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FLUXES OF METHANE AND NITROUS OXIDE FROM RICE FIELDS OF UTTAR PRADESH AND BIHAR: ESTIMATION AND MITIGATION OPTIONS

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ABSTRACT

The continuous increase in the concentration of Greenhouse gases (GHGs) in the atmosphere is likely to cause climate change that can result in large changes in ecosystems. Agricultural rice fields are the important sources of methane (CH_4) and nitrous oxide (N_2O), the two GHGs produced by anaerobic decomposition of organic material in flooded field. Methane from the rice paddy field escapes to the atmosphere primarily by diffusive transport through the rice plants during the growing seasons. N_2O is trapped in the soil long enough to get denitrified to N_2 but during intermittent drying of the rice fields, N_2O emission increases considerably. The quantification of GHGs from agricultural soils in India is uncertain due to varied soil types and climatic conditions. A field study was conducted using the manual closed chamber technique at 4 sites (Chachula (U.P), Meerapur(U.P), Kabar (U.P), and Rasalpur (Bihar)) in Indo-Gangetic region to continuously measure CH_4 and N_2O emissions from rice fields under various agricultural management schedules like water regimes (irrigated and rain fed), transplanting dates and nutritional amendments (fertilization application) in the year 2013. The typical day variation in the CH_4 flux was observed after the rice heading stage, during which the daily time weighted mean CH_4 flux was observed twice (09:00-10:00 and 14:00-15:00) time window (with 15 minutes interval). The results show that the value of CH_4 flux ($Kgha^{-1}d^{-1}$) varied from 0.105 to 1.573 at Chachula and 0.217 to 1.586 at Meerapur whereas at Kabar it varied from 0.093 to 6.881 and 0.12 to1.511 at Rasalpur. The value of N_2O flux ($gha^{-1}d^{-1}$) varied from 0.02 to 6.85 at Chachula and 0.2 to 7.7 at Meerapur while at Kabar it was 0.80 to 6.98 and 0.121 to 0.968 at Rasalpur respectively. The results clearly indicate that the integrative effects of water management and fertilizer application are imperative for mitigating greenhouse gas emissions in order to attenuate the greenhouse effect contributed by rice paddy fields.

Key Words : Close chamber, Greenhouse gas (GHG), Methane, Nitrous oxide, Seasonal variation, Treatment

INTRODUCTION

Rice paddies are considered as one of the most important sources of atmospheric Methane (CH_4), but at the same time they also emit nitrous oxide (N_2O) in the atmosphere and the intensity of emissions is directly associated to the application of nitrogenous fertilizer. Rice cultivation is an important agricultural crop and is used as stable food worldwide. Rice is the seed of the grass species *Oryza sativa* or *Oryza glaberrima*. As a cereal grain, it is the most widely consumed staple food for a large part of the world's human population, especially in Asia. It is the major crop and supports two third of the global population and is expected to feed large number of the ever-growing population in India. Uttar Pradesh is one of the leading producers of rice and rank second in the country. Annual rice production in the state is around 140 million metric tons. Rice is cultivated mainly in Kharif season (wet season) followed by Zaid (summer season) in the country. In Uttar Pradesh, it is cultivated in about 5.90 Mha of area encompassing five major ecological conditions including favour-rable irrigated; unfavourable rained upland; rained lowland; deep water and flood prone and inland salinity condition.

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CH_4 and N_2O are two important greenhouse gases contributing 15 and 5% of the enhanced greenhouse effects respectively. Agricultural and associated sectors produce about 50 and 70% of the total anthropogenic emissions of these gases respectively. Biological origin of CH_4 in anaerobic environment, including enteric fermentation in ruminants, flooded rice fields, and anaerobic animal waste processing, are the principal sources of CH_4 from agriculture**.** The primary sink for CH_4 is oxidation with hydroxyl radicals in the troposphere**.** The aerobic soils also make available an additional sink of 10–20% of annual CH_4 emissions. As per estimates**,** agricultural sector contributed over 80% of all-India CH_4 emissions in 1995, including 42% from livestock-related activities, 23% from rice cultivation and 16% from biomass use[1]. N_2O, with its current concentration of 311 ppmV in the atmosphere, besides being an important greenhouse gas is responsible for the destruction of stratospheric ozone[2]. Concentration of N_2O in the atmosphere is increasing at a rate of $0.22 \pm 0.02\%$ per year [3] .The concern of N_2O emission is of greater importance because of its longer atmospheric lifetime of 166 ± 16 years and higher global warming potential.

Soil is considered to be one of the major sources of N_2O emissions, contributing 65% to the global N_2O emission. Annual emission of N_2O from agricultural system amounts to 6.3 Tg, which includes the direct emission from agricultural soil and animal system and the indirect emission from agricultural soil through loss of nitrogen to aquatic system and atmosphere[4]**.** Biologically fixed nitrogen along with chemical fertilizer supplement in soil contributes to N_2O emission during the processes of nitrification and denitrification. In modern agricultural practices, consumption of nitrogenous fertilizer has risen sharply throughout the world. This is expected to increase further to meet the food demand of the growing population. Consequently, the emission of N_2O from the soil would also increase.

Carbon dioxide (CO_2), CH_4 and N_2O are major GHGs to contribute for climate change and all have significant flux contribution from agro-ecosystem and are likely to be a target for GHG mitigation[5]. Paddies are major emitter of CH_4 and emit N_2O as well. Global emissions from paddy fields range from 29 to 61 Tg/yr [6]. It has been estimated that global rice production will almost double by the year 2020 in order to meet the growing demand of billions of people for food [7]. CH_4 is one of the important greenhouse gases which account for 15% of the total enhanced global warming[8]. Its concentration in the atmosphere has increased from 0.7 ppmV in the pre-industrial time to 1.72 ppmv at present and is increasing at the rate of 0.3 % per year [9]. On the other hand the residence time of CH_4 in the atmosphere is relatively less (10 years) as compared to that of other GHGs such as CO_2 (100 year) and N_2O (170 year) [10]. Therefore, reduction of the global CH_4 emissions offers possibilities for curtailing the increasing trend of global warming on a short time scale. Low land paddy fields are one of the main anthropogenic sources of CH_4[10].It is evident that the waterlogged condition in rice field creates an anoxic environment, which is conducive for CH_4 formation by the anaerobic methanogenic bacteria[11] .In order to supplement the demand of several billions of people, the world's annual paddy output needs to be enhanced by about 65 % over the next three decades or an increase of 1.7 % per year[12]. As per estimates the rice production in south Asia has to be doubled by the year 2020 due to increase in population. Therefore, the CH_4 emission estimate from rice fields is a matter of paramount concern[11].

The major sink for atmospheric CH_4 is mainly by OH radical in the troposphere for N_2O emission, soil is considered to be one of the major sources, contributing 65% to the total global emission**.** Annual emission of N_2O from agriculture system may amount to 6.3 Tg, including the direct emission from agriculture soil through loss of nitrogen of N_2O is an integral part of the N-transformation process in soil. The biological process of denitrification, nitrification, dissimilatory nitrate reduction, assimilatory nitrate reduction and biological reaction of chemo-denitrification are the probable mechanism of N_2O emission from soil. However, it has been established that de-nitrification and nitrification are important mechanisms and rests contribute very little (< 1%) to this pool. De-nitrification in soil also use N_2O through reduction to nitrogen. Thus, de-nitrification may serve source or sink for N_2O. In the field, several factors affecting GHGs emission but water management in given rice-wheat ecosystem play a crucial role. It has been found that water regime in irrigated rice fields with large water percolation and scanting water supply; often lead to multiple aeration, which has a direct impact on CH_4 emission. On the other side, wheat crop does not have water flooding. Thus, due to oxic environment N_2O becomes important. In this study intermittently flooded water regimes were simulated at Chachula (GautamBudh Nagar), Meerapur (Muzaffarnagar), Kabar (Etah) experimental fields in western Uttar-Pradesh and Rasalpur (Gaya) in Bihar.

Wetland paddy as a source of CH_4

CH_4 emission from rice field was noted by Harrison and Aiyar in 1993, however the first *in situ* measurement of the methane flux was done in California, in the late 1970s, followed by extensive studies in countries[13].These experiments stressed the importance of rice plant as a pipe for CH_4 transport from soil to the atmosphere. At present, the CH_4 source strength of wetland rice fields is estimated at around 60 Tg per year, with a range of 20 – 100 Tg per year .These estimate are tentative and efforts are being made to make it more realistic. For this purpose International Panel on Climate Change (IPCC) has started a worldwide campaign to update the inventory of CH_4 emission from various sources.

CH_4 consumption

There are some aerobic ecosystems which function as sinks for CH_4. Such a transformation of CH_4 to CO_2 by the oxidation process is carried out by methanotropic bacteria. About 80 % of the potential diffusive CH_4 flux through the soil-water interface is oxidized in the oxic surface layers, indicating that CH_4 oxidizing bacteria in the shallow oxic surface layers of rice field operate very efficiently. Methanotrophs are a subset of physiological group of methylotrophs. Some of the microorganisms responsible for the oxidation of CH_4 are strictly aerobic, obligate methylo- or methanotropic bacteria. These microorga-nisms can use CH_4 and other C_1-compounds such as methanol as substrates. Ammonium could possibly inhibit the oxidation of methane by constraining the availability of oxygen while sulphate may cause a significant removal of methane from soil.

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$$

Estimates of CH_4 emission

The estimates on CH_4 emission from rice fields have varied considerably over time with the advance in the method of measurement and availability of more data. The best estimate of the global emission of CH_4 from rice fields is in the range of 30-70 Tg/y based on various model calculations by different groups[14]. Methane emission contributions from different countries are given in **Table 1**. The measurements in rice paddies at various locations have indicated that there are large temporal variations of CH_4 emissions differing significantly with climate, soil and paddy characteristics, fertilizers and applied organic matter. Moreover, rice is cultivated in different ecosystem, like irrigated; rain fed and deep-water rice contribute 75, 22, and 3 %of the total global CH_4 emission from paddy fields, respectively. Most of the CH_4 emitted from rice fields is contributed to be from Asia as it has 90 % of the total world rice harvested area, out of which about 52 % falls India and China. The estimates of methane emissions from Indian fields are of special importance as India has 42.2 million ha of land under rice cultivation ,of which 16.4 million ha is irrigated and the remaining is rain fed (19.7 and 5.9 million ha as lowland and upland , respectively) CH_4emission from rice paddies in India is 3.64±1.26Mt $yr^{-1.}$

Transfer of CH_4 from soil to atmosphere

The three processes control the transfer of CH_4 from soil to the atmosphere are (i) Vascular transport, (ii) Ebullition (iii) diffusion.

Vascular transport process

CH_4 is emitted from rice fields mainly by transport through rice plant and it acts as the bunches of stacks for transporting CH_4 from the rhizosphere to the atmosphere. The path of CH_4 through a rice plants includes diffusion into the root, movement through cortex and arenchyma and release to the atmosphere by micropores in the leaf sheath. CH_4 transport capacity of rice plant is dependent mainly on its size. The concept of plant mediated transport for the emission of CH_4 from the rice fields has been established by comparative measurements in rice planted and un-planted soils. It has been found that with the growth of rice plants, there is an increase in the contribution of plant –mediated CH_4 emission. As per some researchers about 50 % of CH_4 is released from the leaf blades before shoot elongation; whereas only a fraction fit is emitted through leaves as plant grow older. Although CH_4 can also be emitted through panicles, but this pathway is negligible as long as leaves and nodes were not submerged.

Table1 : Seasonal methane emission from rice field in different countries

Country	Average (Kg ha^{-1})
Philippines	175
Vietnam	336
China	256
Indonesia	161
Thailand	49
Korea	367
Japan	181
India	45

Source : Gupta and Mitra (1999)

Ebullition

Several workers have identified ebullition of gases entrapped in sediments and peats as a possible form of CH_4 release to the ambient atmosphere. The ebullition process could get affected by many factors like wind, water, temperature, solar isolation, flood water level, water table, and atmospheric pressure. It has been reported that unplanted field emit 50 % amount of CH_4 emitted by the fields planted with rice .The CH_4 ebullition is important during the early stage of flooding , when rice plant are small, whereas vascular transport becomes important as the rice plants grow older and matures.

Diffusion and factors affecting CH_4 emission

The diffusion of gases in water is ten thousand times slower than in air, and therefore, gases exchange almost stops when soils are waterlogged. The actual diffusion of CH_4 from rice fields is a function of CH_4 supply to the floodwater, its concentration in floodwater and available wind speed. Diffusion through the floodwater is generally less than 1 % of the total fluxes however, the rate –limiting step in plant –mediated CH_4 transport (vascular transport) is its diffusion across the root and shoot junction. Methane production and consumption in soil are biologically –induced processes, and therefore, are affected by prevalent weather conditions, water regime, soil properties and other cultural practices like irrigation and drainage, organic amendments, fertilization, and rice cultivars.

Temperature, pH and Redox potential (Eh)

The temperature influences CH_4 formation by regulating (i) anaerobic carbon mineralization, availability of alternative electron acceptors and (ii) methenogesis activity. At higher temperature, carbon mineralization increases and more carbon substrate becomes available, resulting in faster depletion of the alternative electron acceptor pool. However, the influence of temperature on CH_4 production is mainly through its effect on methanogenic activity. Most of the methenogesis bacteria display optimum rates of CH_4 production at around 30-35°C with very little methanogenesis between 5 and 15^0C. CH_4 emission rate increase sharply when the soil temperature rises from 10 to 30^0C. Methanogens are generally neutrophilic; therefore CH_4 production is most efficient in a pH range 6.4 to 7.8. Methanogenesis is a highly pH sensitive process and small change in the pH value sharply lowers the methane production. Below pH 5.8 and above pH of 8.8 methane production in the soil is almost completely restricted. Methanogenesis take place under anaerobic conditions. A significance low value (-150mV) of redox potential (Eh) is required for CH_4 formation and is negatively related to CH_4 emission. The soils which have high contents of iron (Fe) and organic matter, the Eh falls to –50 mV and may slowly decline further to -200 mV over period of one month. Soils low in active-Fe with high organic matter attain lower Eh value much faster, may be within a week after submergence. Flooded rice may have Eh value as low as –200 to –300 mV while Eh of -150 to 190 mV is needed for methane formation[15].

Organic substrates

Organic, manure and crop residues application can enhance methanogenesis process. The CH_4 production in paddy soils is positively correlated with soil organic-C and water-soluble organic C provides other factor, such as bacterial population and oxidizing capacity of the soil are not limiting. Rice straw introduction in the soil increase methane production by 120-800 % over that of unammended soil. Even the method of incorporation of straw is also important in regulation of CH_4 emission. Methane emission is highest with the incorporation of straw followed by straw compost, zero tillage with straw mulching and least with straw ash application [16]**.** Biogas spent slurry use as manure also results in low of methane emission compared to application of (FYM) from rice-field [17.] Use of biogas slurry, therefore, could be a mitigation option for minimizing methane flux from flooded rice fields. It has been found that growing of azolla for biological nitrogen fixation could enhance methane emission from rice field due to mediation of methane transport from floodwater of rice soil in to the atmosphere[18]. The presence of azolla could modify the chemical properties of soil, stimulating methane production and decreesing the in situ methane removal. It also lowers the Eh value, which increase the methane production. Also, NH_4^+-N content gets lowered, leading to reduction in biological methane oxidation and porosity of rice soil. Resulting in higher emission of methane.

Cultivars and mineral fertilizers

Plants influence CH_4 flux by (i) providing channels (arenchyma) for the transport of CH_4 from soil to the atmosphere, (ii) releasing root exudates or root autolysis products to methanogenic bacteria, and (iii) creating oxic environment in the anoxic soil through the transport of O_2 into the rhizosphere stimulation the oxidating of methane and inhibits methanogenesis[19]. There are variations in the quantities of CH_4 emitted from soils growing in different cultivars. Early –maturing cultivars emit less CH_4 as compared to that from late – maturing cultivars. The high yielding varieties like IR-64 show moderately high emission[20]. Such differences in CH_4 emission from the rice cultivars could be due to difference in amounts of root exudates production per plant, the CH_4 oxidizing capacity of rice roots , and the population of methanogenic bacteria in roots.

CH_4 fluxes are highly dependent on the type, method and rate of fertilizer application in field. Sulphate-containing fertilizers reduce methane emission. It has been reported that methane emission, on an average, decrease by 42 and 60 % in the ammonium sulphate treatments at rates of 100 and 300 kg N $ha^{-1,}$ respectively, compared to control[21]. Phosphogypsum, a sulphate-containing by-product of industrial production of phosphoric acid, reduced CH_4 emissions by 56-73 % when applied in combination with urea. In a field study, P applied as single super phosphate (SSP), inhibited CH_4 emission from a flooded field plot planted under rice[22]. Supplementary addition of K_2SO_4 with K_2HPO_4 mimicked the inhibitory effects of SSP on CH_4 production. In practice, use of SSP in rice cultivation could mitigate production, in addition to supplying P to the crop.

Water and salts management

Water is important in soil for gas exchange between soil and atmosphere and has impact on CH_4 emission. For methanogenesis, it is important that the soils should have enough water to create an anoxic regime. Drainage is a significant modifier of seasonal CH_4 emission pattern. A single mid-season drainage may reduce seasonal emissions and the emissions could be reduced further by intermitted irrigation yielding a 30 % reduction as compared to mid season drainage. Thus, intermittent flooding practice may be very effective in reducing CH_4 emission without a significance effect on grain productivity [23]. In a four year study in northern India , it has been observed that low emission are indirectly caused by high percolation rates of the soil and the frequency of water replenishment cause constant inflow of oxygen in the soil [24]. CH_4 emission is also inversely related to salinity and sulphate concentration in the soil. The sulphate and sulphides are considered as toxic to methanogens and hence reduce CH_4 production. Between the two main pathways of CH_4 formation, the reduction of CO_2 is less susceptible to NaCl than the decomposition of acetic acid[25]. Soil texture and mineralogy through their effects on puddling can affect percolation rate of water and thereby net emission of CH_4 in waterlogged paddy soils.

Nitrous oxide formation mechanism in soil

The biological processes of denitrification; nitrification, dissimilatory nitrate reduction, assimilatory nitrate reduction and assimilatory nitrate reduction as well as the biological reaction of chemo-denitrification are the possible mechanisms of nitrous oxide emission from soil. However, it has been established that denitrification and nitrification are the most important mechanisms other contributing very little (<1 %). The scheme of reactions in the nitrification process is explained in **Fig. 1**. Denitrification occurs when nitrate is present in anaerobic soil development wherever the microbial demand for oxygen dexceed the diffusion –mediated supply .This may well occurs where oxygen diffusion is impeded by water, either at the centers of soil or in water saturated region or wherever the local oxygen demand is exceptional high. Denitrification in soil also consumes nitrous oxide through the reduction of nitrous oxide to nitrogen. Hence denitrification may serve either as a source or as a sink for nitrous oxide. **(Table 2)**.

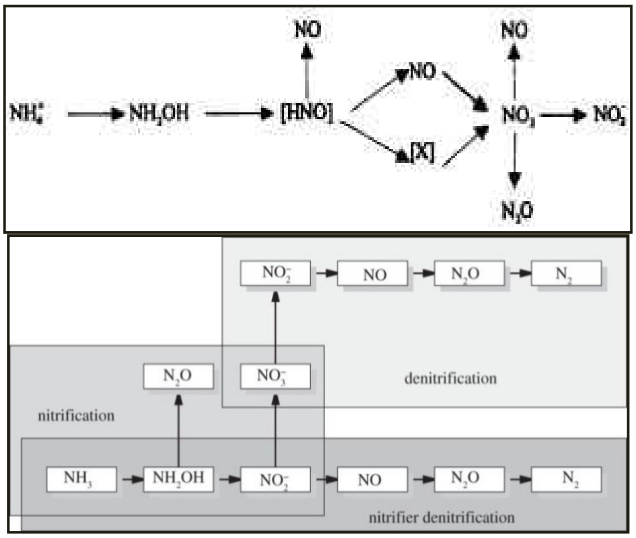

Fig. 1 : Nitrification and denitrification processes

METHODOLOGY

Sampling site and experimental design

Field experiments by employing closed chamber techniques were carried out in rice paddy system with identified locations of Chachula (Gautam Budhnagar, UP), Kabar (Etah, UP) Meerapur (Muzaffarnagar, UP) and Rasalpur (Gaya, Bihar) falling in western Uttar-Pradesh and Bihar of Indo-Gangetic-region of India. All the sites are located in the Indo-Gangetic region 28°21′N and 77°35′ E , 29°21′N 78°00′ E , 27°28′275’ N, 78° 44′ 021‘ E, and 24°51′ N 85° 00′ E, at an altitude of 191m, 214 m ,161 m ,105 m respectively above mean sea level. The climate of the Indo-Gangetic Plain (IGP) region is subtropical, semi-arid and the mean maximum and mean minimum temperatures from July to October (rice season) are found between 34 and 17^0C. Rice (*Oryza sativa*) variety of Sughand-1121 and other rice variety of PR-14 were sown in the fields. Rice were transplanted in the flooded field with 30 days old seedling Kumar et al., 2014 and the irrigation in rice field were given at 3-5 days intervals. **(Fig. 2).**

Table 2 : Source and sink of nitrous oxide

Source	N_2O -N (Tg yr^{-1})
Natural	
Oceans	1.4-2.6
Tropical Soils	
Wet Forests	2.2-3.7
Dry Savannas	0.5-2.0
Temperate Soils	
Forests	0.05-2.0
Cultivated soils	0.3-5.0
Biomass burning	0.2-1.0
Stationary combustions	0.1-0.3
Mobile sources	0.2-0.6
Adipic acid production	0.4-0.6
Nitric acid production	0.1-0.3
Total	5.2-17.0
Sinks	
Photolysis in stratosphere	7-13
Removal by soil	Not estimated
Atmosphere increase	3-4.5

Source : IPCC (1996)

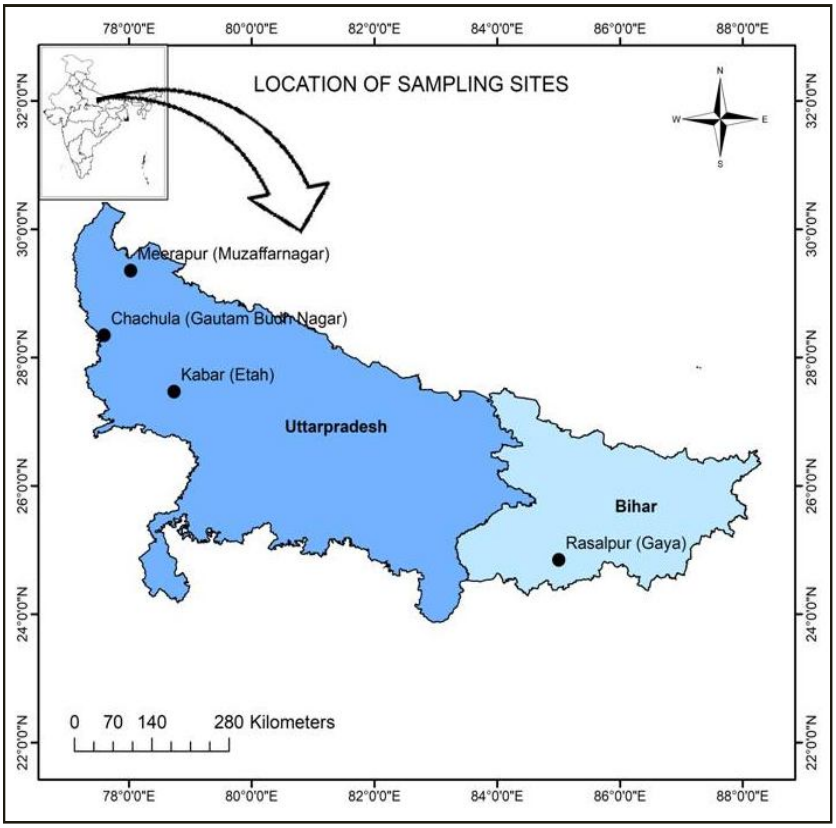

Fig. 2 : Map of sampling sites in Indo-Gangetic region, India

Collection of greenhouse gases CH_4 and N_2O from different sites

Collection of gases samples were carried out by employing previously explained closed chamber technique[26]. Chambers of 50 cm × 30 cm × 100 cm (length × width × height) were fabricated with of 6 mm thick acrylic sheets **(Fig. 3)**. An aluminium channel of 15 cm height and 5 cm internal diameter was placed in the field to mount over the each chamber. The channels were inserted with 10 cm depth in the soil and filled with water to make the arrangement as air-tight. One 3-waystopcock was fitted at the top of chamber to collect the gaseous samples. The chamber were thoroughly flushed several times with a 50 ml syringe to homogenize the inside air. Gas samples were drawn with 50-ml syringe with the help of a hypodermic needle (24 gauges).

The number of measurement per day and the time of day when measurement were taken for the flooded and non flooded rice growing period were as per protocol : two measurement per day during the 09:00-10:00 (Morning) and 14:00-15:00 (after noon) time window period. The sampling was done at 0, 30, 60 min interval to collect samples from the chamber and one ambient samples was taken prior to the sampling[27]. The chamber was lifted and kept aside after 15 min. water depth (level), channel height, plant height, number of plants, plant biomass volume, temperature inside the chamber, air and soil temperature were measured during each sample collection from the location. CH_4 and N_2O samples of gases were brought to the laboratory and their concentrations were determined by using GC (Gas Chromatography).

Fig. 3a : Close chamber method for collection of gas samples from rice field

Fig. 3b: Transplanting of rice crop in flooded field

Gaseous samples analysis through Gas-chromatography

Methane (CH_4)

Analysis of CH_4 has been done by using GC-FID (Gas Chromatography with Flame Ionization Detector) by using Porapak N column (3-m long stainless steel or nickel with 3.175 –mm outside diameter) maintained at 50 °C with a carrier gas flow (helium, nitrogen or argon) of 20 cm^3 $min^{-1.}$

Nitrogen oxide (N_2O)

Analysis of N_2O has been done by using GC-ECD (Gas Chromatography with Electron Capture Detector) is used for N_2O analysis. ECD is used for the detection of those substances which have affinity for electron. Air samples are analysed for N_2O by using GC-ECD was (operated at 300-400 °C) and by using a Porapak column (3m long stainless steel or nickel with 3.175 mm outside diameter). The temperature of column, injector and detector are generally kept at 50 °C, 120 °C, and 320 °C, respectively. The flow rates of carrier, back flush and detector purge gases (95% argon + 5% methane or N_2) are kept as 18 cm^3 min^{-1}.Gas sampling are introduced into a gas sampling loop (size depends upon the sensitive of the EC detector being used) through an inlet system .Both CO_2 and water vapors are removed from the gas samples..

Soil characteristic analysis

Soil Sample with the depth of 0 to15 cm soil layer from these four locations and with each selected plots were taken by using a core sampler. The entire volume of soil was taken to determine dry weight. The fresh soil was air –dried, sieved a 2mm screen, mixed and was stored in sealed plastic jars for the analysis. Representative sub-sample was drawn to determine physico-chemical properties of soil using standard. The physico-chemical properties of the soil are given in table **Table 3**.

Table 3 : Physico-chemical properties of soils at various experimental sites

Soil parameters	Sampling sites			
	Chachula	**Meerapur**	**Kabar**	**Rasalpur**
Clay (%)	30.08	30.92	28.06	29.02
Sand (%)	29.92	64.08	28.85	64.58
Silt (%)	40.0	32.0	39.0	31.0
Available Nitrogen (kg/ha^{-1})	295	289	290	280
pH (1:2 soil water)	5.2-6.9	5.6-6.8	5.8-7.0	5.5-6.8
S.O.C (%)	0.56	0.64	0.56	0.65

Global warming potential (GWP) and CEE (Carbon Equivalent Emission)

GWP is an index defined as the cumulative irradiative 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 GHG to trap heat in the atmosphere relative to some standard gas, by convention CO_2. The GWP for CH_4 (based on a 100-year time horizon) is 21 and that of N_2O is 310 whereas for CO_2 the value is taken as 1. The GWP of different treatments were calculated by using the following equation:

GWP ¼ CO_2þ CH_4n21 þ N_2On310: (1)

CEE value and carbon efficiency ratio (CER) of the treatments were calculated Using the following equations: CEE ¼ GWPn12=44; (2) CER ¼ grain yield (in terms of C) of the rice system[8].

RESULTS AND DISCUSSION

In our present study, measurements of CH_4 flux were carried out through the rice fields falling across the Indo-Gangetic region. Two plots were selected at each location of IGP region and different treatments were given in the plots. The first plot was treated with urea and the other plot was treated with urea and NPK to observe the effects of the treatment processes in the flux of CH_4. The samples for gases flux were studied from these plots for morning and evening hours as per the protocols described in the methodology part. The first CH_4 flux was monitored from 10 Days After Transplanting (DAT) at each site. It is observed that the magnitude of CH_4 flux varied significantly due to the treatment processes done in different plots in morning and evening at different sampling locations. When rice plants are less developed, bubble formation and vertical movement of CH_4 from the soil is the chief transfer mechanism. During early stages of rice crop value of CH_4 flux increased in both the treatments which may be attributed to reduction in oxidation rate of CH_4 due to direct transport by aerenchyma to atmosphere.

CH_4 is formed due to anaerobic condition of submerged soils by anaerobic decomposition of organic matter by methanogenesis and oxidation into CO_2 by methanotrophs in aerobic zones of rice soil and in upland soils[28]**.** The field was not continuously flooded during the experiment except on the day of irrigation and therefore anaerobic condition prevailed only for a very short period of time while aerobic condition were present for longer time during the crop cycle in different treatments. Drying period would have led to reduce the activity of methanogens and increased activity of methanotrophs due to aerobic condition. Various studies have reported a significant decrease in CH_4emission from rice field that are drained ones and several times during the rice crop.[29-31]

The gradual increase in CH_4 flux was observed in all the treatment processes during August. CH_4 emission was reported highest during September month and the value of CH_4 flux decreased by the end of the month of

October. A specific pattern of CH_4emission from the rice field was observed from the observations of all the treatments. The study was comprised of four treatments viz. T_1, T_2, T_3 and T_4 with chamber denoted as 1, 2, 3 and 4 respectively. Among the four treatments T_1 and T_2 were in morning with urea application in T_1 and involving urea+NPK application in T_2 treatment. While on the other hand T_3 and T_4 were in evening with urea in T_3 and urea +NPK application in T_4 treatment respectively.

Variations of CH_4 flux at different experimental locations

During the rice crop cycle the peak was observed on 40 DAT while the minimum value was observed on 100 DAT respectively in all the treatments at chachula **(Fig. 4)**. On the other level at Meerapur **(Fig. 5)** location the maximum value of methane flux was observed on 40 DAT in all the treatments while the minimum value was observed on 100 DAT in T_4 and 110 DAT in T_1, T_2 and T_3 respectively. At Kabar site **(Fig. 6)**, maximum value was observed on 50 DAT in T_1, T_2 and T_4 while on 60 DAT in T_3 and the minimum value was observed on 10 DAT in all the treatments. The results obtained for methane flux were found different at Rasalpur **(Fig. 7)** site where the peak was observed on 20 DAT in all the treatments. On the other hand, the minimum value was observed on 100 DAT in T_1 and 110 DAT in T_2, T_3 and T_4 respectively. It is evident that there was a notice all effect of treatment with urea+ NPK in rice fields on GHG emissions. The soil moisture level also drops below saturation many times during the crop cycle and anaerobic condition required for the formation in soil did not exist always. Therefore, in such experiment flux of CH_4 was also dictated by irrigation event. This indicated that the aerobic soil conditions during crop cycle favored the growth of methanotrophs and consumption of methane [32].

Variations of N_2O flux at different experimental locations

N_2O flux emitted from the treatments showed more or less trends with appearance of flux of N_2O emission days after urea and urea+NPK application in both morning and evening event. Urea usually takes two to three days for hydrolysis under optimum moisture and temperature condition which undergoes further nitrification resulting in peak generally three to four days after urea application. The value of N_2O flux has shown fluctuations with the treatments. At Chachula **(Fig. 8)**, maximum value was observed on 30 DAT in T_1 and T_3 while on 40 DAT in T_2 and 60 DAT in T_4 respectively. The minimum value was reported on 100 DAT in all the treatments at the site Chachula. The different pattern was reported in all the treatments at Meerapur site **(Fig. 9)** where the peak was observed on 50 DAT and the minimum value was reported on 110 DAT in all the treatments. Among the sampling sites many fluctuations in the value of nitrous oxide flux were reported at Kabar **(Fig. 10)** where the peak was observed on 60 DAT in T_1, 20 DAT in T_2, 50 DAT in T_3 and 40 DAT in T_4 respectively. The more variations were not seen in the minimum values as they were reported on 110 DAT in all the treatments studied. Rasalpur site **(Fig.11)** has also shown some similar patterns in fluctuations of nitrous oxide values with Kabar location where the peak was observed on 20 DAT in T_1 and T_2 while on 80 DAT in T_3 and 90 DAT in T_4. The minimum value of nitrous oxide flux was reported on 110 DAT in all the treatments done at Rasalpur site.

Statistical Analysis

In this paper we have also carried out descriptive statistics. **(Table 4)** The statistical parameters like mean, median, Skewness, kurtosis and coefficient of variation (COV) have been calculated for CH_4 and N_2O under various treatment regimes at various locations of chachula, meerapur, kabar and Rasalpur of IGP Region. The result of CH_4 and N_2O flux data by descriptive statistics are represented in table 4. For treatment (T-1) the emission values of CH_4 were 3.65 ± 2.00 and COV was 0.55. Under the treatment (T-2) value of mean was found $3.71\pm$ 1.88 with COV 0.55. Similarly the value of mean and COV were calculated as 3.95 ± 2.00 and 0.5 respectively under (T-3) processes and $4.09\pm$ 1.97 and 0.48 respectively under (T-4) treatment processes In case of N_2O at chachula location the average values of flux was 1.74 ± 1.43 with COV 0.82. Under treatment (T-2) mean value of N_2O was estimated 1.76 ±1.21 with COV 0.69. Under treatment (T-3) the mean value of CH_4 flux was estimated 3.61±1.96 with exhibited COV as 0.54. Under treatment (T-4) value of N_2O flux was obtained 3.94±2.21 with COV0.56. The above values have been calculated at all locations including Uttar -Pradesh as a major part of IGP Region.

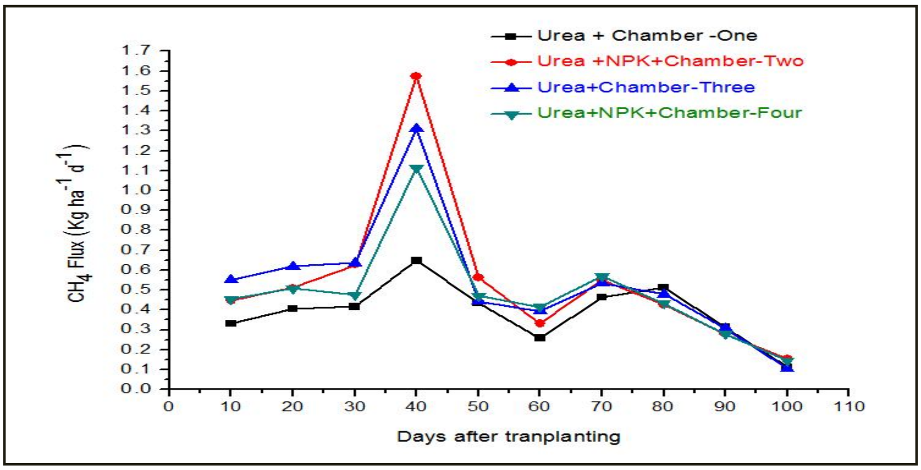

Fig. 4 : Temporal variation in CH_4 flux from Rice crop at Chachula

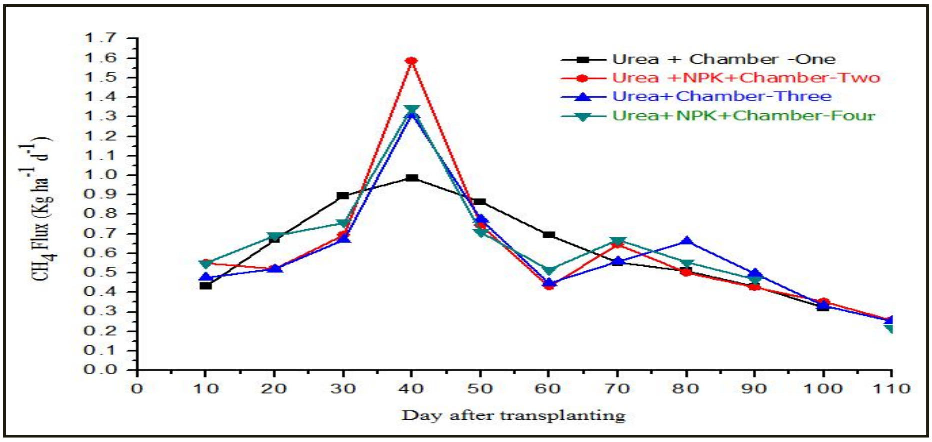

Fig. 5 : Temporal variation in CH_4 flux from Rice crop at Meerapur

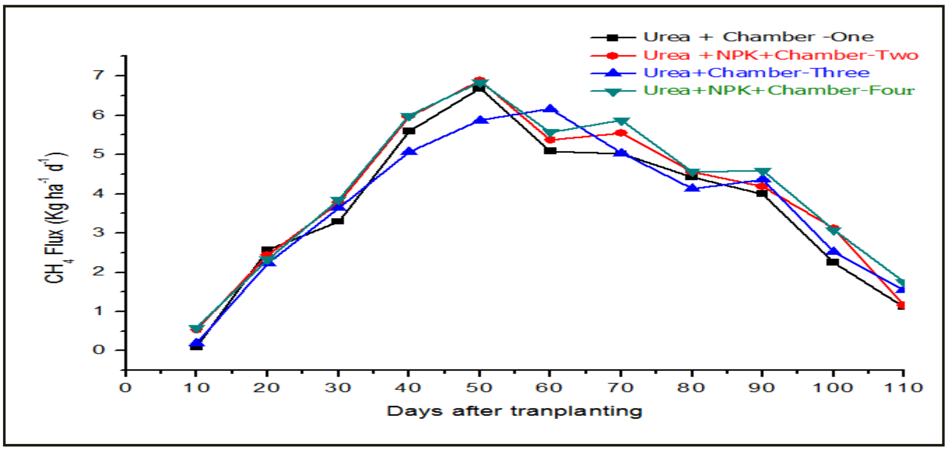

Fig. 6 : Temporal variation in CH_4 flux from Rice crop at Kabar

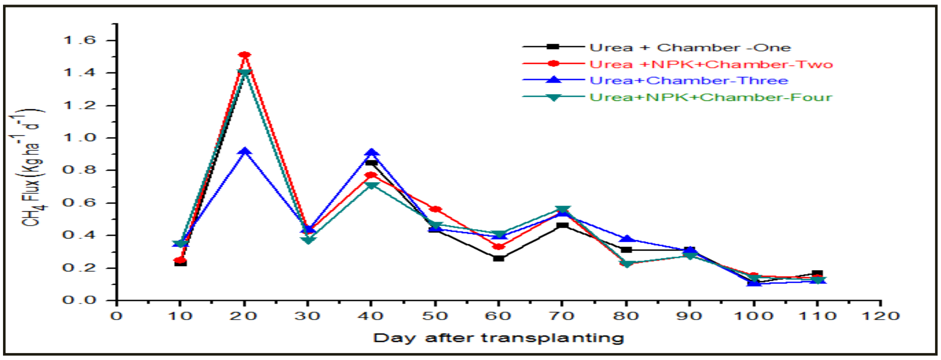

Fig. 7 : Temporal variation in CH_4 flux from Rice crop at Rasalpur

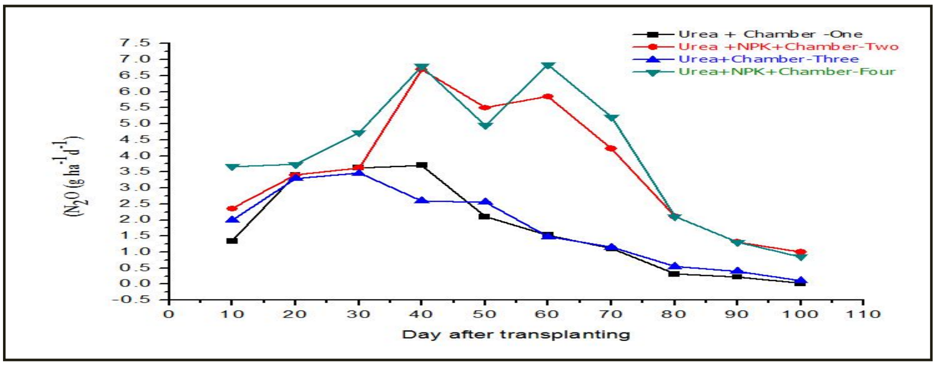

Fig. 8 : Temporal variation in N_2O flux from Rice crop at Chachula

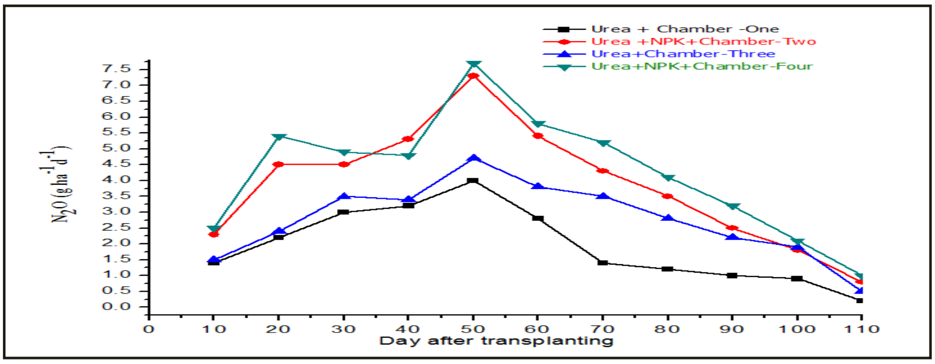

Fig. 9 : Temporal variation in N_2O flux from Rice crop at Meerapur

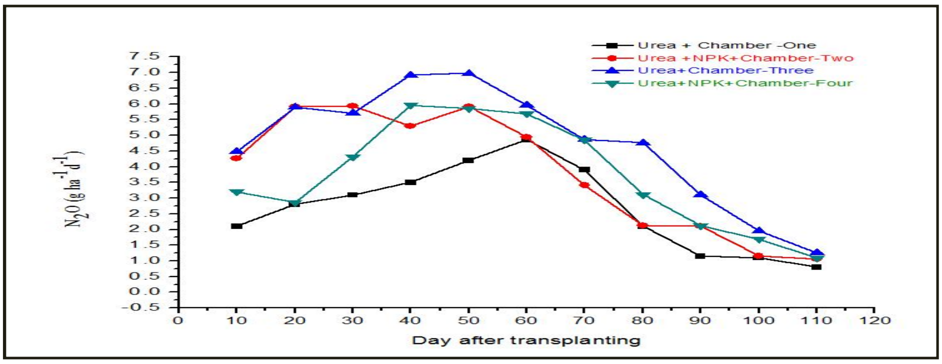

Fig. 10 : Temporal variation in N_2O flux from Rice crop at Kabar

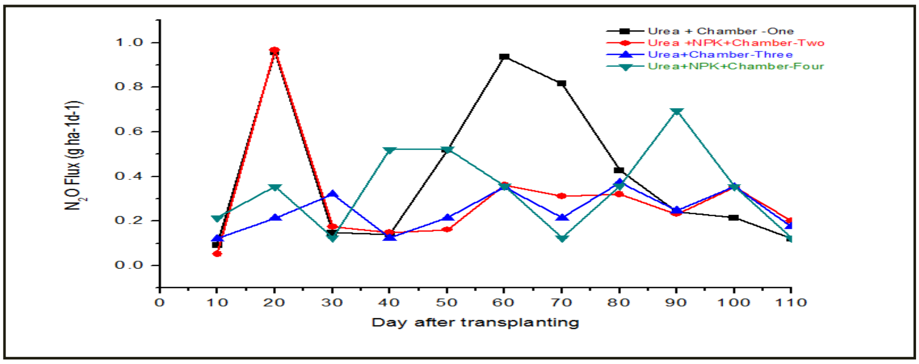

Fig. 11 : Temporal variation in N_2O flux from rice crop Rasalpur

For a location of Rasalpur which falls in Gaya, Bihar- analysis of monitoring data has been done by using descriptive statistics. In case of CH_4 emission flux the average values of flux were estimated as 0.28 ± 0.08 with COV 0.30. It may be noticed that these mean values of CH_4 flux have determined as lowest among the four locations under T-1treatment process. For the CH_4 flux under treatment (T-2) mean values of flux have been calculated as 0.19±0.11 with COV0.57.Under treatment (T-3) mean flux values were calculated as 0.26±0.08 with COV 0.30 and in case of treatment four (T-4) mean flux values were calculated as 0.27±0.06 with COV 0.21.

Table 4 : Statistical analysis of the emission flux CH_4 (Kg ha^{-1} d^{-1}) and N_2O g $ha^{-1}d^{-1}$ rice crop with treatments

Locations	Statistics	Methane (CH_4) flux				Nitrous oxide (N_2O)Flux			
		Treatment				Treatment			
		T-1	T-2	T-3	T-4	T-1	T-2	T-3	T-4
Chachula	Average	3.65	3.71	3.95	4.09	1.74	1.76	3.61	3.94
	SD	2.00	1.88	2.00	1.97	1.43	1.21	1.96	2.21
	Median	4.00	4.13	4.18	4.56	1.44	1.74	3.51	3.74
	Skewness	-0.36	-0.51	-0.39	-0.41	0.35	0.05	0.24	-0.05
	Kurtosis	-0.57	-0.59	-0.70	-0.82	-1.48	-1.48	-1.20	-1.31
	CV	0.55	0.51	0.51	0.48	0.82	0.69	0.54	0.56
Meerapur	Average	0.64	0.59	0.61	0.65	1.94	2.75	3.84	4.25
	SD	0.22	0.28	0.36	0.29	1.18	1.19	1.88	1.91
	Median	0.61	0.52	0.52	0.61	1.4	2.8	4.3	4.8
	Skewness	0.27	1.74	2.34	1.43	0.36	-0.31	0.12	-0.05
	Kurtosis	-1.23	4.23	6.58	4.05	-0.93	-0.08	-0.26	-0.15
	CV	0.35	0.48	0.58	0.45	0.61	0.43	0.49	0.45
Kabar	Average	3.65	3.71	3.95	4.09	2.69	4.72	3.83	3.71
	SD	2.00	1.88	2.00	1.97	1.36	1.90	1.94	1.73
	Median	4.00	4.13	4.18	4.56	2.8	4.87	4.26	3.2
	Skewness	-0.36	-0.51	-0.39	-0.41	0.05	-0.71	-0.31	0.00
	Kurtosis	-0.57	-0.59	-0.70	-0.82	-1.21	-0.48	-1.69	-1.44
	CV	0.55	0.51	0.51	0.48	0.50	0.40	0.51	0.47
Rasalpur	Average	0.28	0.19	0.26	0.27	0.42	0.25	0.30	0.34
	SD	0.08	0.11	0.08	0.06	0.34	0.09	0.24	0.19
	Median	0.30	0.16	0.28	0.24	0.24	0.21	0.23	0.35
	Skewness	-0.51	0.95	-0.69	0.13	0.76	0.11	2.38	0.45
	Kurtosis	-0.48	-0.34	-0.85	-1.73	-1.18	-1.39	6.80	-0.44
	CV	0.30	0.57	0.30	0.21	0.81	0.37	0.81	0.55

SD- Standard deviation; COV, Coefficient of Variation; T-1(Urea) or T-2 (Urea+ NPK) Treatment- one or two (Morning); T-3(Urea), or T-4, (Urea+NPK) Treatment –Three or Four (Evening)

In case of N_2O fluxes at Rasalpur location the mean values of emission flux were estimated as 0.42±0.34 with COV 0.81. In case of treatment (T-2) the N_2O flux values were determined as 0.25±0.09 with COV 0.37. In case of Treatment (T-3) the average flux value was calculated as 0.30±0.24 with high COV value 0.81. In the last treatment (T-4) average value of N_2O flux was determined as 0.34±0.19 with COV 0.55. Different parameters like mean, median Skewness, kurtosis and COV have been studied for the measured CH_4 and N_2O. The variation of parameters under different mode of treatment processes have been represented in **Table 4**.

CONCLUSION

CH_4 and N_2O emissions, from rice field soils in IGP region have obvious seasonal variations. There is an appreciable trade- off relationship between the emissions of CH_4 and N_2O. CH_4 emissions from rice growing season are much higher than N_2O emissions in rice field. Intermittent irrigation can significantly reduce CH_4 emission and there is a slight increase in N_2O emission. However the overall GWP of greenhouse effect is greatly decreased without significantly reducing the productivity of rice crop. Therefore, the intermittent irrigation is an effective and efficient measure to cut down the GHGs from rice fields of IGP region. The microbial processes also have effects on CH_4 and N_2O emissions. The methanogens concentration has positive correlation with CH_4 emission. It has been found that the emissions of CH_4 from rice ecosystem are higher by following the application of urea and were reduced there after the CH_4 flux have been reported higher side in evening in both the cases of treatment with urea and urea+NPK. The emissions of CH_4 were found lowest at Rasalpur site of Gaya in all the four treatments of the study. In case of N_2O the emissions were found on higher side in other locations except Rasalpur site of Gaya district where the flux values of N_2O were significantly lower in all the four treatments of the study. It has also been observed that rice crop has shown less seasonal N_2O emission as compared to CH_4 flux. Intermittent wetting and drying of soil in rice is a potential effective method to decrease the flux of CH_4 emissions. There may be slight reduction in rice yield with intermittent wetting and drying. Therefore, it is indeed required to optimize the irrigation practices to reduce CH_4 and N_2O flux without compromising with the rice productivity. It maybe, noted that rice crop ecosystem could be a major source of CH_4 and N_2O emission because of its large area of 10.5 million hectare and high use of commercial fertilizer as agricultural input. Intermittent irrigation can also be an effective water management tool to reduce green house gas emissions from rice fields.

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