatment. The 100% FYM treatment showed 5.1 and 6.1% reduction and 50% urea + 50% FYM treatment showed 2.0 and 4.1% reduction in first and second season, respectively. However, these emission reductions are not significant. Cumulative N_2O-N emission under different wheat treatments was in order of N0 < Urea + NI < NOCU < 100% FYM < 50% urea + 50% FYM < N120 < N140 (NST) and both first and second season (Table 4.3).

Nitrous oxide emission from maize crop

The temporal N_2O emissions varied widely throughout the maize crop growing seasons (Fig 4.4 A & B). Flux of N_2O–N ranged from 1.23 to 29.07 g ha^{-1} day^{-1} in first season while, in second season it varied from 1.61 to 27.71 g ha^{-1} day^{-1} among different treatments. First peak flux of N_2O–N emission on 2nd day after sowing (DAS) varied from 5.78 to 29.05 g ha^{-1} day^{-1} in first season and 5.51 to 27.71 g ha^{-1} day^{-1} in second season among different treatments. Subsequently, there was lowering of the emission. Highest peak of N_2O–N emission was 29.07 gha^{-1} day^{-1} in first season and 27.71 g ha^{-1} day^{-1} in second season was from N140 (NST) treatment while, the lowest flux 1.23 g ha^{-1} day^{-1} and 1.61 g ha^{-1} day^{-1} was observed in control (N0) treatment in first and second season, respectively. However, at the time of first peak, in 100% FYM and 50% urea + 50% FYM treatments, the peak of N_2O-N emission is lower and subsequently remain higher till next peak of N_2O-N occurs.

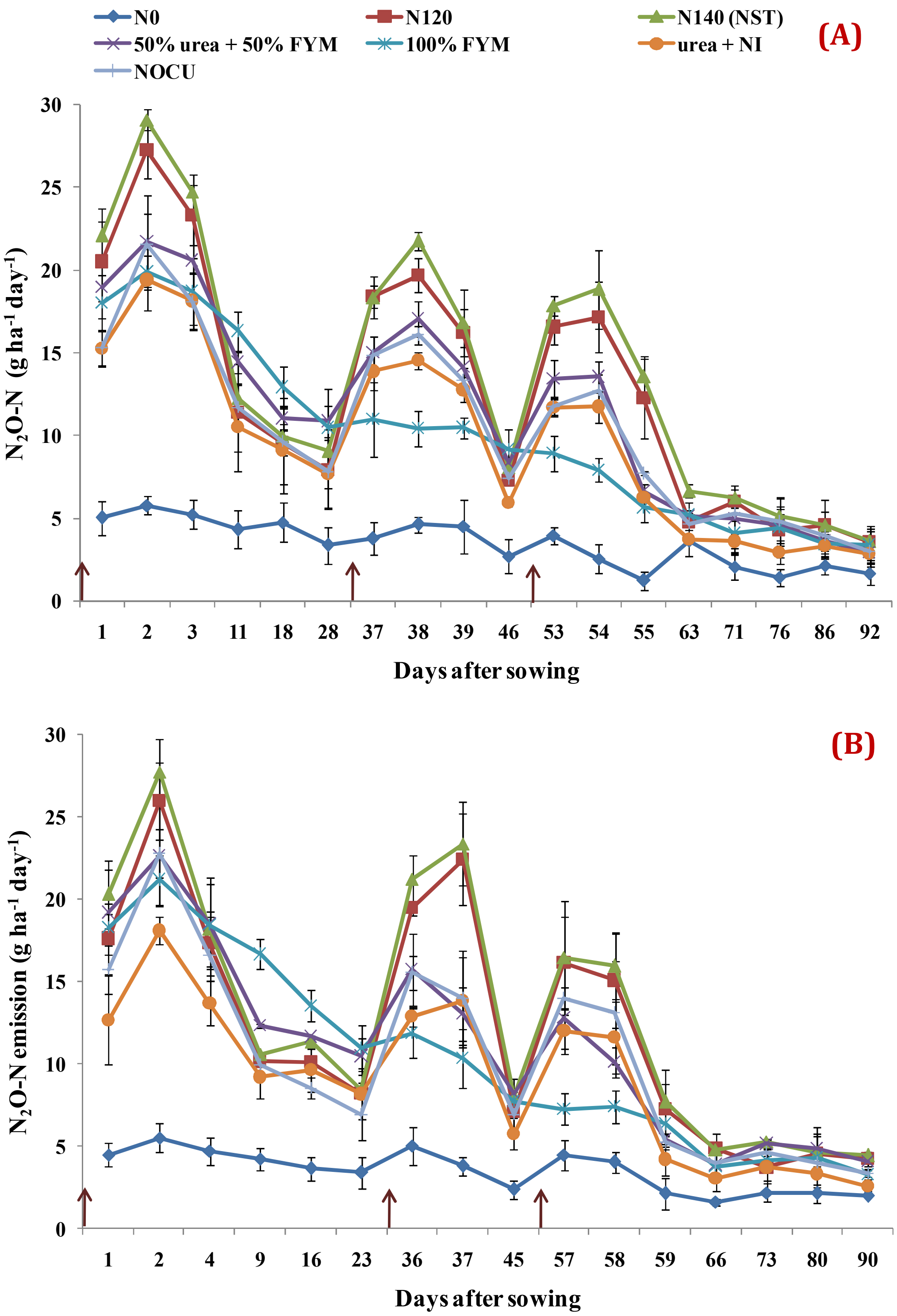


Figure 4.4 Temporal variation in N_2O-N emission flux from maize crop under different treatments: (A) Season-I and (B) season-II. Arrow indicates date of fertilizers application

Average daily emission of N_2O-N was more in treatments where nitrogen was applied through urea, while it was lower in the treatments where N was applied though NOCU and urea with nitrification inhibitor (urea + NI). After every dose of N fertilizer application N_2O-N flux increased due to availability of substrate for nitrification.

The cumulative emission of N_2O-N from maize crop field was significantly affected by different treatments. The cumulative emission of N_2O-N varied from 0.28 to 0.93 and 0.29 to 0.97 kg ha^{-1} in first and second season respectively among different treatments (Table 4.3). The highest N_2O-N emission 0.93 and 0.97 kg ha^{-1} in first and second season, respectively were from the N140 (NST) treatment while, the lowest emission in 0.28 and 0.29 kg ha^{-1} were from control (N0) treatment. The N_2O-N emission in N140 (NST) was 6.9 and 6.6% higher in first and second season, respectively as compared to N120 treatment; however these emissions were not significantly higher. Under all the other treatment N_2O-N emissions were low as compared to N120 treatment (Table 4.3). Application of NOCU and nitrification inhibitor (urea + NI) caused significant reduction in emission. Average reduction in N_2O-N emission due to NOCU application was 10.3 and 15.4 % in first and second season, respectively while reduction due to application of nitrification inhibitor was 19.5 and 23.1% in first and second season, respectively as compared to N120. In 50% urea + 50% FYM treatment N_2O-N emission was at par with N120 treatment in first season while, in second season it was lowered by 4% as compared to N120 treatment. In 100% FYM treatment N_2O-N emission was lower by 6.9% in first season but not significantly affected while, in second season it was significantly lowered by 9.9% as compared to N120 treatment. Cumulative N_2O-N emission under different treatments was in order of N0 < Urea + NI < NOCU < 100% FYM < N120 and 50% urea + 50% FYM < 140 (NST) in first season however, differed in second season and was in order of N0 < Urea + NI < NOCU < 100% FYM < 50% urea + 50% FYM < N120 < 140 (NST).

4.4.2 Carbon dioxide emission

In both wheat and maize crops there were more or less similar temporal trend of CO_2-C flux under all the treatments in both the crop seasons (Fig 4.5 & 4.6). While there were differences in the magnitude of emission. CO_2-C flux were lower during initial 20-25 days after sowing (DAS) then it increased and reached maximum value between 30-80 DAS in wheat (Fig. 4.5) and 30-65 DAS in maize (Fig. 4.6) and then decreased again. However, in the 50% FYM + 50% urea and 100% FYM treatments fluxes were generally higher during the initial growth of the crops (Fig 4.5 & 4.6).

Carbon dioxide emission from wheat crop

In wheat crop the temporal fluxes of CO_2-C were affected significantly. In first season the CO_2-C fluxes were gradually increased after sowing of crop then reached at peak on 62 DAS and decreased again after that (Fig 4.5A). While, in second season CO_2-C fluxes were low during initial 25-30 DAS then it increased and reached at maximum value on 56 DAS and thereafter again decreased (Fig 4.5 B). The CO_2-C fluxes varied greatly and it ranged from 2.27 to 11.50 kg ha^{-1} day^{-1} in first season (Fig. 4.5 A) and 2.76 to 15.35 kg ha^{-1} day^{-1} in second season (Fig. 4.5 B) among different treatment. In first season the highest value of CO_2-C flux was 11.50 kg ha^{-1}day^{-1} and it was observed in N120 treatment, while during second season it was 15.35 kg ha^{-1} day^{-1} and observed in 50% urea + 50% FYM treatment. The lowest values of CO_2-C fluxes were 2.27 and 2.76 kg ha^{-1} day^{-1} in first and second season, respectively and it was observed in control (N0) treatment. In both the season CO_2-C fluxes were higher in 100% FYM and 50% urea + 50% FYM treatments during initial 40-45 DAS compare to other treatments.

The cumulative emission of CO_2-C from wheat crop field is significantly affected by different treatments. The cumulative emission of CO_2-C varied from 446 to 909 kg ha^{-1} in both the season of wheat crop among different treatments (Table 4.3). The highest CO_2-C emission was from the 50% urea + 50% FYM treatment and it was at par with 100% FYM treatment while, the lowest emission was from N0 treatment (Table 4.3). In N140 (NST) treatment the CO_2-C emission was higher by 1.4 and 2.3% in first and second season, respectively as compared to N120 treatment but these differences are not significant. The 50 and 100% substitution of urea by FYM (50% FYM + 50% urea and 100% FYM) showed the significantly higher emission of CO_2-C compared to N120 treatment (Table 4.3). The 100% FYM treatment showed 5.3 & 11.2% higher CO_2-C emission and 50% urea + 50% FYM treatment showed 6.3 & 11.5% higher CO_2-C emission in first and second season, respectively. NOCU and urea + NI treatment showed the significant reduction in CO_2-C emission compared to N120 treatment (Table 4.3). Average reduction in CO_2-

C emission due to NOCU application was 9.6 and 8.6% in first and second season, respectively. Reduction due to application of nitrification inhibitor was 11.5 and 10.9% in first and second season, respectively. Cumulative CO_2-C emission under different wheat treatments was in order of N0 < Urea + NI < NOCU < N120 < 140 (NST) < 100% FYM < 50% urea + 50% FYM and both first and second season (Table 4.3).

Carbon dioxide emission from maize crop

In maize crop in both the season CO_2-C fluxes were gradually increased after sowing of crop then reached at peak on 46 DAS in first season (Fig. 4.6 A) and on 37 DAS in second season (Fig. 4.6 B) then decreased again till the harvest of crops (Fig 4.6 A & B). The CO_2-C fluxes varied widely and it ranged from 2.65 to 16.19 kg ha^{-1} day^{-1} in first season (Fig. 4.6 A) and 2.97 to 15.85 kg ha^{-1} day^{-1} in second season (Fig. 4.6 B) among different treatment. The highest values of CO_2-C fluxes 16.19 and 15.85 kg ha^{-1} day^{-1} in first and second season, respectively were observed in 100% FYM treatment while, the lowest values of CO_2-C fluxes 2.65 and 2.97 kg ha^{-1} day^{-1} in first and second season, respectively was observed in control (N0) treatment. Under 100% FYM and 50% urea + 50% FYM treatments in both the season CO_2-C fluxes were higher during initial 40-45 DAS compare to other treatments (Fig. 4.6 A & B).

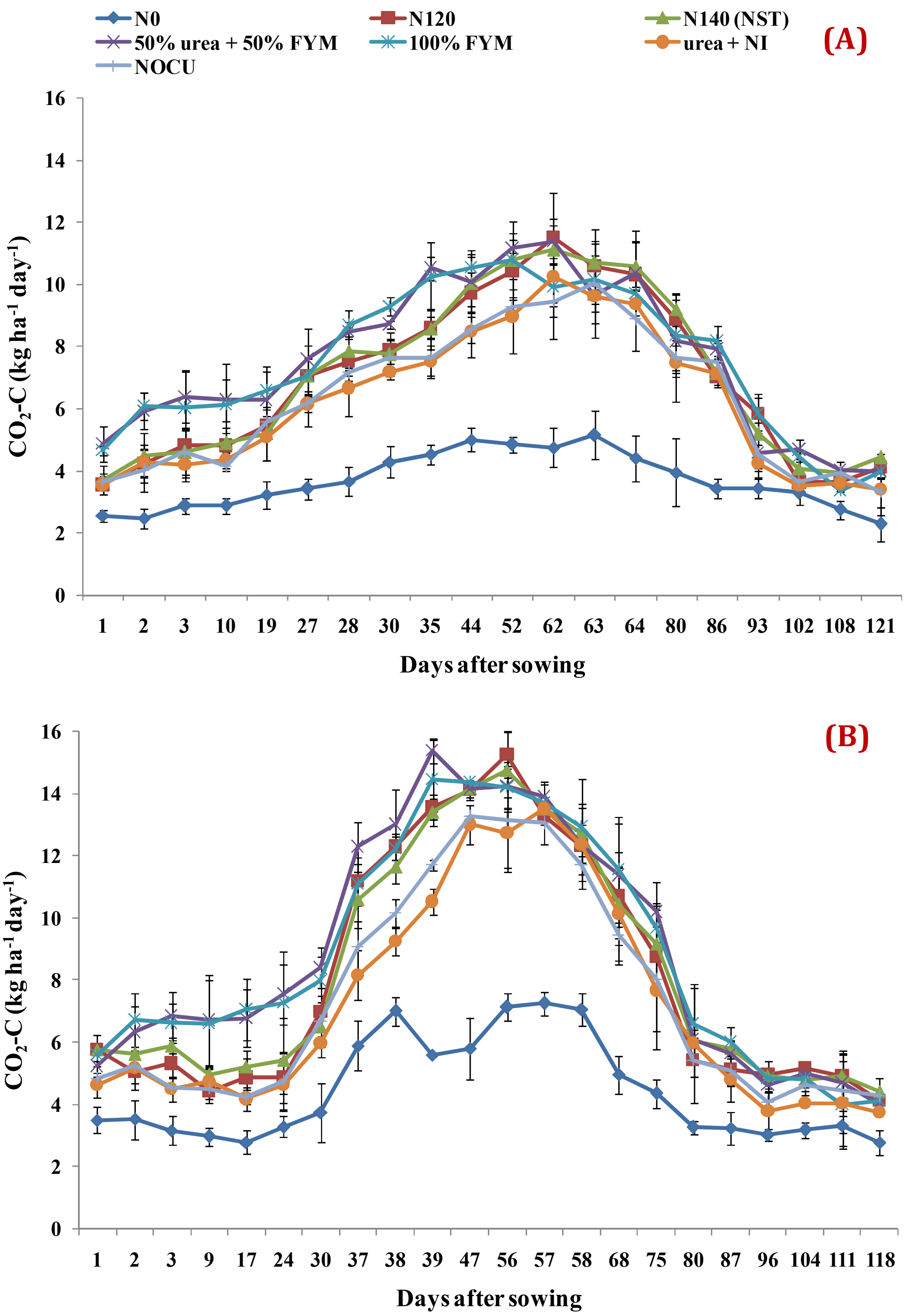


Figure 4.5 Temporal variation in CO_2-C emission flux from wheat crop under different treatments: (A) Season-I and (B) season-II.

The cumulative emission of CO_2-C from maize crop field affected significantly among different treatments (Table 4.3). The cumulative emission of CO_2-C varied from 310 to 711 kg ha^{-1} in first season and 336 to 729 kg ha^{-1} in second season among different treatments (Table 4.3). The highest CO_2-C emission was from the 100% FYM treatment while, the lowest emission was from control (N0) treatment in both the season (Table 4.3). In N140 (NST) treatment the CO_2-C emission was higher by 2.8 and 4.7% in first and second season, respectively as compared to N120 treatment but these differences are not significant. The 50 and 100% substitution of urea by FYM showed the significantly higher emission of CO_2-C compared to N120 treatment. The 50% urea + 50% FYM treatment showed 15.5 and 16.5% higher emission and 100% FYM treatment showed 18.7 and 19.1% higher emission in first and second season, respectively. NOCU and urea + NI treatment showed the reduction in CO_2-C emission compared to N120 treatment but these reductions are significant in second season only (Table 4.3). Average reduction in CO_2-C emission due to NOCU was 7.5 and 8.5% in first and second season, respectively.

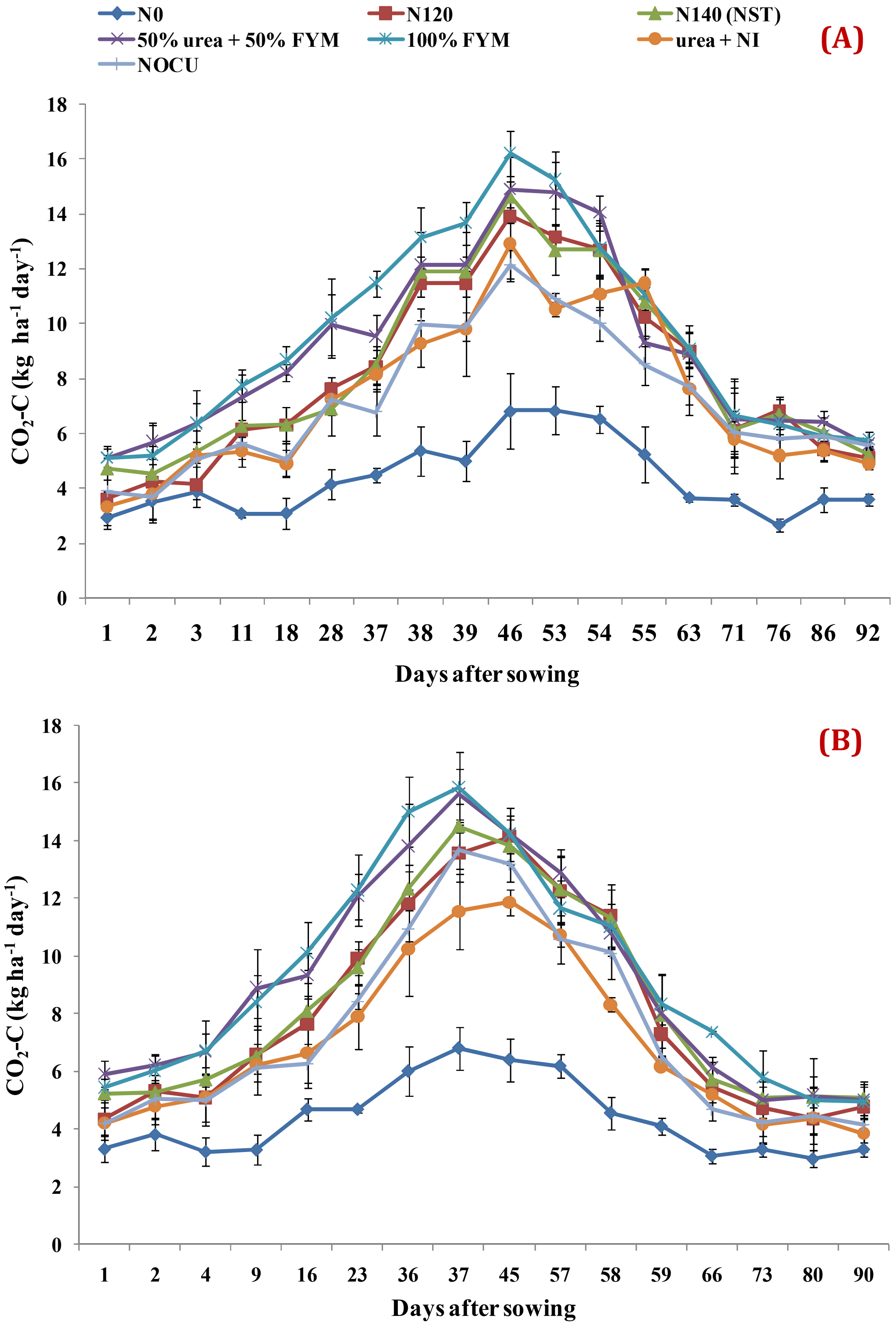


Figure 4.6 Temporal variation in CO_2-C emission flux from maize crop under different treatments: (A) Season-I and (B) season-II

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Table 4.3 Cumulative greenhouse gas (GHG) emission (kg ha^{-1}) in different treatments from wheat and maize crops

Treatments	**Wheat**				**Maize**			
	N_2O-N		**CO_2-C**		**N_2O-N**		**CO_2-C**	
	I season	II season	I season	II season	I season	II season	I season	II season
N0	0.36	0.36	446	446	0.28	0.29	310	336
N120	0.98	0.98	855	815	0.87	0.91	599	612
N140 (NST)	1.04	1.03	867	834	0.93	0.97	616	641
50% urea + 50% FYM	0.96	0.94	909	909	0.87	0.87	692	713
100% FYM	0.93	0.92	900	906	0.81	0.82	711	729
Urea + NI	0.75	0.73	757	726	0.70	0.70	550	530
NOCU	0.81	0.79	773	745	0.78	0.77	554	560
CD p=0.05	0.05	0.05	42	30	0.07	0.06	35	41
SE(d)	0.02	0.02	19	14	0.03	0.03	16	19

4.5 Global warming potential

After measuring cumulative GHG emission from both wheat and maize crops field under different treatments we quantify global warming potential (GWP) of each wheat and maize treatments to better understanding of complete impact of different treatments on global warming. All though agricultural soils emit all three GHG namely nitrous oxide, carbon dioxide and methane but agriculture soils are not considered as net source of CO_2 emission. Agricultural soils also act as a sink of CO_2 because CO_2 is fixed during photosynthesis in plant biomass (IPCC, 2007). Keeping this in mind we estimated GWP of wheat, maize and wheat-maize system in two ways. GWP1, which included emission of both N_2O + CO_2 where as GWP2 included only N_2O emission. Since, we did not measure CH_4 flux in both the crops hence, CH_4 had not included in GWP1 and GWP2.

4.5.1 Global warming potential of different treatments in wheat crop

In wheat crop both, GWP1 and GWP2 (N_2O) was significantly differed. GWP2 (N_2O) ranged from 177 to 506 and 177 to 501 kg CO_2 eq. ha^{-1} in first and second season, respectively (Table 4.4). Lowest value of GWP2 was observed in control (N0) treatment while highest value was observed in N140 (NST) treatment in both the season. GWP2 was observed 6.3 & 4.6% higher under N140 (NST) treatment compared to N120, although the differences were not significant. In all other treatment GWP2 was lower than the N120 treatment which means all these treatment showed reduction in GWP2. In case where 50 and 100% urea was substituted by FYM showed non-significant reduction in GWP2. 50% urea + 50% FYM treatment showed 1.1 and 4.0% while, 100% FYM treatment showed 4.2 and 6.1% reduction in GWP2 in first and second season, respectively over N120 treatment. There was significant reduction in GWP2 in urea + NI and NOCU treatment. GWP2 was 16.6 and 19.8% lower in NOCU treatment while, in urea + NI treatment it was 23.5 and 25.7% lower in first and second season, respectively as compared to N120 treatment.

Table 4.4 Global warming potential (kg CO_2 e) of different treatments in wheat and maize crops

Treatments	**Wheat**			**Maize**			**Wheat-maize systems**	
	N_2O	**CO_2**	**GWP1***	**N_2O**	**CO_2**	**GWP1***	**GWP1***	**GWP2****
I season								
N0	177	1634	1811	138	1137	1275	3086	315
N120	476	3136	3612	425	2197	2623	6234	901
N140 (NST)	506	3178	3684	452	2259	2711	6396	958
50% urea + 50% FYM	471	3332	3802	422	2539	2961	6763	893
100% FYM	456	3301	3756	395	2607	3002	6758	851
Urea + NI	364	2777	3141	343	2017	2360	5501	707
NOCU	397	2833	3230	379	2031	2410	5639	776
CD p=0.05	23	154	163	33	129	126	208	38
SE(d)	10	70	74	15	59	57	94	17
II season								
N0	177	1635	1812	140	1233	1372	3184	317
N120	479	2987	3467	443	2244	2688	6154	922
N140 (NST)	501	3058	3558	474	2349	2823	6381	975
50% urea + 50% FYM	460	3334	3793	424	2615	3039	6833	884
100% FYM	450	3324	3774	397	2673	3070	6844	847
Urea + NI	356	2663	3019	340	1942	2282	5301	696
NOCU	384	2733	3118	377	2055	2433	5550	762
CD p=0.05	25	112	120	28	150	167	176	38
SE(d)	11	51	55	13	68	76	80	17

Note = * GWP1= GWP (CO_2+ N_2O); **GWP2 = GWP (N_2O)

GWP1 of different treatments ranged from 1811 to 3802 and 1812 to 3793 CO_2 eq. ha^{-1} in first and second season respectively (Table 4.4). Likewise GWP2 the lowest value of GWP1 was also observed in control (N0) treatment. However, highest values was observed in 50% urea + 50% FYM followed by 100% FYM instead of N120 like GWP2. There was significant higher GWP1 was observed in 50% urea + 50% FYM and 100% FYM treatment. The GWP1 was 4.0 and 8.9% higher in 100% FYM treatment while, it was 5.3 and 9.4% higher in 50% urea + 50% FYM treatment in first and second season, respectively as compared N120 treatment. In N140 (NST) treatment 2.0 and 2.6% non-significant higher GWP1 was observed in first and second season respectively compared to N120 treatment. NOCU and urea + NI treatment showed significantly lower GWP1. GWP1 was lowered by 10.6 and 10.1% in NOCU treatment while, in urea + NI treatment it was lowered by 13.0 and 12.9% in first and second season respectively compared to N120 treatment.

The percentage share of CO_2 in total GWP was much higher as compared to N_2O and on an average ranged from 86% in N140 (NST) to 90% in control (N0). While percentage share of N_2O ranged from 10% in control (N0) to 14% in N140 (NST) treatment (Fig. 4.7A).

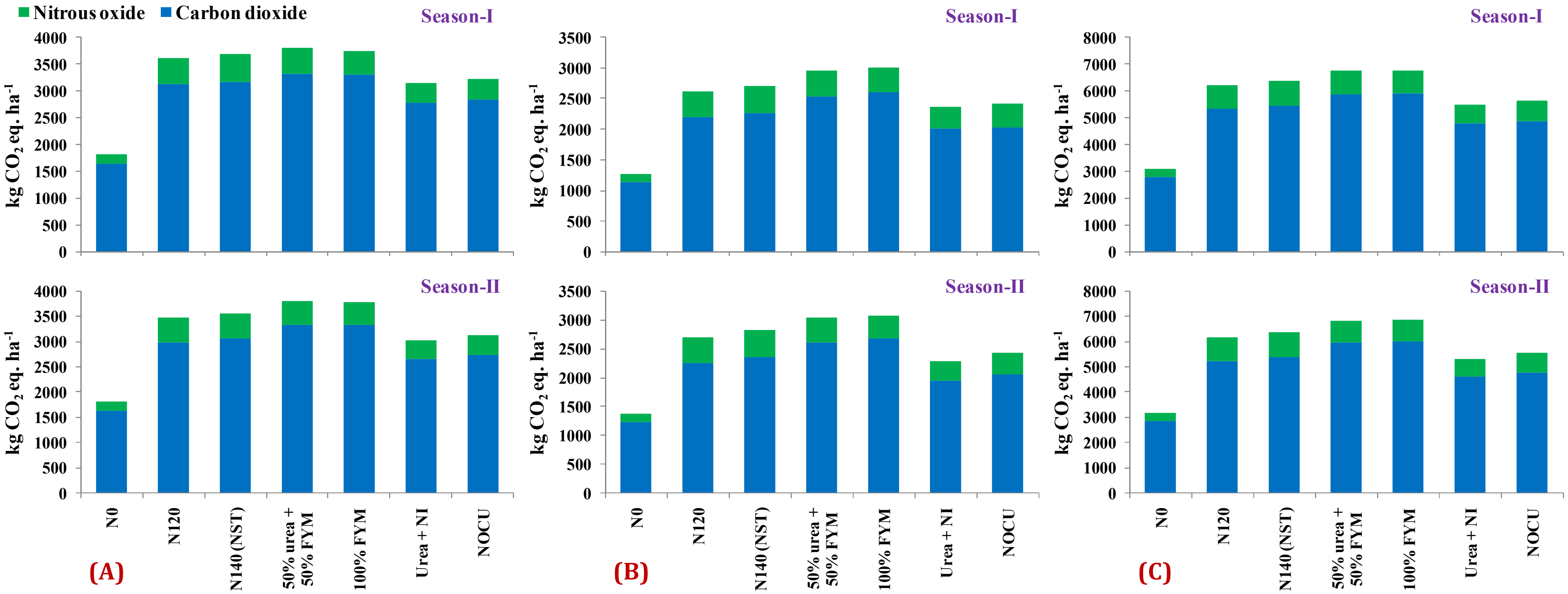

Fig. 4.7 Global warming potential (GWP1) of different treatments: (A) Wheat, (B) Maize and (C) Wheat-maize system

GWP1 of different treatments ranged from 1275 to 3002 and 1372 to 3070 CO_2 eq. ha^{-1} in first and second season, respectively (Table 4.4). The lowest value of GWP1 was observed in control (N0) treatment while, highest values was observed in 100% FYM followed by 50% urea + 50% FYM and N140 (NST) (Table 4.4). There was 3.4 and 5.0% non-significant higher GWP1 was observed in N120 treatment in first and second season, respectively over N120. Significant higher GWP1 was observed in 50% urea + 50% FYM and 100% FYM treatments (Table 4.4). The GWP1 was 12.9 and 13.1% higher in 50% urea + 50% FYM treatment, while it was 14.4 and 14.2% higher in 100% FYM treatment in first and second season, respectively as compared N120 treatment. NOCU and urea + NI treatment showed significant reduction in GWP1 (Table 4.4). There was 8.1 and 9.5% reduction in GWP1 in NOCU treatment while, in urea + NI treatment reduction was 10.0 and 15.1% in first and second season, respectively compared to N120 treatment. The percentage share of CO_2 in total GWP was much higher as compared to N_2O and on an average ranged from 83 to 89% in first season and 83 to 90% in second season (Fig. 4.7 B).

4.5.3 Global warming potential of different treatments in wheat-maize system

In wheat-maize system both, GWP1 and GWP2 (N_2O) were significantly differed (Table 4.4). GWP2 (N_2O) ranged from 315 to 958 CO_2 eq. ha^{-1} and 317 to 978 CO_2 eq. ha^{-1} in first and second season, respectively (Table 4.4). The highest values were observed in N140 (NST) treatment while the lowest values were observed in control (N0) treatment (Table 4.4). In N140 (NST) treatment GWP2 was significantly higher by 6.3 and 5.7% in first and second season, respectively compared to N120 treatment. Except 50% urea + 50% FYM all other treatments showed significant reduction in GWP2 compared to N120 treatment (Table 4.4). 100% FYM, NOCU and urea + NI treatment showed reduction by 5.5 and 8.1%, 13.9 and 17.4%, 21.5 and 24.5% in first and second season, respectively over N120 treatment. The percentage share of wheat crop in total GWP2 was higher as compared maize crop and on an average ranged from 51.2% in NOCU to 56.2% in control (N0) treatment in first year while, during second year it ranged from 50.5% in NOCU to 55.9 in control (N0) treatment (Fig. 4.8 B).

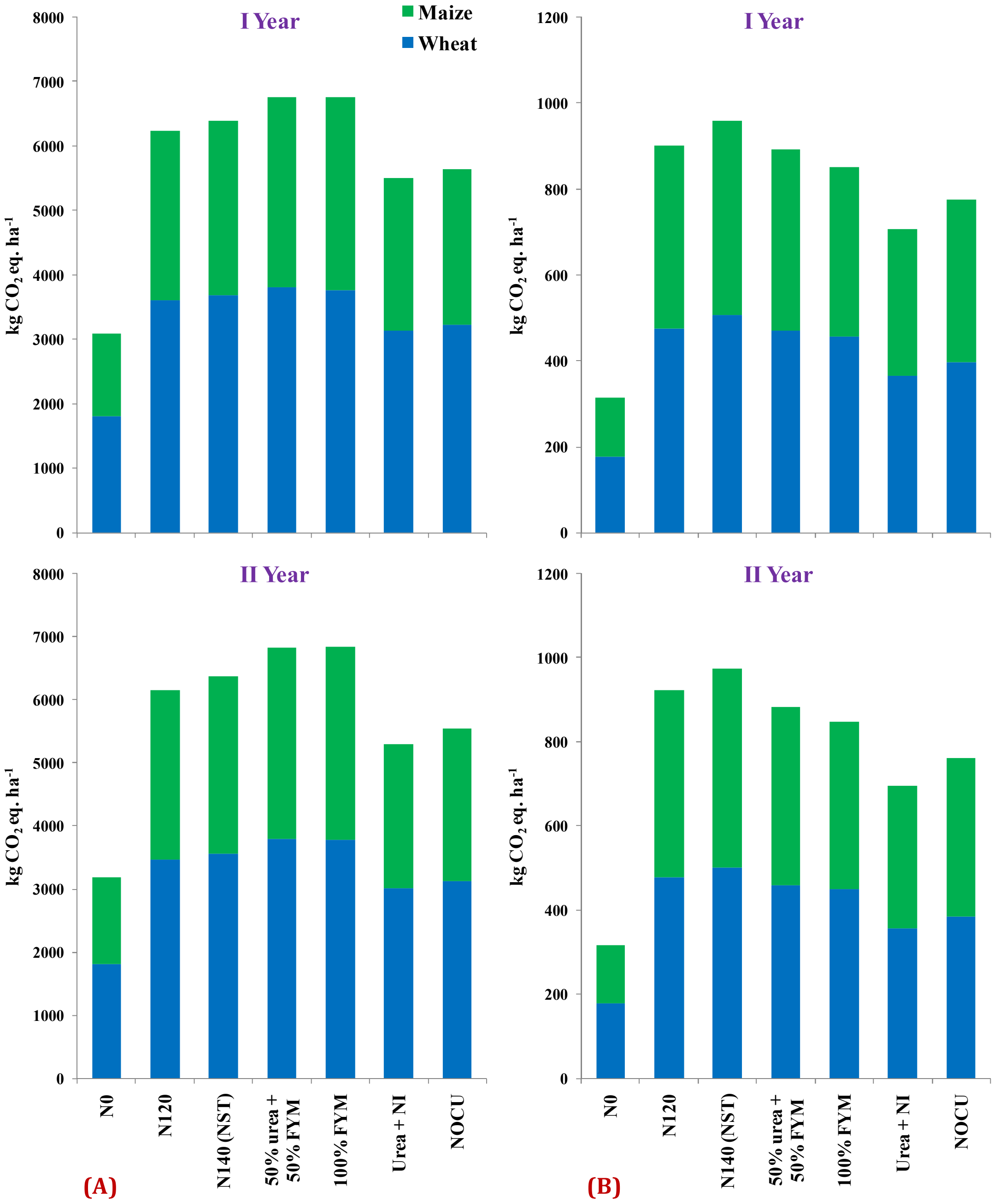

Figure 4.8 Global warming potential of different treatment and contribution of wheat and maize crop: (A) GWP1 (CO_2+N_2O) and (B) GWP2 (N_2O)

GWP1 of different treatments ranged from 3086 to 6763 and 3184 to 6844 CO_2 eq. ha^{-1} in first and second season, respectively (Table 4.4). The lowest value of GWP1 was also observed in control (N0) treatment while, highest values was observed in 50% urea + 50% FYM in first season and in 100% FYM in second season (Table 4.4). N140, 50% urea + 50% FYM and 100% FYM treatments showed higher GWP2 compared to N120 treatment (Table 4.4) however, in N140 treatment differences were not significant. N140, 50% urea + 50% FYM and 100% FYM treatments showed 2.6 and 3.71%, 8.4 and 11.2%, 8.5 and 11.0% higher GWP1 in first and second season, respectively over N120 treatment. NOCU and urea + NI treatments showed significant reduction in GWP2 as compared to N120 treatment (Table 4.4). The reduction was 9.5 and 9.8% in NOCU treatment while it was 11.8 and 13.9% in urea + NI treatment in first and second season, respectively. The percentage share of CO_2 in total GWP was much higher as compared to N_2O and on an average ranged from 85% in N140 (NST) to 90% in control (N0) treatment in both the season (Fig. 4.7 C). The percentage share of wheat crop in total GWP1 was also higher as compared to maize crop and it ranged from 55.6% in 100% FYM to 58.7% in control (N0) treatment in first year while, during second year it ranged from 55.5% in 100% FYM to 56.9 in urea + NI treatment (Fig. 4.8 A). Contribution of wheat crop to both GWP1 and GWP2 was higher than the maize crop which, might be due to longer duration of wheat crop.

If we consider only N_2O emission then the GWP1 of different treatment was in the order of N0 < Urea + NI < NOCU < 100% FYM <50% urea + 50% FYM < N120 < 140 (NST) in both the season (Table 4.3). However, the order of GWP2 was differed when we consider CO_2 emission too. GWP2 of different treatment was in the order of N0 < Urea + NI < NOCU < N120 < 140 (NST) < 100% FYM <50% urea + 50% FYM in both the season (Table 4.4). It means 50 and 100% substitution of urea by FYM reduced emission of N_2O compared to N120 treatment while, it enhanced emission of CO_2 compared to N120. When we considered contribution of CO_2 in GWP, the N_2O reduction due to substitution of 50 and 100% urea by FYM was counter acted by higher CO_2 emission.

4.6 Green house gas intensity

We calculated the green house gas intensity (GHGi) from different treatments in wheat and maize crops and in wheat-maize system. GHGi is defined as GWP per unit of economic yield (grain yield) of crop. GHGi is calculated by dividing total GWP (N_2O + CO_2) from grain yield. Lower the GHGi means lower GWP per unit grain production.

4.6.1 Green house gas intensity of different treatment in wheat crop

In wheat crop GHGi varied widely and it ranged from 0.92 to 1.51 in first season while, in second season it ranged from 0.95 to 1.43 (Table 4.5). In both the season the lowest GHGi was observed in urea + NI treatment and it was 0.92 and 0.95 in first and second season, respectively (Table 4.5). In NOCU treatment GHGi was at par with urea + NI treatment. In N120 and N140 (NST) treatment GHGi was at par and it was 1.09 and 1.10 in N120 and 1.06 and 1.09 in N140 (NST) treatment in first and second season, respectively (Table 4.5). In case of 50% urea + 50% FYM and 100% FYM treatments the GHGi was higher than the N120 treatment. In 50% urea + 50% FYM GHGi was 1.15 and 1.20 while, in 100% FYM treatment it was 1.51 and 1.43 in first and second season, respectively (Table 4.5). The highest values of GHGi were observed in 100% FYM treatment in both the season. It might be due to largest CO_2 emission and smaller amount of carbon fixed (grain yield). In wheat crop GHGi of different treatment were much higher than the maize crop, which is due to longer duration of wheat crop compared to maize crop.

4.6.2 Green house gas intensity of different treatment in maize crop

In Maize crop GHGi ranged from 0.60 to 0.86 and 0.61 to 0.93 in first and second season, respectively (Table 4.5). In both the season the lowest GHGi was observed in urea + NI treatment while, highest GHGi was observed in 100% FYM treatment. In N120 and N140 (NST) GHGi was at par and it was 0.69 and 0.72 in N120 treatment and 0.68 and 0.73 in N140 (NST) in first and second season, respectively (Table 4.5). In treatment urea + NI and NOCU GHGi was lower than the N120 treatment and it was 0.60 and 61 in urea + NI treatment and 0.61 and 0.66 in NOCU treatment in first and second season, respectively (Table 4.5). In case of 50% urea + 50% FYM and 100% FYM treatments the GHGi were higher than the N120 treatment and it was 0.77 and 0.81 in 50% urea + 50% FYM treatment while in 100% FYM treatment it was 0.86 and 0.93 in first and second season, respectively (Table 4.5). In GHGi maize crop of different treatment were much lower than the wheat crop, which is due to shorter duration of maize crop compare to wheat crop.

4.6.3 Green house gas intensity of different treatment in wheat-maize system

We also calculated the GHGi of wheat-maize system. In wheat-maize system GHGi ranged from 0.74 (urea + NI) to 1.57 (100% FYM) in first year while, during second year GHGi ranged from 0.76 (urea + NI) to 1.59 (100% FYM) (Table 4.5). In N120 and N140 (NST) GHGi were equal in both the season and it was 0.86 and 0.90 in first and second year, respectively (Table 4.5). In case where 50% urea was substituted by FYM (50% urea + 50% FYM) was higher than N120 treatment and it was 1.08 and 1.11 in first and second year, respectively. However, in case where 100% urea was substitute by FYM (100% FYM) GHGi is much higher as compared to N120 treatment and it was 1.57 and 1.59 in first and second year respectively (Table 4.5). It means that substitution of urea by FYM is responsible for increased in GHGi which might be due to higher emission of CO_2 and lower grain yield compare to N120 treatment. In case of NOCU and NI application with urea (urea + NI) GHGi was lower than the N120 treatment. In these treatments GHGi was lower due to lower emission of N_2O and higher grain yield compare to N120. In urea + NI treatment GHGi was 0.74 and 0.76 in first and second year, respectively, while in NOCU treatment GHGi was 0.76 and 0.80 in first and second year respectively (Table 4.5). GHGi of different treatment was in the order of Urea + NI < NOCU < N120 = 140 (NST) < N0 <50% urea + 50% FYM < 100% FYM in both the season (Table 4.5).

Table 4.5 Green house gas intensity (kg CO_2 e kg^{-1}) in different treatments from wheat and maize crops

Treatment	**Wheat**		**Maize**		**Wheat-maize system**	
	I season	II season	I season	II season	I season	II season
N0	1.04	1.21	0.80	0.92	0.92	1.06
N120	1.09	1.10	0.69	0.72	0.86	0.90
N140 (NST)	1.06	1.09	0.68	0.73	0.86	0.90
50% urea + 50% FYM	1.15	1.20	0.77	0.81	1.08	1.11
100% FYM	1.51	1.43	0.86	0.93	1.57	1.59
Urea + NI	0.92	0.95	0.60	0.61	0.74	0.76
NOCU	0.93	0.96	0.61	0.66	0.76	0.80
CD p=0.05	0.27	0.12	0.08	0.05	0.16	0.18
SE(d)	0.12	0.06	0.03	12.22	0.07	0.08

4.7 Economic analysis of experimented wheat-maize systems

All the treatments of nitrogen dose and sources in wheat, maize and wheat-maize systems showed great variability in GWP2 (N_2O). Although, GWP2 was lower in urea + NI, NOCU, 100% FYM and 50% urea + 50% FYM treatments as compared to N120 treatment. Urea + NI treatment followed by NOCU showed great potential of reducing GWP2. These system may or may not be economical viable, to assess this we done economic analysis of all these treatments in wheat, maize and wheat-maize system to identified different cost factors responsible for affecting income. The results obtained are described beneath.

In wheat crop 1000 grain weight in first season and harvest index in second season affected significantly. Significant difference showed in control (N0) treatment only while, all other treatment showed non-significant difference in 1000 grain weight and harvest index as compared to N120 treatment (Table 4.6). Similarly in maize crop 100 grain weight and shelling percentage in both the season and harvest index in second season were not affected significantly. Harvest index in first season affected significantly (Table 4.6) however, significant difference showed by control (N0) treatment as compared to N120 treatment while, in other treatment differences were non-significant (Table 4.6).

Table 4.6 Thousand/hundred grain weight, shelling percentage and harvest index in wheat and maize crops

Treatments	**Wheat**					
	1000 grain Weight (g)		**Harvest index**			
	I season	II season	I season	II season		
N0	36.8	37.47	0.34	0.3		
N120	40.53	40.3	0.41	0.41		
N140(NST)	40.63	39.97	0.42	0.42		
50%urea+50%FYM	40.47	39.8	0.41	0.43		
100%FYM	39	38.67	0.4	0.4		
Urea+NI	40.27	39.93	0.42	0.41		
NOCU	40.37	40.37	0.42	0.42		
CD p=0.05	1.93	N/A	N/A	0.04		
SE(d)	0.88	1.13	0.03	0.02		
	Maize					
	100 grain Weight (g)		**Shelling Percentage (%)**		**Harvest index**	
	I season	II season	I season	II season	I season	II season
N0	16.93	16.93	68.44	72.17	28.99	30.04
N120	19.67	19.67	77.3	79.91	39.88	37.86
N140(NST)	19.93	19.93	77.94	78.06	40.16	38.56
50%urea+50%FYM	17.93	17.93	79.07	78.68	38.72	36.33
100%FYM	17.13	17.13	77.39	80.43	38.57	38.86
Urea+NI	19.6	19.6	76.16	79.22	37.9	35.69
NOCU	18.8	18.8	77.11	79.35	36.41	35.28
CD p=0.05	N/A	N/A	N/A	N/A	6.28	N/A
SE(d)	1.42	1.42	3.82	4.65	2.85	3.7

4.7.1 Grain yield

In wheat crop grain yield was affected significantly in both the season. Grain yield ranged from 1784 to 3478 kg ha^{-1} and 1503 to 3247 kg ha^{-1} in first and second season, respectively (Table 4.7). In both the season lowest yield was observed in control (N0) treatment while, highest yield was recorded in N140 treatment. Control (N0), 100% FYM and 50% urea + 50% FYM treatments showed reduction in grain yield over N120 treatment. There was 10.2 and 4.5% insignificant lower yield was recorded in 50% urea + 50% FYM as compared to N120 treatment first and second season, respectively (Table 4.7). In 100% FYM treatment grain yield was significantly lowered by 33.2 and 26.0% in first and second season, respectively over N120 treatment. Urea + NI and NOCU treatment showed slightly higher yield as compared to N120 treatment however, these difference were non-significant (Table 4.7). The 2.2 and 1.4% higher yield was observed in Urea + NI treatment in first and second season, respectively while in NOCU yield was 3.2% higher in both the season as compared to N120 treatment.

In maize crop also grain yield was affected significantly in both the season. Grain yield ranged from 1597 kg ha^{-1} in control (N0) to 3967 kg ha^{-1} in urea + NI treatment in first season, while during second season it ranged from 1514 kg ha^{-1} in control (N0) to 3767 kg ha^{-1} in urea + NI treatment (Table 4.7). In Control (N0), 100% FYM and 50% urea + 50% FYM treatments grain yield was lower as compared to over N120 treatment (Table 4.7). There was 13.6 and 12.0% lower yield recorded in 50% urea + 50% FYM while, in 100% FYM treatment reduction in grain yield was much higher and it reduced by 46.7 and 46.8% as compared to N120 treatment first and second season, respectively (Table 4.7). NOCU and Urea + NI and treatment showed slightly higher yield as compared to N120 treatment (Table 4.7). The yield was increased by 0.80 and 0.21% in NOCU treatment in first and second season, respectively while, in Urea + NI yield was increased by 1.87 and 1.18% in first and second season, respectively as compared to N120 treatment. However, this increase in yield was insignificant (Table 4.7).

Productivity of wheat-maize systems were affected significantly and it ranged from 3381 to 7480 kg ha^{-1} in first year while during second year it ranged from 3016 to 7123 kg ha^{-1} (Table 4.7). In both the season productivity was highest in N140 (NST) and lowest was in control (N0) treatment. In N140 (NST), urea + NI and NOCU treatments productivity was slight higher than the N120 treatment (Table

4.7). Productivity was higher by 3.0 and 3.8% in N140 (NST), 2.04 and 1.27% in urea + NI and 1.91 and 1.56% in NOCU treatment in first and second year respectively. In case where 50 and 100% urea was substituted by FYM, productivity was lower than N120 treatment. However, it lowered significantly in 100% FYM treatment only (Table 4.7). Productivity was lowered by 12.0 and 8.6% in 50% urea + 50% FYM and 40.4 and 37.3% in 100% FYM treatment in first and second year respectively.

Table 4.7 Grain and residue yield (kg ha^{-1}) of different treatments in wheat and maize crops

Treatment	**Wheat**				**Maize**				**Wheat-maize system**			
	Grain		**Residue**		**Grain**		**Residue**		**Grain**		**Residue**	
	I season	II season	I season	II season	I season	II season	I season	II season	I season	II season	I season	II season
N0	1784	1503	5267	4955	1597	1514	6037	6044	3381	3016	11304	10999
N120	3365	3141	8067	7467	3894	3723	11873	11867	7259	6865	19939	19334
N140 (NST)	3487	3267	8267	7791	3993	3856	12577	12469	7480	7123	20844	20260
50%urea+50%FYM	3023	3001	7373	7288	3364	3277	11786	11699	6387	6278	19159	18986
100% FYM	2247	2323	5900	6302	2076	1979	9123	8573	4323	4302	15023	14875
Urea + NI	3440	3184	8247	7554	3967	3767	11889	11840	7407	6952	20135	19394
NOCU	3473	3242	8267	7729	3925	3731	12337	12639	7398	6972	20603	20368
CD p=0.05	893	155	1675	728	274	833	624	1502	825	837	1782	1550
SE(d)	405	70	733	331	124	378	283	682	374	380	809	703

4.7.2 Cost of cultivation

We calculated the cost of cultivation for both wheat and maize crop and it is found that the cost for hiring human labour services were highest followed by tractor operations and fertilizers and FYM (Fig. 4.9). Contribution of human labour services, tractor operations and fertilizer and FYM in total operational cost ranged from 34.06-36.61%, 10.89-20.21% and 12.98-15.87%, respectively in different treatments of wheat crop & 44.32-49.39% 44.5% 11.29-19.13% and 13.33-15.65%, respectively in different treatments of maize crop in first season (Fig. 4.9). In second season it ranged from 34.28-37.13%, 11.01-19.19% and 12.50-15.35% in wheat crop and 43.61-48.20%, 11.21-19.58% and 12.67-14.98% in maize crop.

In wheat crop the total cost of cultivation was significantly lower by 20.9% and 21.6% in first and second season, respectively in N0 (control) treatment as compared to N120 treatment (Table 4.8). In all the other treatments the total cost of cultivation was higher than the N120 treatment; however, it was significantly higher in urea + NI, 50% urea + 50% FYM and 100% FYM treatments in both the seasons (Table 4.8). In urea + NI, 50% urea + 50% FYM and 100% FYM treatments the total cost of cultivation was higher by 5.9%, 9.5% and 15.5% in first season and 3.91%, 7.3% and 12.8% in second, respectively as compared to N120 treatment (Table 4.8).This difference was mainly due to contribution of human labour, tractor operations and fertilizers and FYM applications.

In maize crop also the total cost of cultivation showed similar trend like wheat and it was significantly lowered in N0 (control) treatment by 21.5% and 20.5% in first and second season, respectively as compared to N120 treatment (Table 4.8). All the other treatments showed higher total cost of cultivation as compared N120 treatment but it was significantly higher in urea + NI, 50% urea + 50% FYM and 100% FYM treatments only in both the seasons (Table 4.8). The total cost of cultivation was higher by 6.09%, 13.04% and 20.50% in first season and 5.75%, 12.6% and 19.3% in second season in urea + NI, 50% urea + 50% FYM and 100% FYM treatments, respectively as compared to N120 treatment (Table 4.8).

Among wheat-maize systems, total cost of cultivation was highest in 100% FYM followed by 50% urea + 50% FYM and urea + NI treatments and increased the total cost by about 18.0%, 11.4% and 6.0% in first season and 16.0%, 9.9% and 4.8% in second season, respectively as compared to N120 treatment (Table 4.9). These differences in 100% FYM and 50% urea + 50% FYM treatment are mainly due to human labour and tractor operations during handling of the bulky FYM, while in urea + NI it was mainly due to cost of NI.

4.7.3 Benefit-cost ratio

The B:C ratio was significantly differed in both season of both the crops (Table 4.8). In wheat crop the B:C ratio ranged from 0.95 to 1.49 and from 0.87 to 1.36 in first and second season, respectively while in maize crop it ranged from 0.76 to 1.61 in first season and 0.66 to 1.59 in second season (Table 4.8). In wheat crop the B:C ratio was lower in N0, 50% urea + 50% FYM, 100% FYM and Urea + NI treatments as compared to N120 treatment, however it was higher in NST (N140) and NOCU treatments. Among these different treatments of wheat crop the B:C ratio was highest in NST (N140) followed by NOCU, N120 and urea + NI treatments in first season, while during second season it was highest in NST (N140) and NOCU followed by N120 and urea + NI treatments.

In maize crop the B:C ratio was higher in NST (N140) treatment in first season and NOCU treatment in second season as compared to N120 treatment (Table 4.8). While, in all other treatment it was lower than the N120. In first season B:C ratio was highest in NST (N140) followed by N120. In NOCU treatment it was at par the N120 treatment (Table 4.8). During second season the highest B:C ration was observed in NOCU treatment followed by N120 treatment.

Among wheat-maize systems during first season the B:C ratio was highest in NST (N140) (1.55) followed by1.53 in N120 and NOCU treatment (Table 4.9). In urea + NI treatment it was 1.48. During second season B:C ratio was 0.98 in N120, N140 and urea + NI treatments. The highest B:C ratio was observed in 50% urea + 50% FYM followed by 100% FYM and NOCU treatment (Table 4.9). The B:C ratio of systems ranged from 0.86 in N0 (control) to 1.55 in NST (N140) in first year and 0.86 to 1.11 in second year (Table 4.9).

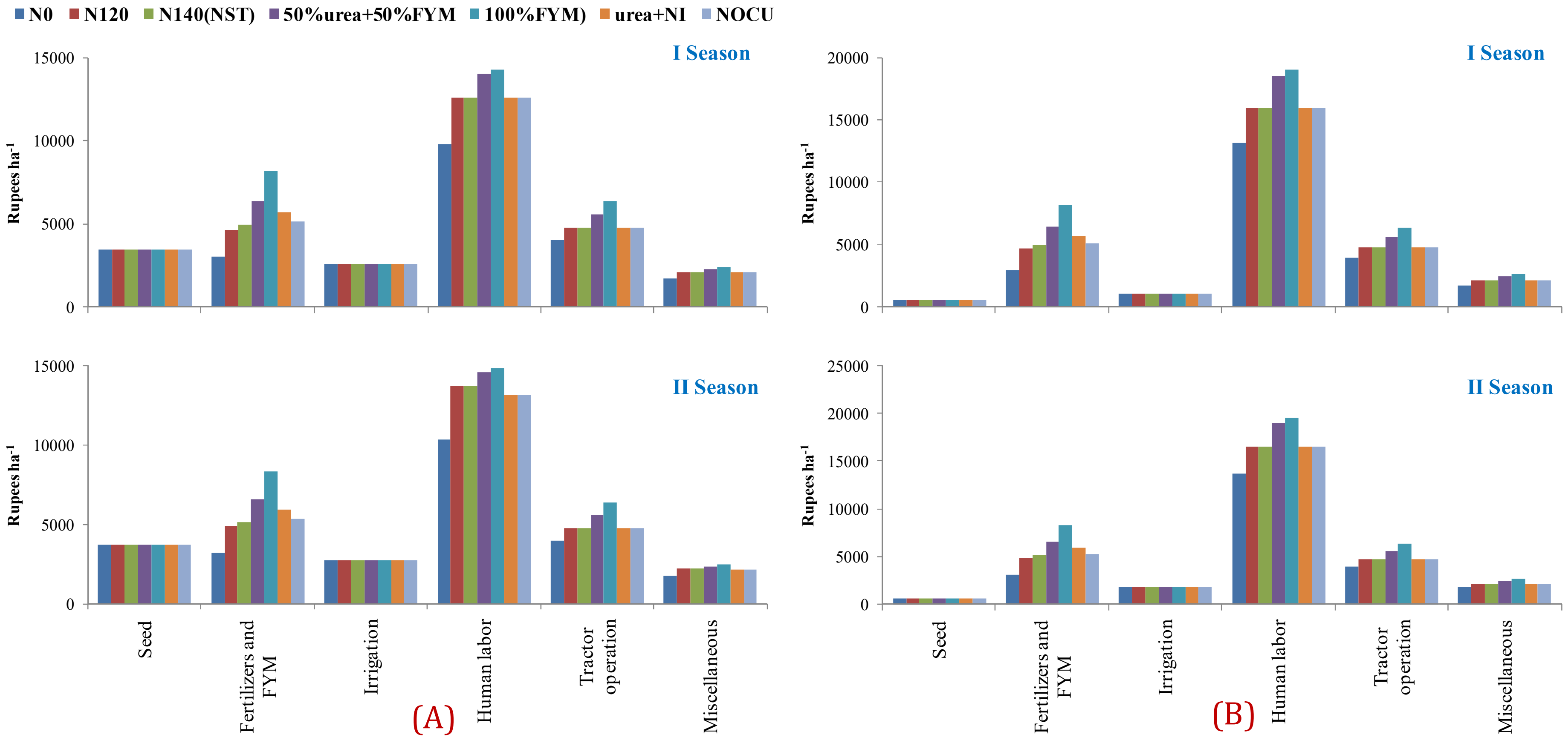

Fig. 4.9 Share of different factors in total cost of cultivation: (A) Wheat and (B) Maize

Table 4.8 Cost of cultivation and total income in different treatments in wheat and maize crops

Treatment	**Cost (Rs ha^{-1})**				**Total income (Rs ha^{-1})**				**B:C ratio**			
	Wheat		**Maize**		**Wheat**		**Maize**		**Wheat**		**Maize**	
	I season	II season	I season	II season	I season	II season	I season	II season	I season	II season	I season	II season
N0	27624	28982	26648	28467	28264	25184	23127	18894	1.023	0.869	0.868	0.664
N120	34923	36950	33947	35818	51149	49364	54207	54067	1.465	1.336	1.597	1.509
N140 (NST)	35480	37515	34503	36384	52730	51167	55665	54706	1.486	1.364	1.613	1.504
50% urea + 50% FYM	38245	39629	38500	40346	51086	49296	47734	60568	1.336	1.244	1.240	1.501
100% FYM	40335	41693	40898	42718	38402	41972	31140	30187	0.952	1.007	0.761	0.707
Urea + NI	36989	38395	36013	37879	52208	50140	55532	55946	1.411	1.306	1.542	1.477
NOCU	35810	37221	34834	36705	52638	50772	55319	58536	1.470	1.364	1.588	1.595
CD p=0.05	1137	1155	1143	1013	990	949	1023	970	0.020	0.021	0.065	0.056
SE(d)	369	375	371	329	321	308	332	315	0.006	0.007	0.021	0.018

Table 4.9 Cost of cultivation and total income in different treatments in wheat-maize system

Treatment	**Cost (Rs ha^{-1})**		**Total Income (Rs ha^{-1})**		**B:C ratio**	
	I Year	II Year	I Year	II Year	I Year	II Year
N0	54272	57449	51391	44078	0.947	0.858
N120	68870	72768	105356	103431	1.530	0.982
N140 (NST)	69983	73899	108395	105872	1.549	0.977
50% urea + 50% FYM	76745	79975	98821	109864	1.288	1.112
100% FYM	81233	84411	69542	72159	0.856	1.038
Urea + NI	73002	76274	107741	106086	1.476	0.985
NOCU	70644	73926	107957	109308	1.528	1.013
CD p=0.05	2273	2104	2007	1909	0.021	0.016
SE(d)	738	683	651	620	0.007	0.005

4.8. Calibration of InfoCrop-Maize and wheat Model

The model parameters and interpolation functions were calibrated for wheat variety WR-544 (Pusa Gold) and maize composite (PC-3) from the field experiment data set. The simulated values on phenology (days to 50% flowering, days to 50% physiological maturity), grain yield (GY) and N_2O emission from crops field were compared with those of observed values. The observed data set of first season of both the crops from the field experiment was used for the calibration of the model.

4.8.1 Calibration of InfoCrop-Wheat Model

In wheat crop the observed data set of first season were used for fine tuning of the model. From the results it was observed that the simulated phenology (days to 50% anthesis and days to 50% physiological maturity) slightly delayed that of measured values under the all the conditions (Table 4.10). The simulated value of days to 50% anthesis was one day higher under control (N0), two days higher in N120, N140 (NST), NOCU and 100% FYM. While, it was three days higher in case of application of NI in combination with urea (urea + NI) and 50% substitution of nitrogen with FYM (50% urea + 50% FYM) treatments (Table 4.10).

The simulated value of days to 50% physiological maturity was one day higher in control (N0), N120 and N140 (NST) conditions. Two days higher simulated values were also observed in case of application of NOCU condition. Difference in simulated and observed values was 3 days in case of urea + NI and 50% urea + 50% FYM conditions. The highest difference of four days was observed in case where 100% nitrogen is substituted bye FYM (100% FYM) (Table 4.10).

The simulated values on yield in N120, N140 (NST), 50% urea + 50% FYM, urea + NI and NOCU conditions were slightly lower than the observed one and it was 3324 kg ha^{-1} in all these above conditions (Table 4.10). Simulated values of yield were higher than the observed one in control (N0) and 50% substitution of urea by FYM (50% urea + 50% FYM). Observed values on yield were 1784 and 2514 kg ha^{-1} while, that of simulated were 1950 and 2920 kg ha^{-1} under N0 and 50% urea + 50% FYM conditions, respectively (Table 4.10).

The simulated values of GHG (N_2O) emission from soil of wheat crop field were slightly higher and at par with observed one in N120, N140 (NST), 50% urea + 100% FYM and 100% FYM conditions. While, simulated values on N_2O emission were slightly lower and at par with observed one in urea + NI and NOCU conditions. The simulated values on N_2O emission under control (N0) condition was much lower than the observed one. Under control condition the simulated and observed values were 0.57 and 0.14 kg ha^{-1} respectively (Table 4.10).

Table 4.10 Observed and simulated values of the calibration of InfoCrop-Wheat model

Treatment	**Days to 50 % anthesis**		**Days to 50% PM**		**Grain yield (kg ha^{-1})**		**N_2O emission (kg ha^{-1})**	
	O	S	O	S	O	S	O	S
N0	86	87	115	116	1784	1950	0.57	0.14
N120	89	91	119	120	3365	3324	1.54	1.59
N140 (NST)	89	91	119	120	3487	3324	1.64	1.69
50% urea + 50% FYM	88	91	116	120	3356	3324	1.51	1.53
100% FYM	87	89	115	118	2514	2920	1.46	1.53
Urea + NI	88	91	117	120	3440	3324	1.17	1.14
NOCU	89	91	119	120	3473	3324	1.28	1.22

Where,
PM= Physiological Maturity; O=Observed values; S=Simulated values

4.8.2 Calibration of InfoCrop-Maize Model

It was observed that the simulated phenology (days to 50% silking) matched with the observed values in soil test basis N140 (NST) and NOCU conditions (Table 4.11). It was one day higher in urea N120 and 100% substitution of nitrogen by FYM (100% FYM) and two days higher in 50% substitution of nitrogen with FYM (50% urea + 50% FYM) and urea + NI conditions. The simulated value of 50%

silking was two days lower than observed one in control condition (N0) (Table 4.11).

The simulated phenology (days to 50% physiological maturity) was two to six days higher than the observed values in different condition (Table 4.11). It was two days higher in control (N0); four days higher in N140 (NST), 100% substitution of N by FYM (100% FYM) and NOCU conditions; while, it was six days higher in 50% nitrogen substitution by FYM (50% urea + 50% FYM) (Table 4.11). It was observed that the simulated values of days to 50% days to physiological maturity was 92 days in N120, N140 (NST), 50% nitrogen substitution by FYM (50% urea + 50% FYM), urea + NI and NOCU conditions (Table 4.11).

The simulated values on yield were lower than observed values in control (N0) and 100% FYM conditions. The observed values on yield were 1597 and 2076 kg ha^{-1} while, that of simulated were 1404 and 2015 kg ha^{-1} under control and 100% FYM conditions (Table 4.11). The simulated values on yield in N120, N140 (NST), 50% substitution of urea by FYM (50% urea + 50% FYM), urea + NI and NOCU conditions were higher than the observed values (Table 4.11).

The simulated values on N_2O emission from soil were matched that of observed one in 50% urea + 50% FYM and urea + NI treatments (Table 4.11). The simulated values in N120 and N140 (NST) treatments were higher than the observed one and observed and simulated values on N_2O emission under N120 condition was 1.37 and 1.49 kg ha^{-1} and under N140 (NST) condition was 1.46 and 1.70 kg ha^{-1}, respectively (Table 4.11). In case of 100% substitution of nitrogen with FYM (100% FYM) and NOCU condition the simulated values on N_2O emission were slightly lower and at par with observed values. The simulated values on N_2O emission under control condition (N0) was much lower than the observed one. Under control condition the simulated and observed values were 0.45 and 0.17 kg ha^{-1} respectively (Table 4.11).

Table 4.11 Observed and simulated values of the Calibration of InfoCrop-Maize model

Treatment	**Days to 50 % silking**		**Days to 50% PM**		**Grain yield (kg ha^{-1})**		**N_2O emission (kg ha^{-1})**	
	O	S	O	S	O	S	O	S
N0	57	55	85	87	1597	1404	0.45	0.17
N120	58	59	87	92	3894	4147	1.37	1.49
N140 (NST)	59	59	88	92	3993	4279	1.46	1.70
50% urea + 50% FYM	57	59	86	92	3364	3542	1.36	1.36
100% FYM	57	58	85	89	2076	2015	1.28	1.34
Urea + NI	57	59	87	92	3967	4150	1.10	1.10
NOCU	59	59	88	92	3925	4149	1.21	1.18

Where,
PM= Physiological Maturity; O=Observed values; S=Simulated values

4.9. Simulating the response of wheat and maize and nitrous oxide emission from crops field

The calibrated maze and wheat model then was used to simulate the response of crops (wheat and maize) to different condition in a crop growth period and response of N_2O emission from soil of crop field. The second season data for both the crops were used for the simulation purpose. The validation was done for the phenology (days to 50% anthesis/silking and days to 50% physiological maturity), grain yield (GY) and N_2O emission from soil under different condition.

4.9.1 Wheat

The simulation result of wheat crop response and N_2O emission from wheat field are shown in figure 4.10. In wheat crop comparision between observed and simulated values showed that the simulated value of 50% anthesis were slightly higher than the observed one in all the conditons and days to 50% anthesis were slightly over estimated by the model (Fig. 10. A). The simulated values were two to secen days higher than the observed one in different tretment. The maximum difference of seven days between the simulated and observed values were recorded in the condition where 50% of N was substituted by FYM (50% urea + 50% FYM) condition while, the minimum difference of two days was recorded in control (N0) condition (Fig. 4.10 A).

Simulation results showed that simulated value of days to 50% physiological maturity were one to four days higher than the observed one and it is simulated well in all the condition except 50% urea + 50% FYM condition (Fig 4.10 B) where, it was slightly overestimated and it was four days higher than the observed one (Fig. 4.10 B).

Grain yield was simulated well in all treatments except control (N0) and 100% FYM conditions (Fig. 4.10 C). Under control and 100% FYM grain yield were slightly over estimated. While in all other treatments grain yield were slightly underestimated (Fig. 4.10 C).

The simulated results of N_2O emission from soil showed that it is simulated well in most of the conditions. Under N140 (NST) condition simulated values of N_2O emission was higher than the observed one and it is simulated well (Fig. 4.10 D). N_2O emission were also simulated well under N120, 50% urea + 50% FYM, 100% FYM, urea + NI and NOCU conditions but it is slightly under estimated. The N_2O emission in control condition is highly under estimated and the simulated value is almost 1/4th of the observed one (Fig 4.10 D).

4.9.2 Maize

The simulation result of maize crop response and N_2O emission from maize field are shown in figure 4.11. In maize crop, comparision of both observed and simulated results showed that the simulated values of days to 50% silking and 50% physiological maturity were higher than the observed values (Fig. 4.11 A & B). Days to 50% silking simulated well by the model in all treatments (Fig 4.11 A). However days to 50% physiological maturity were simulated reasonably well. Days to 50% physiological maturity were simulated very well under control (N0) condition. While, under all other treatments model slightly overestimated the days to 50% physiological maturity (Fig 4.11 B). The simulated value of days to 50% physiological maturity were three to five days higher than the observed one under different situation (Fig. 4.11 B).

Simulated values on grain yield were higher than the observed one in all the treatments (Fig. 4.11 C). Grain yield was simulated very well under control condition. Under N120, N140 (NST), 50% urea + 50% FYM, urea + NI and NOCU conditions grain yield were simulated reasonably well and it was slightly overestimated (Fig 4.11 C). However, grain yield was highly overestimated in 100% FYM condition. The simulated and observed values on grain yield were 2563 and 1979 kg ha^{-1} respectively under 100% FYM condition (Fig. 4.11 C).

Comparision between the simulated and observed values on N_2O emission from soil showed that simulated value was higher than observed one under N140 (NST) condition while, under all other situation it was lower than the observed one (Fig. 4.11 D). N_2O emission was slightly underestimated and simulated reasonably well under N120, 50% urea + 50% FYM, 100% FYM, urea + NI and NOCU conditions (Fig 4.11 D). The N_2O emission under control condition is highly under estimated and the simulated and observed values were 0.17 and 0.45 kg ha^{-1} respectively (Fig 4.11 D).

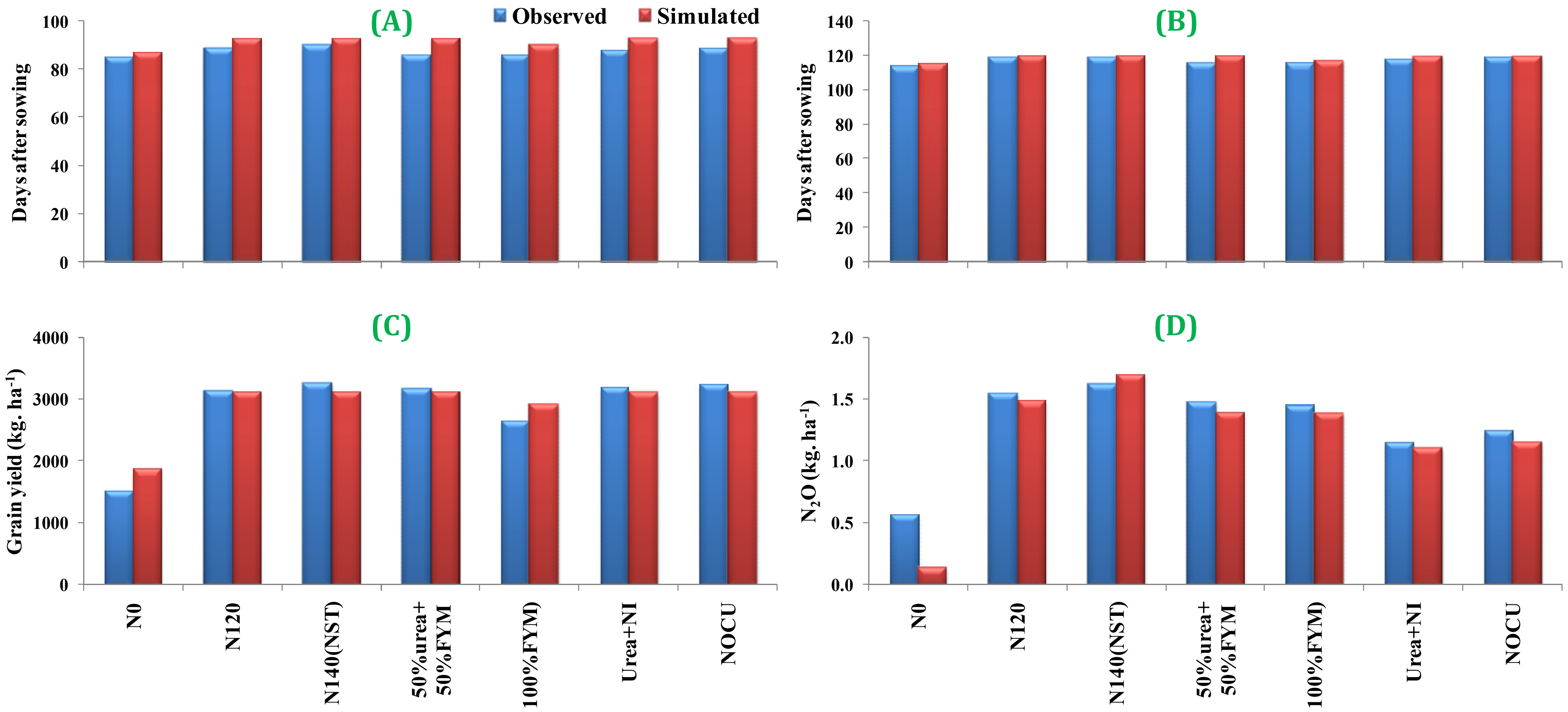

Figure 4.10 Validation results on Infocrop-Wheat model for simulating the effect of different treatment on wheat crop (A) days to 50% anthesis, (B) days to 50% physiological maturity (C) Grain yield (kg. ha^{-1}) and (D) N_2O emission (kg. ha^{-1})

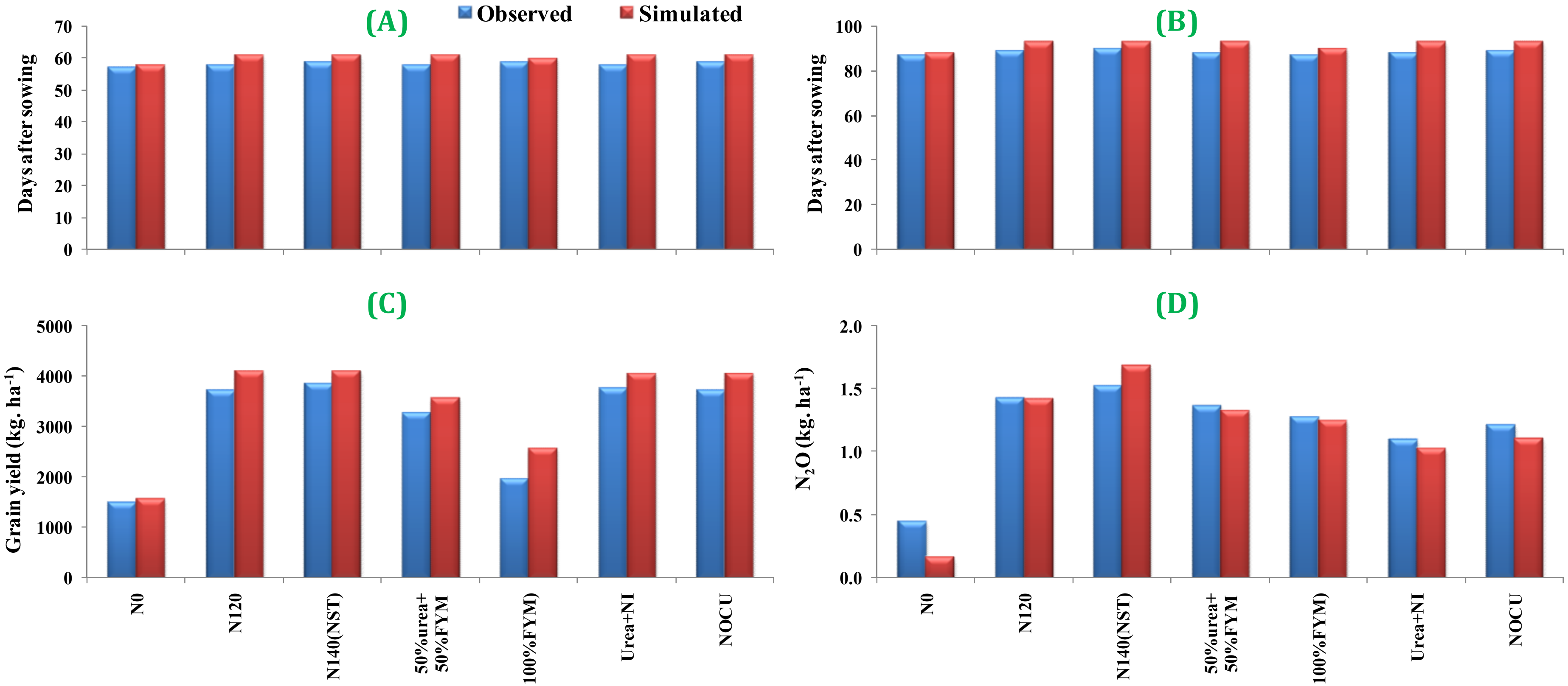

Figure 4.11 Validation results on Infocrop-Maize model for simulating the effect of different treatment on wheat crop (A) days to 50% silking, (B) days to 50% physiological maturity (C) Grain yield (kg. ha^{-1}) and (D) N_2O emission (kg. ha^{-1})

4.10 Statistical performance of model

4.10.1 Wheat

The MBE indicates bias of model error as it accounts for positive and negative deviations. Mean bias error (MBE) showed the positive deviation between the observed and simulated value of days to 50% anthesis, days to 50% physiological maturity and grain yield, while it showed the negative deviation for and N_2O emission from soil (Table 4.12). Value of root mean square error (RMSE) showed the accuracy of model (lower the RMSE value, higher the accuracy). Data indicate that days to 50% physiological maturity, grain yield and N_2O emission was simulated with greater accuracy as also indicated by the modeling efficiency (ME) values, while, the days to 50% anthesis was simulated with low accuracy (Table 4.12). The IA, is an additional method for evaluation of model performance, which ranges between 0 and 1, the closer IA is to 1, the better the simulation. Values of IA showed that the grain yield was simulated with highest accuracy (IA=0.97) followed by N_2O emission (IA=0.95), days to 50% physiological maturity (IA=0.79) and days to 50% anthesis (IA=0.49) (Table 4.12).

Table 4.12 Stastical indices showed performance of InfoCrop-Wheat model

Parameters	Wheat			
	MBE	RMSE	IA	ME
Days to 50 % anthesis	4.14	4.39	0.49	-5.22
Days to 50% physiological maturity	1.57	1.89	0.79	-0.07
Grain yield (kg ha^{-1})	32.94	190.20	0.97	0.90
N_2O emission (kg ha^{-1})	-0.10	0.18	0.95	0.72

Where,
MBE=Mean bias error; RMSE=Root mean square error; IA=Index of agreement; ME= Modeling efficiency

4.10.2 Maize

From the data set it was observed that mean bias error (MBE) showed the positive deviation for the days to 50% silking, days to 50% physiological maturity and grain yield, while it showed the negative deviation for N_2O emission (Table 4.13). Root mean square error (RMSE) values showed that the accuracy of model was higher for the grain yield and N_2O emission, and it was lower for days to 50% silking, days to 50% physiological maturity and maximum LAI (Table 4.13). Modeling efficiency also showed that under estimation of model for days to 50% silking and days to 50% physiological maturity (Table 4.13). Values of IA showed that the grain yield and N_2O emission was simulated with highest accuracy (IA=0.98) followed by days to 50% physiological maturity (IA=0.38), days to 50% silking (IA=0.36) (Table 4.13).

Table 4.13 Stastical indices showed performance of InfoCrop-Maize model

Parameters	**Maize**			
	MBE	**RMSE**	**IA**	**ME**
Days to 50 % silking	2.14	2.30	0.36	-9.79
Days to 50% physiological maturity	3.57	3.80	0.38	-12.60
Grain yield (kg ha^{-1})	306.17	389.89	0.98	0.81
N_2O emission (kg ha^{-1})	-0.05	0.13	0.98	0.75

Where,
MBE=Mean bias error; RMSE=Root mean square error; IA=Index of agreement; ME= Modeling efficiency

4.11 Total nitrogen used in Indian agriculture, resulting emission and uptake of different species and their global temperature change potential (GTP).

4.11.1 Total Nr used in Indian agriculture

Results indicate that total nitrogen consumption in Indian agriculture was increased from 3.54 Tg in 1961 to 23.51 Tg in 2010 (Table 4.14 & Fig. 4.12). In 1961 total 3.51 Tg N was used in Indian agriculture by different sources (Table 4.14). Highest amount of 1.77 Tg (50.04%) was through crop residue, while, atmospheric deposition contributes lowest 0.12 Tg (3.46%). Animal manure and fertilizer contributed 1.39 (39.44%) and 0.25 (7.06%) Tg N, respectively (Table 4.14). In 2010 total 23.51 Tg N was used in Indian agriculture highest amount of which 16.55 Tg (70.40%) was through nitrogenous fertilizers, followed by crop residue, animal manure and atmospheric deposition contributed 3.9 (16.58%), 2.54 (10.79%) and 0.52 (2.23%) Tg N, respectively (Table 4.14). Percentage share of fertilizer to nitrogen application in India was increased tremendously from 7.06% in 1961 to 70.40% in 2010. On the other hand percentage share of animal manure, crop residue are decreased (Table 4.14).

Table 4.14 Contribution of different sources to total nitrogen used in Indian agriculture in year 1961 and 2010.

Parameters	**Nitrogen in Tg (%)**	
	1961	**2010**
Fertilizer N	0.25 (7.06)[a]	16.55 (70.40)
Animal mannure	1.39 (39.44)	2.54 (10.79)
Crop Residue	1.77 (50.04)	3.90 (16.58)
Atmospheric deposition	0.12 (3.46)	0.52 (2.23)
Total N	3.54 (100)	23.51 (100)

[a]Figures in the parenthesis are percent of total N

4.11.2 GTP of N_2O emission

Total N_2O emission from Indian agriculture increased from 0.04 Tg to 0.28 Tg during 1961 to 2010 (Fig. 4.13 A). The GTP of total N_2O emission, thus increased from 11.46 to 76.19 TgCO_2e in a 20-year time-scale (GTP_{20}) (Fig. 4.14 A) and from 12.71 to 84.50 Tg CO_2e in 100-year time-scale (GTP_{100}) (Fig. 4.14 B) during 1961 to 2010.

4.11.3 GTP of NH_3 and NO_x emissions

NH_3 emission from Indian agriculture was 0.64 and 4.28 Tg during 1961 and 2010, respectively (Fig. 4.13 C). Emission of NO_x was 0.02 and 0.12 Tg in 1961 and 2010, respectively (Fig. 4.13 D). Cooling impacts due to these emissions of NO_x and NH_3 were 4.92 and 32.69 Tg CO_2e on GTP_{20} and 0.03 and 0.22 Tg CO_2e on GTP_{100} during 1961 and 2010, respectively (Fig. 4.15). Aerosol formation from NH_3 contributed 76% of the cooling effect, followed by ozone and CH_4 alternation due to NO_x (17%) and aerosol formation from NO_x (7%) (Fig. 4.15 A, C & E). However, on GTP_{100} (Fig. 4.15 B, D & F) these cooling impacts of NH_3 and NO_x were smaller compared to GTP_{20} indicating that as the time horizon becomes longer, short-lived compounds have less effects on GTP (Pinder *et al.,* 2012).

4.11.4 GTP due to altered CO_2 and CH_4 fluxes

Addition of N has inhibitory effect on CH_4 oxidation due to increased concentration of ammonium and (NH_4^+) (Wang *et al.,* 2003) and nitrate (NO_3^-) (Xu, and Inubushi, 2004; Reay and Nedwell, 2004) in soil, thereby increasing the flux of CH_4.The CH_4 flux increased from 0.05 Tg in 1961 to 0.36 Tg in 2010 (Fig. 4.13 E) contributing to 3.06

and 20.37 Tg CO_2e in GTP_{20} (Fig. 4.14 G) and 0.21 and 1.39 Tg CO_2e in GTP_{100} (Fig. 4.14 H) in 1961 and 2010, respectively. Fluxes of CO_2 decreased by 0.69 Tg to 4.57 Tg during the same period (Fig. 4.13 F) due to increased uptake of CO_2 as a result of N application (Fig. 4.15 G&H).

4.11.5 Net impact of N use in agriculture on GTP

Net GTP of N use in Indian agriculture was 8.92 and 59.30 Tg CO_2e on GTP_{20} (Fig. 4.12 A) and 12.20 and 81.11 Tg CO_2e on GTP_{100} (Fig. 4.12 B) in 1961 and 2010, respectively. The net GTP_{20} was lower by 22.16% and GTP_{100} by 4.01% compared to the respective GTPs when N_2O emission alone was considered.

4.11.6 Total GTP during 1961-2010

Total warming due to N use in Indian agriculture during 50 years was 2329.45 Tg CO_2e in GTP_{20} and 2063.33 Tg CO_2e in GTP_{100} (Fig. 4.16). Emission of N_2O due to N use in agriculture contributed 79% and 98% of this warming in GTP_{20} and $GTP_{100,}$ whereas CH_4 contributed 21% and 2% in GTP_{20} and $GTP_{100,}$ respectively. Total cooling was 894.96 and 115.00 Tg CO_2e on GTP_{20} and $GTP_{100,}$ respectively (Fig. 4.16). The major cooling was due to NH_3 aerosol formation (67%) followed by NOx induced O_3 and CH_4 alteration (15%), N fertilizer-induced C sequestration (12%) and NO_x aerosol (6%). However on GTP_{100} N fertilizer-induced C sequestration contributed the maximum (95%) and others were marginal.

The net GTP_{20} was 1424.49 Tg CO_2e i.e., 22.17% lower and GTP_{100} was 1948.33 Tg CO_2e i.e., 4.02% lower compared to the respective GTPs when warming due to N_2O emission alone was considered.

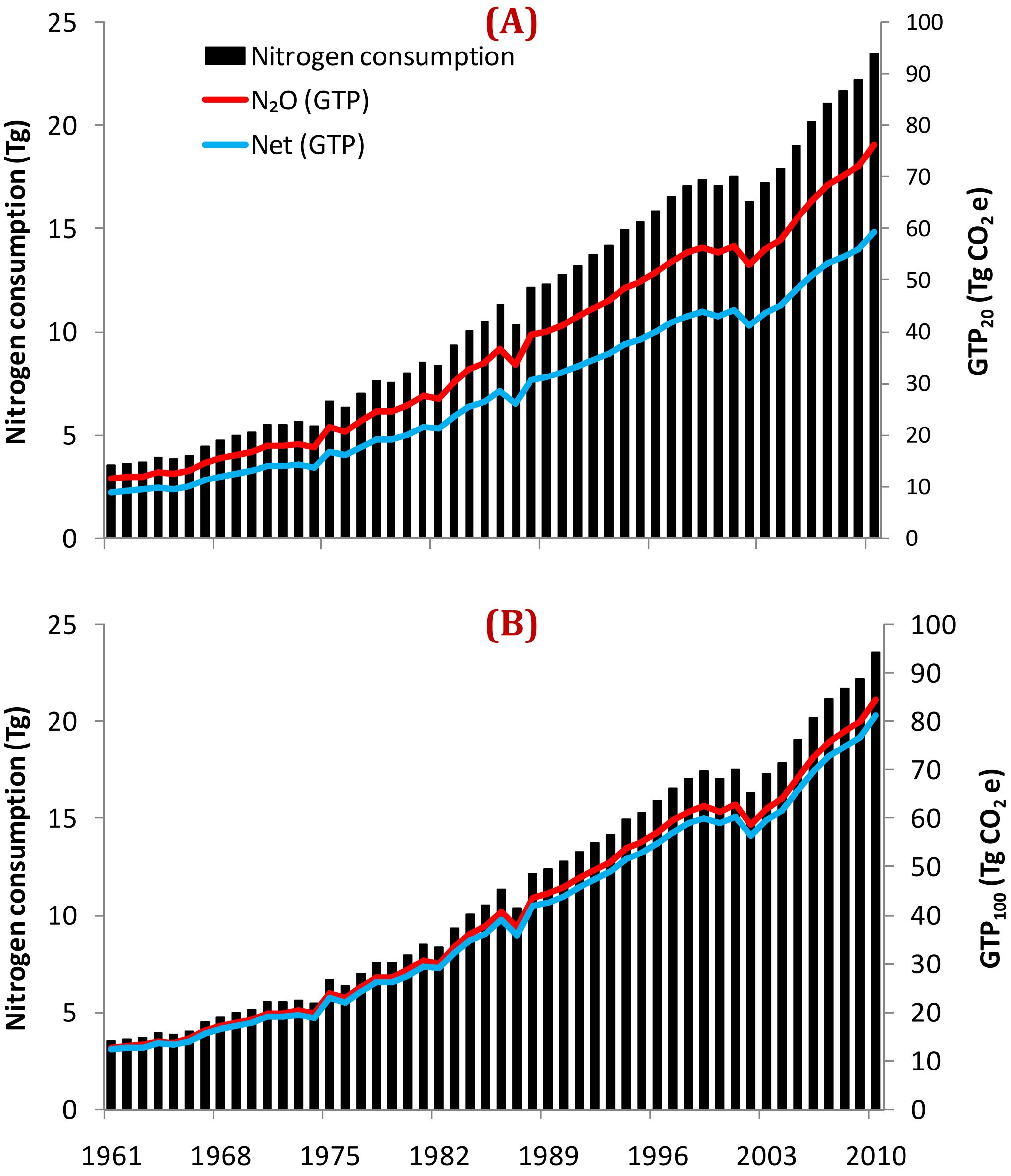

Figure 4.12 Total nitrogen consumption, global temperature change potential (GTP) due to N_2O emission alone and net GTP of N use in Indian agriculture (A) 20-year and (B) 100-year time-scales.

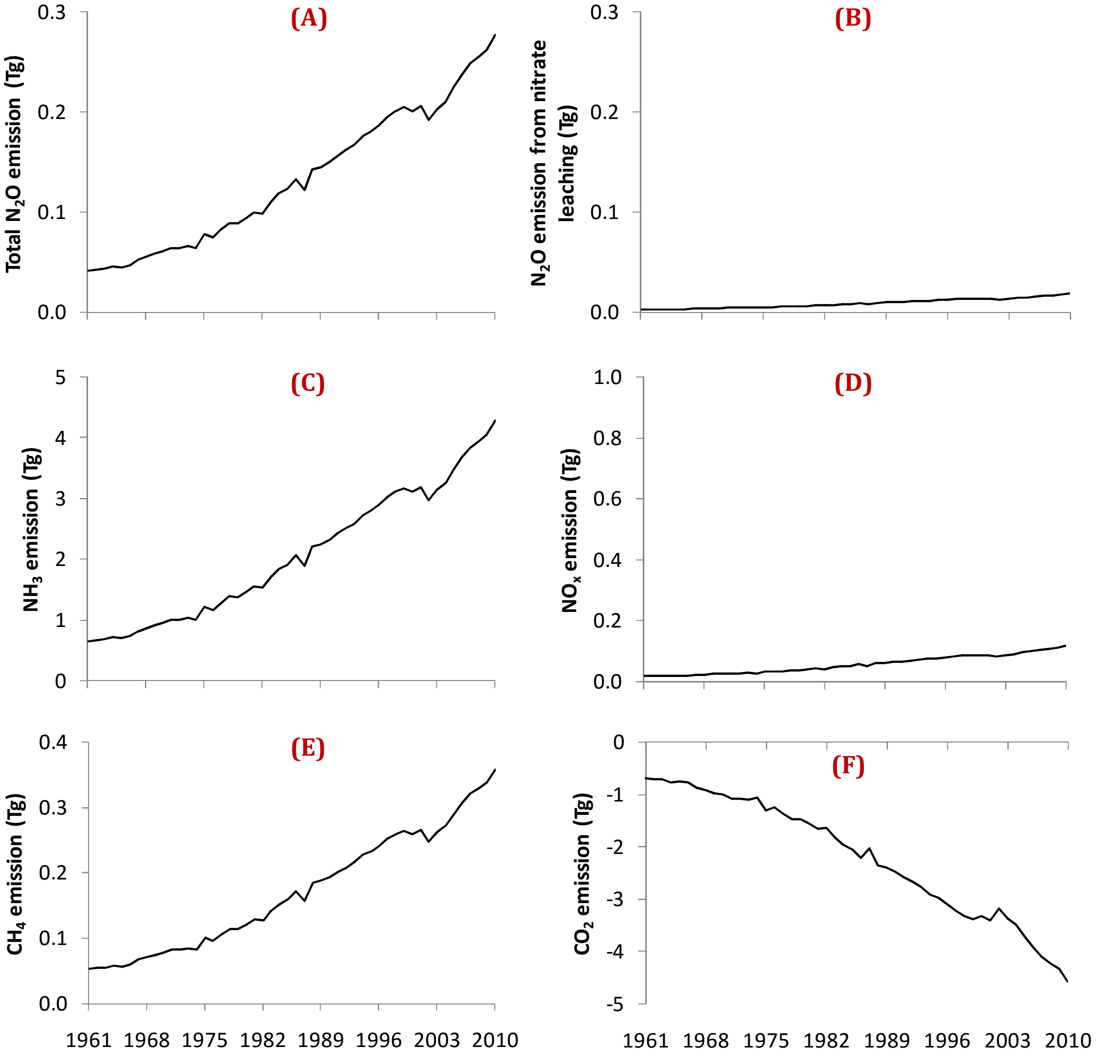

Figure 4.13 Emissions of total (direct + indirect) N_2O (A), N_2O from nitrate leaching (B), NH_3 (C), NO_X (D), CH_4 (E) and CO_2 (F) from N use in Indian agriculture during 1961-2010.

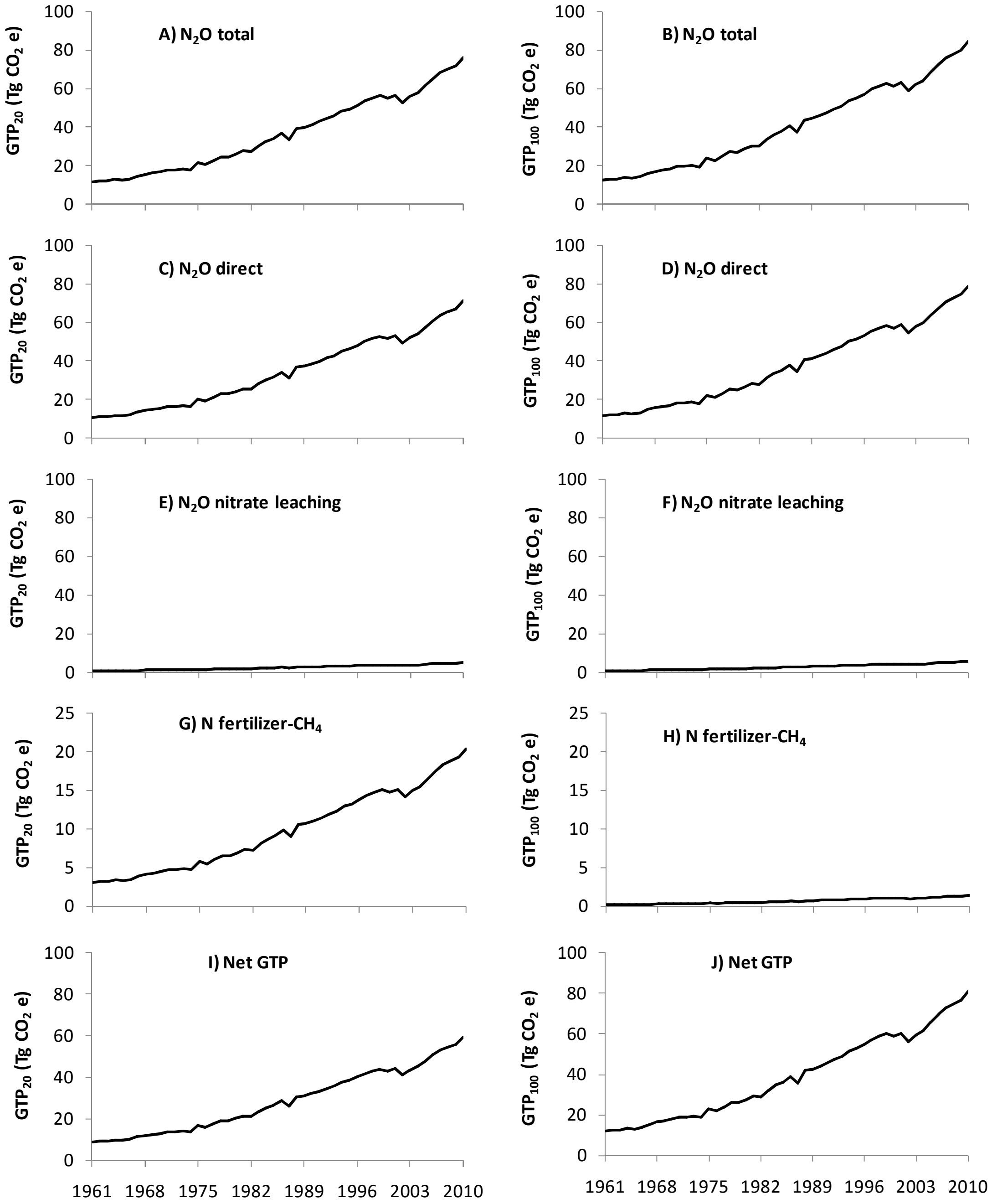

Figure 4.14 Warming or global temperature change potential (GTP) due to total (direct + indirect) N_2O emission (A & B), direct N_2O emission including atmospheric deposition (C & D), N_2O emission from nitrate leaching (E & F), N fertilizer and CH_4 flux (G & H) and net GTP (I & J) of N use in Indian agriculture on 20-year (left) and 100-year (right) times-scales.

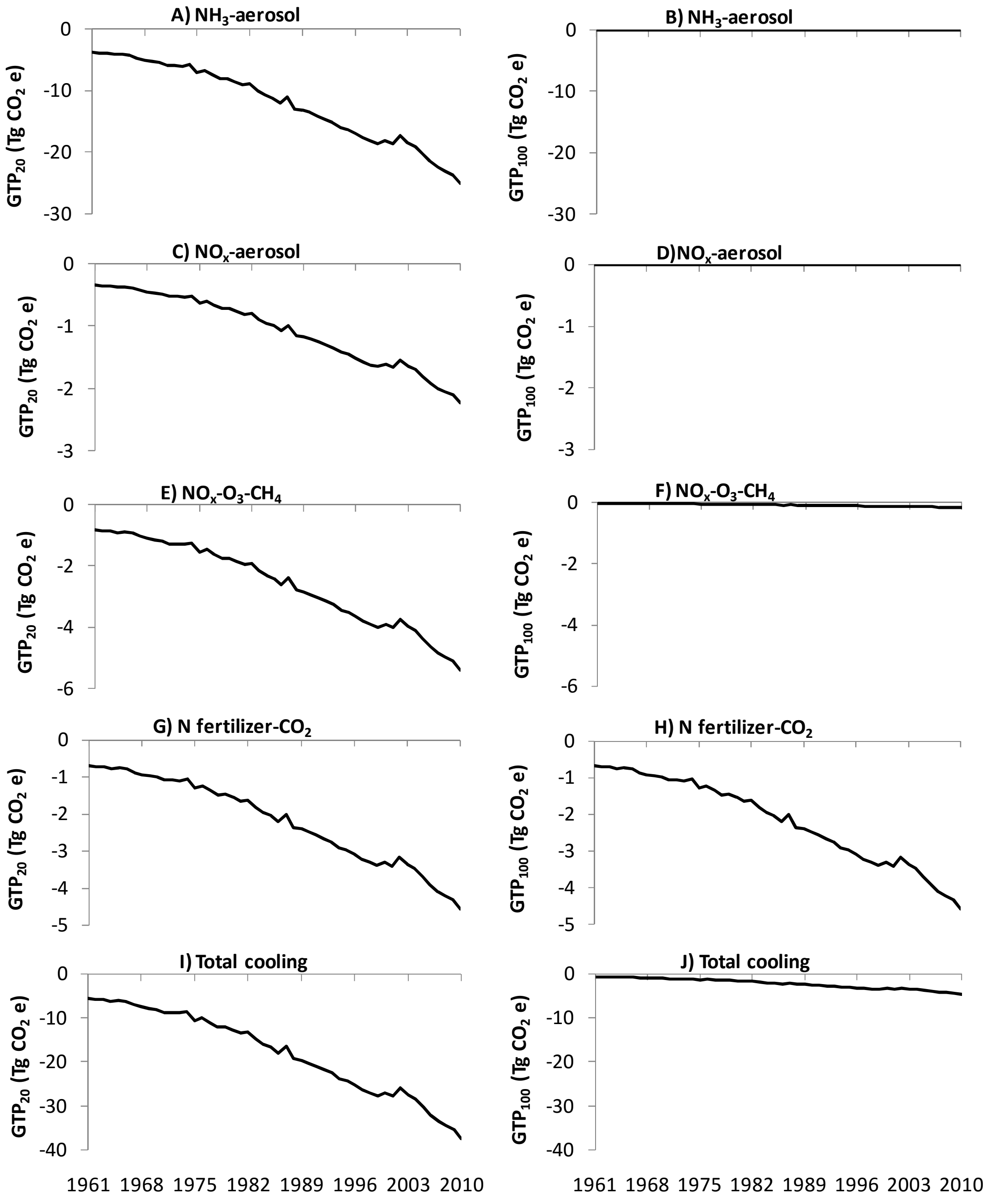

Figure 4.15 Cooling or Global temperature change potential (GTP) due to NH_3 aerosol (A & B), NO_x aerosol (C & D), NO_x-O_3-CH_4 (E & F), CO_2 with N fertilizer (G & H) and total cooling (I & J) of N use in Indian agriculture on 20-year (left) and 100-year (right) times-scales.

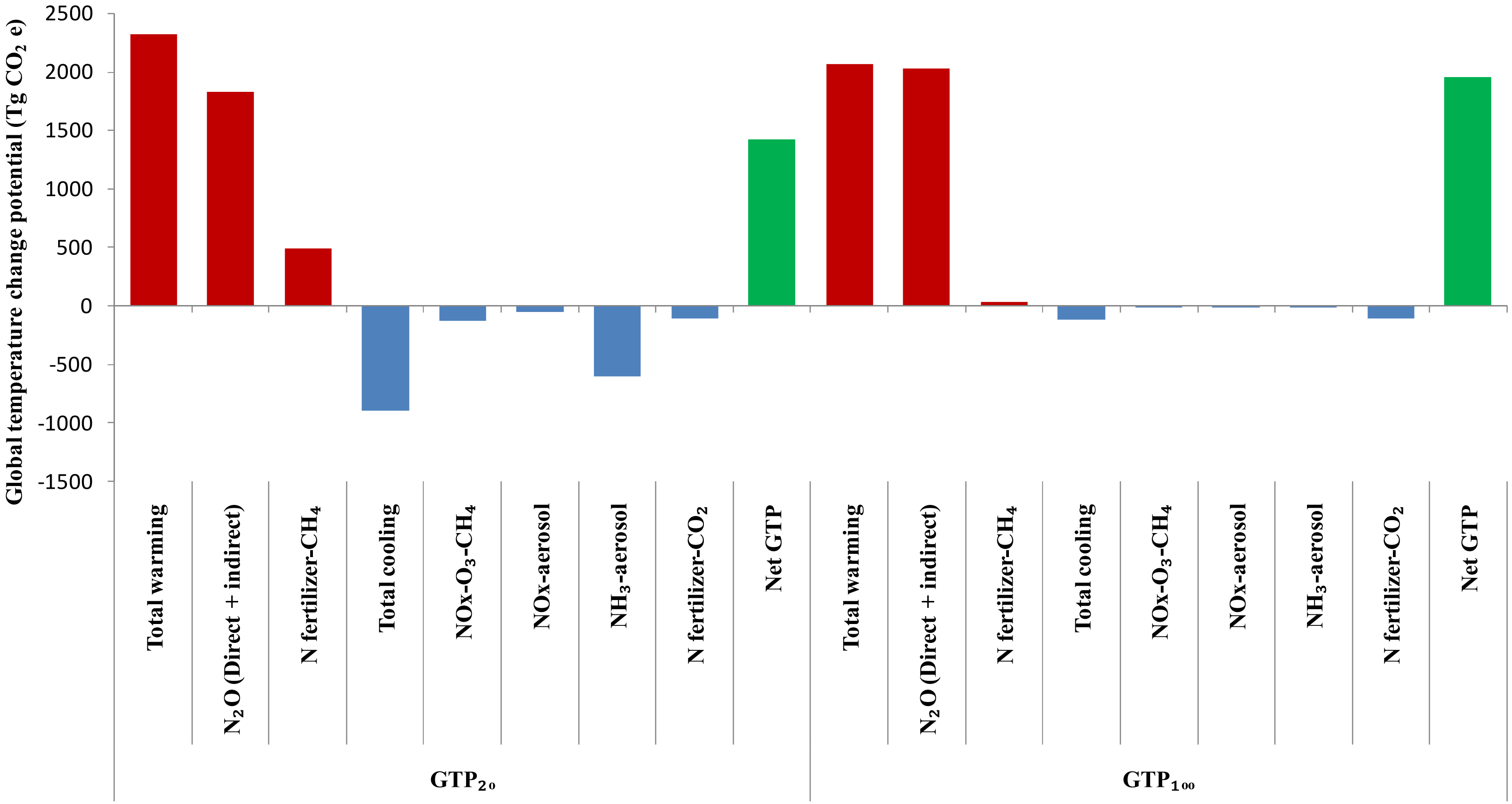

Figure 4.16 Total Global temperature change potentials of N use in Indian agriculture in 50 year on 20-year (left) and 100-year (right) times-scales

CHAPTER-5

DISCUSSION

In presented study, we quantified the emission of GHGs (N_2O and CO_2) in a maize-wheat system and assessed the magnitude and cost of mitigation under different treatments followed by the simulation of yield and GHGs from maize-wheat system using InfoCrop model. Finally we quantified the net global warming potential of N fertilizer use in Indian agriculture. The results obtained from field experiment, varied according to different treatments, and the reason behind these variations have been discussed below

5.1 Greenhouse gas emission from maize and wheat fields

Seven different treatments i.e., control (N0), N120, N140 (NST), 50% urea + 50% FYM, 100% FYM, Urea + NI and NOCU in wheat and maize crop of wheat-maize system for two consecutive years (2012-13 to 2013-14) were tested. There were significant variations in GHGs emission and GWP from maize and wheat crops. The salient findings in terms of variations in GHG emission and GWP among different treatments are discussed below.

5.1.1 Emission of N_2O

N_2O in soil is mainly produced by the microbial processes of nitrification and denitrification (Granli and Bockman, 1994; Snyder *et al.,* 2009; Davidson, E. A. 2009). The dominance of either nitrification or denitrification process and magnitude of N_2O emission depends on several other factors. Hence, the variation in other factors led to variation in emission of N_2O from tested treatments in wheat and maize crop of wheat-maize system, which are discussed below.

Impact of fertilizer application

N_2O emission from soils is greatly affected by fertilizers application in particular nitrogenous (N) fertilizers. The application of N fertilizer directly influences the availability of NO_3^- and NH_4^+ substrate for nitrification and denitrification process

(Lloyd and Sheaffe, 1973). Which result in larger flux of N_2O emission followed by N fertilizer application; however it also depends on type of fertilizer, soil moisture and aeration status. The emission of N_2O increases significantly after application of nitrogenous (N) fertilizers (Wrage *et al.,* 2001; Linquist *et al.,* 2012). Application of urea in crop fields led to increased NH_4-N substrate supply to microorganism for nitrification and denitrification process. However, it takes two to three days for urea hydrolysis into NH_4-N under optimum moisture and aeration condition (Lloyd and Sheaffe, 1973). It might be probable reason that N_2O peak was observed after three days of each dose of urea application in both maize and wheat crop in the present study. In N120 and N140 (NST) treatments the peak of N_2O emissions were higher than the other treatments (Fig 4.3 and 4.4). This might be due to the higher amount of substrate. The greater the amount of substrate in the fertilizer, the greater will be the nitrification process and greater will be N_2O emission (Mosier, 2001; Khalil *et al.,* 2004; Liu *et al.,* 2005). The Lower N_2O emission flux was observed in control (N0) treatment compared to the N120 treatment throughout the crop seasons. It might be due to lower availability of nitrogenous substrate for nitrification and denitrification process. However, in control (N0) treatment slight higher flux of N_2O emission was also observed after the irrigation of crop. The N_2O emissions will decrease with decrease the availability of NO_3^-, (Hellebrand *et al.,* 2008). The observed trend of N_2O emission flux in maize and wheat crop was in line/agreement with the Malla *et al.* (2005); Bhatia *et al.* (2005) and (2010); Gupta *et al.,* (2016).

Impact of nitrification inhibitors and slow release fertilizers

The Nitrification inhibitors (NIs) slowed down the process of nitrification i.e. conversion of NH_4-N into NO_3–N by several modes of action, but did not stop the process completely because NI changes concentration of NH_4^+, thereby the concentration of NO_2^- and NO_3^- (Majumdar *et al.,* 2002; Luo *et al.,* 2010). While slow release fertilizers limit the conversion of NH_4-N into NO_3–N, thereby reducing emissions of N_2O via nitrification directly (Prasad and Power 1995; Subbarao *et al.,* 2006). The NOCU and Urea + NI treatments showed lower flux of N_2O compared to N120 treatment during the most period of crop growth in both maize and wheat crop (Fig. 4.3 & 4.4). This results in significant reduction in cumulative N_2O-N emission

(Table 4.3) which was due to property of slow release fertilizers (NOCU) and nitrification inhibition (DCD). Therefore, the management of nitrification process by the application of NIs is a well proven strategy to improve N use efficiency (NUE), and for reducing GHG emission (Malla *et al.,* 2005; Prasad, 2009; Kumar, 2011). Nitrification inhibitors have great potential to decrease emission of N_2O from fertilized soil in the wider range of nitrogen level and moisture conditions (Aulakh *et al.,* 2001; Signor *et al.,* 2013). Kumar *et al.* (2007) also reported in a soil incubation experiment that the meliacins content in neem oil directly affected the nitrification inhibition. Similar result was also reported by Malla *et al.* (2005).

Impact of organic manure

Organic manures are the source of carbon (C) and nitrogen (N) substrate in the soil and thus strongly effect GHG emission. Higher denitrification rates were reported by Aulakh *et al.,* (1991) as results of application of farm yard manure. However, emission of N_2O and organic manure mineralization are dependent on C:N ratio of organic manures (Huang *et al.,* 2004). During the first few days after the application of low C:N organic manure, increased N_2O flux has been reported (Christensen, 1990; Comfort *et al.,* 1990). In present study in 50% urea + 50% FYM and 100% FYM treatments N_2O emission fluxes were higher than the control (N0) treatment during the first few days after the application of FYM in both wheat and maize crop (Fig 4.3 & 4.4). These higher emissions are results of rapid nitrification and denitrification processes induced by organic manure, because they contain considerable amounts of readily available organic carbon and ammonium (Granli and Bockman, 1994). However, these emission fluxes from 50% urea + 50 % FYM and 100% FYM treatments were lowered down over the period. This might be due to decrease availability of NH_4^+ and NO_3^- substrate over the time (Hellebrand *et al.,* 2008). In 100% FYM and 50% urea + 50% FYM treatments, at the time of first peak, the N_2O-N emission peak was lower than the N120 treatment and subsequently remains higher till next peak of N_2O-N occurs. This might be due to the continuous supply of low quantity substrate as compared to N120 treatment.

5.1.2 Emission of CO_2

The CO_2 emission from soil is mainly due to decomposition of soil organic matter by heterotrophic micro organism and root respiration by higher plants (autotrophic) (Hanson, *et al.* 2000; Rastogi, *et al.,* 2002). In both maize and wheat crop, from all the treatments we observed lower CO_2 flux after sowing of crops. However, during latter crop growth stage, particularly vegetative growth the CO_2 emission flux increased significantly and reached at its maximum value during 30-80 DAS in wheat crop (Fig. 4.5) and 30-65 DAS in maize crop (Fig. 4.6). At initial stage of seed germination CO_2 emission mainly occurs due to decomposition of soil organic matter however, in latter stage when plant get established CO_2 emission from root respiration enhanced the total CO_2 flux. The greater root respiration during the active crop growth period might be the reason for the greater CO_2 flux under all the treatments in both wheat (Fig 4.5) and maize crop (Fig. 4.6), since root respiration accounts for 30 - 50% of the total CO_2 flux (Rochette, *et al.,* 1999; Curtin, *et al.,* 2000). This higher flux might also observe due to the higher availability of the carbon substrates in corresponding period and higher microbial activity (Campbell *et al.,* 2001; Iqbal *et al.*, 2009). In rice crop the highest CO_2 flux during this period has been also reported (Pandey, *et al.*, 2012; Bhattacharyya, *et al.,* 2012).

There are several factors including soil organic matter (SOM), soil temperature, soil physical parameters, soil moisture regime (aeration), tillage and residue management which control soil microbial respiration and emission of CO_2 from soil (Jarecki and Lal, 2006; Huifang, *et al.,* 2014). The quality and availability of soil carbon affects CO_2 emission. In general application of organic matter in soil leads to increased CO_2 emission (Moore and Dalva, 1993; Rao and Pathak, 1996). The soluble/labile organic carbon is the immediate source of carbon for microorganisms and it enhances CO_2 emission (McGill *et al.,* 1981; García-Marco *et al.,* 2014). This might be probable reason for higher CO_2 emission in 50% urea + 50% FYM and 100% FYM treatments than the all other treatments during the initial crop growth periods in both the crops (Fig 4.5 & 4.6), which result in significant higher cumulative CO_2-C emission from these treatments (Table 4.3). These results are in line with Huifang *et al.,* 2014. Similar kind of results was also reported by Jianwen *et al.*, (2004) under application of rapeseed cake and wheat straw application, respectively in rice-wheat system. However, during later stage of crop growth the CO_2 emission from 50% urea + 50% FYM and 100% FYM treatments were at par with the N120 and N140 treatment, this might be due to that during later stage CO_2 emission was primarily from root respiration.

Nitrification inhibitors and yield

In present study we found the slight higher yield of both wheat and maize crops under Urea + NI and NOCU treatments compared to N120 treatment, however, these differences were insignificant (Table 4.7). The productivity of wheat-maize system was higher by 1.91-3.8%. In many studies it has been observed that the application of nitrification inhibitors (NIs) enhanced the crops yield (Majumdar *et al.,* 2002; Bhatia *et al.,* 2010 and Hu *et al.,* 2014)**.** The higher yield of wheat, barley, rapeseed, potato and maize crops under N fertilization with NIs was observed as compared to conventional N fertilization at a particular N rate. Smith *et al.,* (1998) also reported the effectiveness of the NI (DCD) and nitrapyrin on reducing N_2O emissions and slight increase in yield of crops. Bhatia *et al.,* (2010) also reported the increase in yield of wheat crop as results of use of nitrification inhibitors. Majumdar *et al.,* (2002), also reported 4-12% increase in yield of wheat crop due to use of NIs at different places in Gujarat and these results are in line with different places in New Delhi (Bhatia *et al.,* 2010).

5.2 Modelling the impacts of N fertilizer on GHG emissions and yield

Several modelling approaches has been developed to quantify GHG emissions from crop land, i.e., DNDC (Li, 2000) and DayCent (Del Grosso *et al.,* 2001), InfoCROP (Aggarwal *et al.,* 2004b) and WNMM (Li *et al.,* 2005), TechnoGAS (Pathak and Wassmann, 2007), InfoRCT (Pathak *et al.*, 2011b). Some of these simulation models have successfully validated for rice fields in Asian countries including, India (Pathak *et al.,* 2005; Saharawat *et al.*, 2012) and China (Cai *et al.,* 2003). In recent period, simulation models have been used to estimate the emissions of GHG emissions from rice and wheat (Pathak and Wassmann 2007; Bhatia *et al.*, 2012b; Pathak *et al.,* 2012).

In the present study an attempt has been made for calibration and validation of InfoCrop model for the simulation of N_2O emission and grain yield of wheat and maize crop. The model was calibrated using; the experimental values pertaining to first season of both wheat and maize crop. The model was calibrated well for crop phenology, grain yield and N_2O-N emission for both crops.

5.2.1 Simulating the grain yield and N_2O emission from crops field

The calibrated wheat and maize model was used to simulate the response of crops (wheat and maize) to different treatments in a crop growth period and response of N_2O emission from soil of crop field. For this purpose we used the second season data for both the crops. Results showed that the crop phenology, grain yield and N_2O emission from soil in different treatments were simulated well in both wheat (Fig 4.10) and maize (4.11) crops.

In wheat crop the simulation result showed that days to 50% anthesis were simulated well in all the treatments (Fig 4.10 A). However, days to 50% physiological maturity were one to four days higher than the observed one and it is simulated well in all the condition (Fig 4.10 B). Grain yield was simulated well in all treatments except control (N0). In control it was slightly over estimated (Fig. 4.10 C). The N_2O emission from soil were simulated very well in all the treatments except control (N0). The N_2O emission in control condition is highly under estimated (Fig 4.10 D).

In maize crop days to 50% silking simulated well by the model in all treatments (Fig 4.11 A). However days to 50% physiological maturity were simulated reasonably well (Fig. 4.11 B) Grain yield was also simulated reasonably well under all the treatments except 100% FYM, where it was highly overestimated in 100% FYM condition (Fig 4.11 C). N_2O emission was slightly underestimated and simulated reasonably well in all the treatments (Fig. 4.11 D). However under control condition it was highly under estimated

Bhatia *et al.* (2012) evaluated the InfoCrop simulation model to calculate methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions from soils under rice and wheat. Indian rice fields having 42.21 million ha (Mha) area emitted 2.07, 0.02, and 72.9 Tg of CH_4-C, N_2O-N and CO_2-C, respectively. The annual emission of GHG emission from 28.08 Mha wheat-growing areas was 0.017 and 43.2 Tg of N_2O-N and CO_2-C, respectively. Pathak *et al*. (2005) also evaluated the Denitrification and Decomposition (DNDC) model for its ability to simulate nitrous oxide (N_2O), methane

(CH_4) and carbon dioxide (CO_2) emissions from Indian rice growing areas with different management practices.

5.3 Net warming potential of total N use in Indian agriculture

5.3.1 Total nitrogen used in Indian agriculture

Our estimates show that nitrogen consumption in Indian agriculture was increased by 6.5 times in last 50 years from 1961 to 2010 (Table 4.14 & Fig. 4.12.A). Total nitrogen consumption in Indian agriculture from different sources was 3.51 Tg N in 1961 (Table 4.14). Crop residue accounting of about 50% of total N, followed by Animal manure (39.44%), fertilizers (7.06) and atmospheric deposition (3.46%) (Table 4.14). However, scenario changed over the period and in 2010 total N consumption was 23.51 Tg N and fertilizers accounting about 70%, followed by crop residue, animal manure and atmospheric deposition contributed 3.9 (16.58%), 2.54 (10.79%) and 0.52 (2.23%) Tg N, respectively (Table 4.14). These results are in line with pathak *et al.,* 2014.

The N application in agriculture has accelerated nitrogen cycle rapidly by. This severe perturbation of the global N cycle has caused effects on climate due to the manifold impacts of N on the ecosystem C and N cycles and thus on GHG emissions. It causes global warming due to increased N_2O emissions from agriculture (Velthof *et al.,* 2009; De Vries *et al.,* 2010). Besides the N_2O emission from agriculture as a result of N application, it also responsible for NH_3 and NO_x emission and alteration of CH_4 and CO_2 fluxes. Keeping in view literature above mention, in present study we tried to estimate the overall net warming of nitrogen used in Indian agriculture.

5.3.2 GTP of N_2O emission.

Nitrogen (N) fertilizers contribute significantly to anthropogenic nitrous oxide (N_2O) emissions (Davidson 2009). The Nitrous oxide (N_2O) itself is a greenhouse gas, with a global temperature change potential on 100 year basis (GTP_{100}) of 290 (Shine *et al.,* 2005). Mostly N_2O is directly emitted from the agricultural soil during microbial processes namely nitrification and denitrification (Forster *et al.,* 2007; Davidson, E. A. 2009). We estimate the global temperature change potential (GTP) of N_2O emissions from Indian agriculture multiplying total nitrogen consumption by Indian coefficient

0.007 (Bhatia *et al.,* 2004). Our estimate showed that total N_2O emission from Indian agriculture is increased from 0.04 Tg N_2O in 1961 to 0.28 Tg N_2O in 2010 (Fig. 4.13A). The GTP of total N_2O emission, thus increased from 11.46 to 76.19 $TgCO_2e$ in a 20-year time-scale (GTP_{20}) (Fig. 4.14 A). However, these estimates are higher on 100 year-basis and are 12.71 to 84.50 Tg CO_2e (Fig. 4.14 B) during 1961 to 2010. As per IPCC default coefficient of 1% N_2O emission from Indian agriculture total warming due to N_2O emission are 16.05 and 106.67 Tg CO_2e on a GTP_{20} during 1961 and 2010, respectively and GTP_{100} are 17.80 and 118.31 Tg CO_2e during the respective periods. As per IPCC default coefficient value of N_2O emission from Indian agriculture and subsequent global temperature change potential on 20 and 100 year basis are on the higher side compare to Indian coefficient.

GTP of NH_3 and NO_x emissions

Being a potent green house gas (GHG) N_2O contributes directly to global temperature change potential (GTP), whereas both NO_x and NH_3 have indirect effects to GTP (Table 3.1). Nitrogen input in agriculture contributes to NO_x emissions, largely from NO volatilization from fertilized fields. These NO_x and NH_3 are transformed by physico-chemical processes in atmosphere, leading to various climate effects. NO_x after emission into atmosphere rapidly initiates photochemistry and leads to formation of ozone and hydroxyl radical. NO_x increases production of ozone, the third most powerful greenhouse gas (Berntsen *et al.,* 2005) and contributes to warming. Increasing concentration of hydroxyl radical, further remove CH_4 from the atmosphere so, NO_x can also contribute to cooling (Derwent *et al.,* 2001). CH_4 enhance the ozone concentration in upper atmosphere, so over longer timescales NO_x can also reduce production of ozone and contributes to cooling (Wild *et al.,* 2001). These oxidants contribute to cooling by forming the sulphate and organic aerosols. NO_x can be oxidised to form nitric acid which forms ammonium nitrate aerosols in presence of NH_3 (Bauer *et al.,* 2007).

Our estimates showed that the NH_3 and NO_x emission from Indian agriculture are showing the increasing trend during last 50 year. NH_3 emission from Indian agriculture was 0.64 and 4.28 Tg during 1961 and 2010, respectively (Fig. 4.13 C). Emission of NO_x was 0.02 and 0.12 Tg in 1961 and 2010, respectively (Fig. 4.13 D). Cooling impacts due to these emissions of NO_x and NH_3 were 4.92 and 32.69 Tg CO_2e on GTP_{20} and 0.03 and 0.22 Tg CO_2e on GTP_{100} during 1961 and 2010, respectively (Fig. 4.15). However, these impacts are negligible over the 100 year basis (Figure 4.13D, F & H) indicating that as the time horizon becomes longer, short-lived compounds have less effects on global temperature change potential (Pinder *et al.,* 2012).

GTP due to altered CO_2 and CH_4 fluxes

Nitrogen addition to cropland has direct impact on CO_2 and CH_4 fluxes. Due to the limitation of Nr in agriculture system, increased Nr application, increases net primary production and the fixation of CO_2 (Hungate *et al.,* 2003). Increased productivity increase carbon (C) sequestration in soil due to both increased litter production and reduced decomposition of organic matter, depending on the stage of humus formation (Janssens *et al.,* 2010). Further Nr use may decrease the oxidation capacity of soils for atmospheric CH_4, thereby decreasing the net influx of CH_4 from atmosphere to biosphere (Steudler, 1989). In aerobic soils oxidation of CH_4 by methane mono oxygenases (MMOs), is the important CH_4 uptake process (Wuebbles and Hayhoe, 2002; Wang, *et al.,* 2004). In fertilized crop field the applied N mainly ammonium ions (NH_4^+) have inhibitory effects on MMOs, because MMOs, which oxidize methane to methanol, can also oxidize NH_4^+ in soil (Wang and Ineson, 2003). The inhibitory effect of CH_4 oxidation by Nitrate ions (NO_3^-) has also been observed (Xu and Inubushi, 2004; Reay and Nedwell, 2004). Therefore, it is also important to capture these impacts of nitrogen use in agriculture on CO_2 and CH_4 fluxes for net global temperature change potential. To calculate this impact in this study we multiplied the cropland flux factors for CH_4 and CO_2 from Liu and Greaver, 2009 and total N used in Indian agriculture. In this study, increased CH_4 flux is the actually reduction in CH_4 uptake.

Our estimates show that The CH_4 flux increased from 0.05 Tg in 1961 to 0.36 Tg in 2010 (Fig. 4.13 E) contributing to 3.06 and 20.37 Tg CO_2e in GTP_{20} (Fig. 4.14 G) and 0.21 and 1.39 Tg CO_2e in GTP_{100} (Fig. 4.14 H) in 1961 and 2010, respectively. Fluxes of CO_2 decreased by 0.69 Tg to 4.57 Tg during the same period (Fig. 4.13 F) due to increased uptake of CO_2 as a result of N application (Fig. 4.15 G&H).

Net impact of N use in agriculture on GTP

We estimated the net GTP of reactive N used in Indian agriculture from 1961 to 2010, for each of the six effects all together on GTP_{20} and GTP_{100}. Net GTP of N use in Indian agriculture was 8.92 and 59.30 Tg CO_2e on GTP_{20} (Fig. 4.12 A) and 12.20 and 81.11 Tg CO_2e on GTP_{100} (Fig. 4.12 B) in 1961 and 2010, respectively. The net GTP_{20} was lower by 22.16% and GTP_{100} by 4.01% compared to the respective GTPs when N_2O emission alone was considered. On GTP_{100} basis the difference between the warming caused by N_2O alone and overall warming is less compare to GTP_{20} year basis because of cooling effect of short lived aerosols (Pinder *et al.,* 2012). Over 100 year scale aerosols effects are negligible.

CHAPTER 7

SUMMARY AND CONCLUSION

The Green Revolution in India is largely due to high yielding varieties and synthetic fertilizers, particularly nitrogen (N). Fertilizer consumption in India has increased from less than 1 million ton in the mid 1960s to almost 23 million tons today. However, increase use of N fertilizers in agriculture has led to decline in total factor productivity, N use efficiency (NUE) and together with increase in greenhouse gases (GHGs), particularly N_2O. Indian agriculture contributes 18% to total GHGs emission of the country and agricultural soil including fertilizer application contributes 23% of this through N_2O emission. The emission of GHGs from Indian agriculture is likely to increase significantly in future due to our need to increase food production. Besides N_2O, other reactive N (Nr) compounds (NH_3, NO_x, NO_3^-) are also emitted as result of application of N fertilizers. Being a potent GHG, N_2O contributes directly to global warming, whereas other Nr species such as NO_x and NH_3 have indirect effects (cooling) on climate system through aerosols formation and atmospheric ozone and methane alteration. Nitrogen application also has direct impact on CO_2 and CH_4 fluxes from agricultural soils. Hence, nitrogenous fertilizers have both cooling as well as warming impacts on the climate system. Therefore, it is necessary to include both warming and cooling impacts to estimate the net climate change impacts of N fertilizers used in agriculture.

Maize-wheat system is one of the intensively cultivated cropping systems of the country consuming significant amount of N fertilizers. Need is being felt to identify the technologies for GHGs mitigation with enhancement of productivity and sustainability of this cropping system. An experiment was carried out in the farm of Indian Agricultural Research Institute, New Delhi to (a) quantify the emission of GHGs in a maize-wheat system and assess the magnitude and cost of mitigation with suitable technologies in the upper Indo-Gangetic Plain (IGP), (b) simulate the impact of N fertilizer use on global warming potential and yield of a maize-wheat system and (c) quantify the net global warming potential of N fertilizer use in Indian agriculture.

To achieve these objectives, seven treatments i.e. N0 (control-no N was applied), N120 (120 kg N ha^{-1} through urea), N140 (NST) (140 kg N ha^{-1} through urea on soil test basis), 50% urea+ 50% FYM (120 kg N ha^{-1}, 50% N through urea + 50% N through FYM), 100% FYM (120 kg N ha^{-1} through FYM), Urea + NI (120 kg N ha^{-1}, 90% N through urea and 10% N through nitrification inhibitor-DCD) and NOCU (120 kg N ha$^{-1,}$ through NOCU) in wheat and maize crops in the wheat-maize system for two consecutive years from 2012-13 to 2013-14 were tested. In the second step the grain yield and N_2O emission were simulated from maize-wheat system using the InfoCrop model (Aggarwal *et al.* 2006). Experimental values pertaining to first season were used for initial calibration of model.The second season dataset were used for the simulation purpose. In the third step net global temperature change potential (GTP) of N use in Indian agriculture was estimated. For this we calculated the total N used in Indian agriculture from different sources. Thereafter, we estimated the emission and removal of N_2O, NH_3, NO_x, NO_3^{-1} leaching, CH_4 and CO_2. The GTP of different processes altered due to emission and removal of the above species was calculated. Finally, net GTP was estimated by adding GTPs of all the species together.

The GHG samples from different treatments were collected in triplicate by closed chamber technique and N_2O and CO_2 were analyzed by gas chromatography. The global warming potential (GWP) and green house gas intensity (GHGi) were calculated. Lastly we analyzed benefit cost ratio of each experimented treatments to judge economic viability of the mitigation treatment and to identify factors affecting cost of mitigation. The salient findings of the study are as

- The N_2O and CO_2 emission from experimented treatments in both wheat and maize crops varied significantly. The experimented treatments showed more or less similar trends in N_2O and CO_2 fluxes however the magnitude were differed. The cumulative N_2O-N in wheat crop varied from 0.36 to 1.04 and 0.36 to 1.03 kg ha^{-1} in first and second season, respectively, while in maize crop it varied from 0.28 to 0.93 kg ha^{-1} in first season and 0.29 to 0.97 kg ha^{-1} in second season. The cumulative CO_2 emission in wheat crop ranged from 446 to 909 kg CO_2-C ha^{-1} in both first and second seasons. While in maize crops it ranged from 310 to 711 kg ha^{-1} in first season and 336 to 729 kg ha^{-1} in second season.

- NOCU and urea + NI treatments showed significant reduction in N_2O-N. In wheat crop average reduction due to NOCU application was 17.3 and 19.4 % as compared to N120 treatment in first and second season, respectively. However, application of nitrification inhibitor with urea (urea + NI) showed 23.5 and 25.5% reduction in N_2O-N emission in first and second seasons, respectively.
- In maize crop average reduction by NOCU and urea + NI treatments was slight lower than the wheat crop. Average reduction in N_2O-N emission due to NOCU application was 10.3% in first season and 15.4% in second season while, reduction due to application of nitrification inhibitor was 19.5 and 23.1% in first and second seasons, respectively as compared to N120.
- In wheat crop NOCU and urea + NI treatment showed the significant reduction in CO_2-C emission compared to N120 treatment. Average reduction in CO_2-C emission due to NOCU application was 9.6% in first season and 8.6% in second season. Reduction due to application of nitrification inhibitor was 11.5 and 10.9% in first and second seasons, respectively. The reduction in CO_2-C emission in maize crop also shown, however these reductions were insignificant.
- 50% urea + 50% FYM and 100% FYM treatments also showed the reduction of N_2O-N emission compared to N120 treatment in both the crops. However, these emission reductions were insignificant. On the other hand 50% urea + 50% FYM and 100% FYM treatments showed the significantly higher emissions of CO_2-C in both the crops. In wheat crops 100% FYM treatment showed 5.3 and 11.2% higher CO_2-C emission and 50% urea + 50% FYM treatment showed 6.3 and 11.5% higher emission CO_2-C in first and second season respectively. In maize crop the 50% urea + 50% FYM treatment showed 15.5 and 16.5% higher CO_2-C emission and 100% FYM treatment showed 18.7 and 19.1% higher CO_2-C emission in first and second season, respectively.
- The calculation of GWP1 (CO_2 + N_2O) and GWP2 (N_2O) gave clear picture of net impact of different experimented treatments on contribution to global warming. The order of GWP1 among different treatments were N0 < Urea + NI < NOCU < N120 < N140 (NST) < 100% FYM < 50% urea + 50% FYM in both the season of wheat crop. However, in maize crop the order was N0 < Urea + NI < NOCU < N120 < N140 (NST) < 50% urea + 50% FYM < 100% FYM in both the season. The order of GWP2 among

different treatments were N0 < Urea + NI < NOCU < 100% FYM < 50% urea + 50% FYM < N120 < N140 (NST) in both season of both the crop.

- The combination of Urea + NI followed by NOCU was best treatments in terms of GHG (N_2O and CO_2) mitigation and lowering of GWP in maize-wheat system in both the years as compared to conventional nitrogen application (N120). The combination of 50% urea + 50% FYM and 100% FYM treatments also reduced N_2O emission there by lowering GWP1; however it enhanced the CO_2 emission.
- Urea + NI and NOCU treatments showed slightly higher yield however, these differences were insignificant. In wheat crop 2.2 and 1.4% higher yield was observed in Urea + NI treatment in first and second season, respectively, while in NOCU yield was 3.2% higher in both the season as compared to N120 treatment. In maize crop yield was increased by 0.80 and 0.21% in NOCU treatment and 1.87 and 1.18% in Urea + NI in first and second season, respectively.
- In 100% FYM and 50% urea + 50% FYM treatments grain yield was lower as compared to over N120 treatment, however these reduction were significant only in 100% FYM treatment. In 100% FYM treatment grain yield lowered by 33.2 and 26.0% in wheat crop and 46.7 and 46.8% in maize crop in first and second season, respectively.
- In both the crops cost for hiring human labour services followed by tractor operations and fertilizers and FYM were identified as main factors for total cost of cultivation. B:C ratio in NOCU treatment was slightly higher or at par with N120 treatment, however in Urea + NI treatment it was slightly lower as compared to N120 treatment in both the crops. In treatment 50% urea + 50% FYM B:C was also slightly lower than the N120 treatment. However in 100% FYM treatment it was much lower in both the season of both the crops.
- The adoption of NOCU can be a good option for GHG (N_2O and CO_2) in particular N_2O mitigation, lowering of GWP and higher economic yield in maize-wheat system. This was followed by urea + NI treatment in terms of GHG mitigation. The combination of 50% urea + 50% FYM and 100% FYM treatments also reduced N_2O emission there by lowering GWP as compared to N120 treatment in both the seasons of both crops, however it enhanced the CO_2 emission and this was also not economic too.

- Simulation analysis carried out using the InfoCrop wheat and maize models indicated that these models worked satisfactorily for different treatment condition and could be calibrated for the experiemental conditions.
- Both wheat and maize model is efficient in simulating the phenology of crop exposed to different treatment conditions. The simulated grain yield (GY) and N_2O emission from soils were satisfactory in most of the conditions. However, it overestimated the N_2O emission in control (N0) and grain yield in 100% FYM trratment in both the crop.
- Total nitrogen consumption in Indian agriculture was increased by 6.5 times in last 50 years during 1961-2010. In 1961 crop residue accounting about 50% of total N consumption followed by animal manure (39.44%). However the scenario changed over the period and in 2010 fertilizers accounting about 70% of total N used indicating that the percentage share of fertilizer to nitrogen input in India was increased tremendously from 7% in 1961 to about 70% in 2010.
- The GTP of total N_2O emission increased from 11.46 to 76.19 TgCO_2e in a 20-year time-scale (GTP_{20}). However, these estimates are higher on 100 year-basis and are 12.71 to 84.50 Tg CO_2e during 1961 to 2010.
- Net GTP of N use in Indian agriculture was 8.92 and 59.30 Tg CO_2e on GTP_{20} and 12.20 and 81.11 Tg CO_2e on GTP_{100} in 1961 and 2010, respectively. The net GTP_{20} was lower by 22.16% and GTP_{100} by 4.01% compared to the respective GTPs when N_2O emission alone was considered.

Conclusion

The maize-wheat system of the IGP is the highly productive and nitrogen intensive system and it is necessary for sustaining food security of India. However, prevailing conventional N application through urea is results in low nitrogen use efficiency (NUE) and significant contributor of GHG.

- The adoption of NOCU can be a good option for GHG (N_2O and CO_2) in particular N_2O mitigation, lowering of GWP and higher economic yield in maize-wheat system.
- Urea + NI combination was also good in terms of GHG mitigation; however it is less economic as compared to NOCU.

- The combination of 50% urea + 50% FYM and 100% FYM also reduced N_2O emission there by lowering GWP, however it enhanced the CO_2 emission, not economic and required huge amount of bulky FYM.
- Both wheat and maize model is efficient in simulating the phenology of crop, grain yield and N_2O emission from soils were satisfactory in most of the conditions. And could be calibrated for experimantal conditions.
- Total nitrogen consumption in Indian agriculture increased by 6.5 times during 1961 to 2010. Nitrogen fertilizer acts as a source of global warming as it contributes to N_2O emission. The GTP of total N_2O emission was 11.46 and 76.19 Tg CO_2e on GTP_{20} during 1961 and 2010, respectively. However, GTP_{100} was 12.71 and 84.50 Tg CO_2e during respective periods.
- Besides this nitrogen fertilizers also contributes to global cooling with emissions of NH_3 and NO_x. Therefore, while assessing global temperature change potential (GTP), both the warming and cooling effects of N use in agriculture should be considered. Our estimates in this study showed that net GTP of N use in Indian agriculture was 8.92 and 59.30 Tg CO_2e on GTP_{20} and 12.20 and 81.11 Tg CO_2e on GTP_{100} in 1961 and 2010, respectively. The net GTP_{20} was lower by 22.16% and GTP_{100} by 4.02% compared to the respective GTPs when N_2O emission alone was considered.
- Thus, both warming and cooling effects should be considered to estimate the GTP of N use in agriculture.

Contribution of fertilizer N use in India to net global warming and its mitigation in maize-wheat system

ABSTRACT

Green revolution is largely due to use of high yielding varieties and synthetic nitrogenous (N) fertilizers. Fertilizer consumption in India has increased manifold since green revolution resulting decline in total factor productivity, nitrogen use efficiency (NUE) and together with increase in greenhouse gases (GHG) emission particularly N_2O. In this study an attempt has been made to identify low N_2O emission technology with high economic benefit for maize-wheat cropping system (MWCS) in Indo-Gangetic Plain (IGP). Seven different treatments i.e., control (N0), N120, N140 (NST), 50% urea + 50% FYM, 100% FYM, Urea + NI and NOCU in wheat and maize crop of wheat-maize system for two consecutive years in 2012-13 to 2013-14 were tested. The N_2O emission in NOCU and urea + NI treatments was significantly lower than N120 treatment. 100% FYM and 50% urea + 50% FYM treatments also reduced N_2O emission, however led to higher CO_2 emission. GWP of N_2O emission among different treatments ranged from 315 to 958 kg CO_2 eq ha^{-1} in first year and 317 to 975 kg CO_2 eq ha^{-1} in second year. Among different treatment NOCU showed lowest GWP with higher B:C and urea + NI showed lower GWP with slight lower B:C. Adoption of NOCU and urea + NI in IGP on the conventional urea application in MWCS can reduce GWP with higher B:C in NOCU and slight lower B:C in urea + NI. Simulation analysis carried showed that both wheat and maize model is efficient in simulating the phenology, grain yield and N_2O emission. Phenology, grain yield and N_2O emission were satisfactory in most of the conditions. However, it overestimated the N_2O emission in control (N0) and grain yield in 100% FYM treatment in both the crop. Total N_2O emission from Indian agriculture increased by manifold during last 50 years causing global temperature change potential (GTP) of 11.46 and 76.19 Tg CO_2e on 20-year (GTP_{20}) and 12.71 and 84.50 Tg CO_2e on 100-year (GTP_{100}) during 1961 and 2010, respectively. The net GTP is 8.92 and 59.30 Tg CO_2e on GTP_{20} and 12.20 and 81.11 Tg CO_2e on GTP_{100} during 1961 and 2010, respectively. Net effects lowered by 22.16 and 4.02% than the GTP caused by N_2O emission alone on GTP_{20} and $GTP_{100,}$ respectively. Thus, both warming and cooling effects should be considered to estimate the net GTP of N use in agriculture.

भारत में शुद्ध ग्लोबल वार्मिंग में नत्रजन उर्वरक उपयोग का योगदान और मक्का–गेहूं प्रणाली में उसके शमन के लिए उपाय

सारांश

भारत में हरित क्रांति, उन्नत प्रजातियॉ और नत्रजन (एन) उर्वरकों के उपयोग से ही संभव हुई है। हरित क्रांति के बाद भारत में एन उर्वरकों की खपत कई गुना बढ गई है। जिसके कारण कुल उत्पादकता कारक एवं नत्रजन उपयोग दक्षता में गिरावट के साथ ही हरित गृह गैसों में वृद्धि हुई है, इसमें भी मुख्य रुप से नाइट्रस आक्साइड (N_2O) के उत्सर्जन में विशेष वृद्धि हुई है। इस अध्ययन में भारत के इंडो गंगेटिक मैदान (इं.गं.मै.) में मक्का–गेहूं फसल प्रणाली के लिए उच्च आर्थिक लाभ के साथ–साथ नाइट्रस आक्साइड उत्सर्जन को कम करने की तकनीक की पहचान करने की कोशिश की गई है। इसके लिए पर्यावरण विज्ञान एवं जलवायु–समुत्थानशील कृषि केन्द्र, भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली 110012 के प्रयोगात्मक प्रक्षेत्र में परिक्षण के लिए मक्का–गेहूं फसल प्रणाली का प्रयोग आयोजित किया गया। इसके लिए कुल सात उपचार 1. नियत्रिंत (बिना उर्वरक), 2. एन 120, 3. मृदा परिक्षण के अनुसार (एन140), 4. 50 प्रतिशत युरिया + 50 प्रतिशत गोबर की खाद, 5. 100 प्रतिशत गोबर की खाद, 6. यूरिया + नाइट्रीकरण अवरोधक (एन आई) एवं 7. नीम लेपित यूरिया का वर्ष 2012–13 और 2013–14 के दौरान लगातार दो वर्षो के लिए तीन प्रतिलिपी में परिक्षण किया गया। प्रायोगिक उपचारो में एन 120 उपचार की तुलना में नीम लेपित यूरिया एवं यूरिया + नाइट्रीकरण अवरोधक के उपचार में नाइट्रस आक्साइड उत्सर्जन में कमी देखी गई, इसके साथ–साथ 50 प्रतिशत युरिया + 50 प्रतिशत गोबर की खाद और 100 प्रतिशत गोबर की खाद वाले उपचारो में भी कमी दर्ज की गई। परन्तू इनमें कार्बन डाईआक्साईड (CO_2), के उत्सर्जन में वृद्धि देखी गई। प्रायोगिक मक्का–गेहूं फसल प्रणाली के विभिन्न उपचारो में संभावित वैश्विक गर्माहट (GWP) में N_2O की सीमा पहले साल 315–958 कि.ग्रा. CO_2 eq. प्रति हेक्टेयर एवं दूसरे साल 317–975 कि.ग्रा. CO_2 eq. प्रति हेक्टेयर की भिन्नता पाई गई। नीम लेपित यूरिया उपचार में सबसे कम GWP, अधिकतम लाभःलागत अनूपात के साथ पाया गया। नीम लेपित यूरिया उपचार में सबसे कम GWP, अधिकतम लाभःलागत अनूपात के साथ पाया गया। तथापि यूरिया + एन आइ वाले उपचार में भी GWP कम गया लेकिन एन 120 की तुलना में लाभःलागत अनूपात थोडा कम था। पारंपरिक यूरिया उपयोग की अपेक्षा में नीम लेपित यूरिया को अंगीकरण करके मक्का–गेहूं फसल प्रणाली से कम लाभःलागत अनूपात के साथ GWP को कम किया जा सकता हैं। यूरिया + एन आइ वाले

उपचार को भी अंगीकरण करके कूछ कम लाभःलागत अनूपात के साथ GWP को कम किया जा सकता हैं। सिमुलेशन विश्लेषण से पता चलता है कि दोनो फसल गेहूं और मक्का का आकॅलन इन्फोक्राप मॉडल को प्रयोगात्मक परिस्थितियो के अनूकूल करके फसल की फिनोलोजी, दाने की उपज और मिटटी से N_2O उत्सर्जन का कुशल अनूकरण किया गया एवं अधिकतर परिस्थितियों में परिणाम संतोषजनक प्राप्त हुए हैं। हालाकि, यह नियत्रिंत उपचार में N_2O उत्सर्जन एवं 100 प्रतिशत FYM उपचार में दाने की उपज अनूमान से अधिक दर्शाता हैं। नाइट्रोजन उपयोग के परिणाम स्वरुप भारतीय कृषि से कूल N_2O उत्सर्जन में पिछले 50 वर्षो के दौरान कई गुणा वृद्दि हुई हैं। जिसकी वजह से संभावित वैश्विक तापमान परिवर्तन (जी.टी.पी.) 11.46 एवं 76.19 टेरा ग्राम CO_2e 20 साल समय पैमाने (जी.टी.पी.$_{20}$) पर और 12.71 एवं 84.50 टेरा ग्राम CO_2e 100 साल समय पैमाने (जी.टी.पी.$_{100}$) पर क्रमशः 1961 एवं 2010 में पाया गया। कृषि में एन इस्तेमाल का शुद्व प्रभाव केवल N_2O उत्सर्जन के प्रभाव से 22.16 प्रतिशत जी.टी.पी.$_{20}$ पर एवं 4.02 प्रतिशत जी.टी.पी.$_{100}$ पर कम पाया गया। इस प्रकार, कृषि के क्षेत्र में एन उपयोग के शुद्व वैश्विक तापमान परिवर्तन का अनुमान लगााने के लिए गर्माहट एवं ठंडापन दोनो प्रभाव के उपयोग के लिए विचार किया जाना चाहिए।

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