भारत की विभिन्न मृदाओं से नाइट्रस ऑक्साइड का उत्सर्जन

NITROUS OXIDE EMISSION FROM DIFFERENT SOILS OF INDIA

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NEW DELHI - 110 012, INDIA

2011

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NITROUS OXIDE EMISSION FROM DIFFERENT SOILS OF INDIA

By

DINESH KUMAR

A Thesis

Submitted to the Faculty of the Post-Graduate School,

Indian Agricultural Research Institute, New Delhi

In partial fulfillment of the requirements

For the award of the degree of

Master of Science

In

ENVIRONMENTAL SCIENCES

2011

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C E R T I F I C A T E

This is to certify that the thesis entitled, **" Nitrous oxide emission from different soils in India"** submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the award of the degree of **Master in Science in Environmental Sciences,** is a record of ***bonafide*** research work carried out by **Mr. Dinesh Kumar,** under my guidance and supervision, and that 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.

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ACKNOWLEDGEMENT

I acknowledge the great power, who has paved the way on which I have walked so far. As a prelude to my thanks giving, at first I wish to thank and bow my head before Lord Almighty for blessing me all his grace to successfully complete my studies and research endeavor in IARI.

It is my to great privilege to express deep sense of gratitude to Dr. Niveta Jain Senior Scientist, Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi and the Chairman of my advisory committee, who guided me as a teacher, helped me like a friend and cared me as guardian for providing me an opportunity to work under her guidance. I am also thankful for her valuable guidance, personal attention, constructive criticism, immense patience, untiring help, wholehearted support and encouragement to me throughout the period of my study and preparation of this manuscript.

I express deep sense of gratitude and my sincere thanks and gratefulness to Dr. Himanshu Pathak ,Senior Scientist, Division of Environmental Sciences, IARI, New Delhi and Co-Chairmen of my advisory committee for encouraging me to undertake this study and providing me with his precious advice, necessary guidance and help rendered during my course of study.

I would like to extend my heartfelt gratitude to Dr. Arti Bhatia, Scientist, Division of Environmental Sciences, IARI, New Delhi and the Member of my Advisory Committee for his most valuable help rendered in relation to planning, execution and analysis of this work.

I express my heartiest and esteem sense of gratitude to Dr.T.J.Purukasthya Senior Scientist, Division of soil science and agriculture chemical, IARI, New Delhi for his constant support, valuable suggestions and timely help whenever I required.

I am highly obliged to Dr. H. C. Joshi, Head, Division of Environmental Sciences, Dr. S. D. Singh, professor Division of Environmental Sciences and all my teachers for their valuable suggestions and constant encouragement during my course of research. I feel very fortunate to come across such an affectionate personality whose constant encouragement was a catalyst in my M.Sc. Programme.

My sincere thanks go to Usha Rani Madam, and all staff members of Environmental Sciences for their timely help. I also wish to record my sincere thanks to Dr. Jagpal Singh, Durga Saran Dubey ,Ritu Tomar,Tripti Agarwal

,Savitri ji and all laboratory staffs of Division of Environmental Sciences for their help and support during the laboratory work.

No words can describe the unending love, moral support and help by my dearest friends, Gaurav Dhir, Saubhagya, Ram Kishor Fagodiya during my course of study. I wish to express my heart full thanks to my seniors Dipak Kumar Gupta, , Rachana Dubey ,Amrita Mam, Satyvan Sir, Dhanya M. S. Mam, Namita Das Mam, Sushobhit Sir, Harvinder Singh, for their moral support and all guidance during my course of study. Instead of saying thanks, I put all my good wishes for them. I also wish to express my heart full thanks to my juniors Nishant, Prassan Prabhakar, Amit Kumar ,Sweta Lakra for their support and help during my course of study.

I shall ever remain indebted and affectionately cherish the blessings and good wishes of my beloved Dadijee, Maa, Papaji, Himkar, Guriya, and all my relatives who bestowed on me from miles apart, who were the constant sources of inspiration to me.

I will ever remain indebted for the facilities and knowledge, IARI provided to me. Also, I express my sincere thanks and gratitude to the Indian Council of Agricultural Research for providing financial assistance in the form of Junior Research Fellowship during my M.Sc. Programme.

Date : ***(DINESH KUMAR)***

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INTRODUCTION

Concentration of greenhouse gases (GHG) in the atmosphere has increased substantially due to anthropogenic activities causing global warming which is adversely affecting agro-ecosystems. Nitrous oxide (N_2O) is an important GHG contributing 5% to the enhanced greenhouse effect. Agriculture and associated sectors produce about 58% of the total anthropogenic N_2O emission (Carlo et al., 2007). With its current concentration of 315 ppbv, N_2O is also responsible for the destruction of the stratospheric ozone (IPCC, 2007). Apart from its effects in atmosphere, emission of N_2O from soil results in diminution of pool of soil-N available to plant. The concern of N_2O emission is greater because of its long atmospheric lifetime of 114 ± 16 years and higher global warming potential (298 times that of CO_2). In the last 2 decades, atmospheric concentrations of N_2O continued to increase at a rate of 0.25 percent per year. There has been a significant multiyear variance in observed growth of N_2O concentrations, but the reasons for these trends are not yet fully understood (IPCC, 2001b). The N_2O emission in 2030 is projected to reach 0.60 to 0.81 Tg (10^{12} g or million ton) depending upon development and mitigation scenarios. From agricultural perspective, N_2O emission from soil represents a loss of N from soil system thereby decreasing N use efficiency.

The soil receiving chemical fertilizer and biologically fixed nitrogen contributes to nitrous oxide emission during the processes of nitrification and denitrification together with non-biological chemodenitrification. Nitrification is the aerobic microbial oxidation of ammonium ions to nitrite via NH_2OH, and then to nitrate:

$$NH_4^+ \rightarrow NH_2OH \rightarrow NO_2^- \rightarrow NO_3^-$$

When oxygen is limiting, ammonium oxidisers can use NO^-_2. N_2O is also formed in the course of denitrification, the anaerobic microbial (mainly bacterial) reduction of nitrate successively to nitrite and then to the gases NO, N_2O and N_2:

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

Chemo-denitrification involves, as its name implies, the chemical reduction of nitrite ion to N2O by compounds such as amines present in soil organic matter, and by inorganic ions (Fe2+, Cu2+), particularly in subsoil (Granli and Bøckman, 1994). It is less important than nitrification or biological denitrification as a source of N_2O from agricultural soils. Microbial production of N_2O is dependent on the presence in the soil of suitable mineral N substrates, i.e. ammonium and nitrate. Thus additions of mineral N fertilizers, and N from

other sources such as animal manures, crop residues, N_2-fixing crops, and sewage sludge (from which ammonium is released by mineralisation) to agricultural soils are recognised as major drivers of N_2O emissions (Bøckman and Olfs, 1998). Additionally, There is an another "background" source due to the mineralisation of soil organic matter (humus), and where soils have only relatively recently been brought into cultivation the accelerated decomposition of organic matter that may have slowly accumulated over thousands of years under natural forest or grassland vegetation will enhance this "background" source. Organic (peat) soils that have been drained and cultivated can give rise to particularly high N_2O fluxes (Kasimir-Klemedtsson et al., 1997). The emissions of N_2O that result from anthropogenic N inputs or N mineralization occur through both a direct pathway (i.e., directly from the soils and indirect pathways: (i) following volatilization of NH_3 and NOx from managed soils and from fossil fuel combustion and biomass burning, and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3 - from managed soils. Therefore total N_2O emitted from soils can be represented as:

$$N_2O\text{-}N\ (total) = N_2O\text{-}N\ (direct) + N_2O\text{-}N\ (indirect)$$

A range of soil and climatic factors such as moisture, temperature, soil aeration, pH, soil texture, soil carbon, and agricultural soil management activities, including irrigation, drainage, tillage practices and fallowing of land, can influence N mineralization in soils thereby affecting direct emissions.

There are uncertainties in estimation of N_2O emissions from Indian agriculture because of diverse soil, climate, land-use types, socio-economic conditions and non-availability of reliable region specific emission coefficients for nitrous oxide. India represents all the major soil orders of the world except few soil orders (Andisols, Spodosols). An accurate evaluation of the N_2O emissions from agricultural land on a field scale is required to quantify the amount of total emissions more precisely and to establish practical methods of reducing N_2O emissions. Considering the importance of N_2O in the atmosphere and the lack of information from Indian subcontinent, the present study was undertaken with the objective to estimate nitrous oxide emission from different soils of India.

2

BACKGROUND

Nitrous oxide was first discovered and prepared in 1793 by an English scientist and clergyman, Joseph Priestley. Nitrous oxide, also known as laughing gas, a term coined by Humphrey Davy of the Pneumatic Institute, Bristol, England, is a colourless, almost odourless gas with a molecular weight of 44, a specific gravity of 1.53, and a boiling point of -89^{o} C (Pathak, 1999). Soil is considered to be one of the major sources of N_2O emissions contributing 65% of total global emissions (Prather et al., 1995). Nitrous oxide (N_2O) with its current concentration of 319 ppb is an important GHG accounting for approximately 5% of the total greenhouse effect. It is also responsible for the destruction of stratospheric ozone (IPCC, 2007). Agricultural soils contribute 65% of anthropogenic N_2O (Mosier et al., 1998). So this increasing concern about the global consequences N_2O emission from soil has led to various researches on N_2O emission, N_2O emission pattern and factors controlling emission of N_2O by various scientist and organization.

IPCC (1992) reported that, the global N_2O emissions from natural soils were estimated to be in the range 3.2-7.7 Tg N yr^{-1}, while the additional emission from agricultural soils was very uncertain (0.03-3.0 Tg N yr^{-1}). IPCC further in 1995 reported that, the direct contribution from agricultural soils receiving N from mineral fertilizers, manure and N-fixing legumes is 3.5 (1.8-5.3) Tg N yr^{-1}, i.e. nearly 25% of the total global source strength of 14.7 Tg N yr^{-1}.

Bandibas and Vermoeson (1994) have tested 18 different soil samples in laboratory during 20 days incubation under three different moisture regimes: the field capacity, saturation and waterlogged conditions. The highest nitrous oxide production and consumption occurred under saturated conditions, confirming development of marginal anaerobic condition (Savannah grassland).

More recently, using the IPCC Phase II methodology (1997), the direct emissions from agricultural soils have been estimated at 2.1 (0.4-3.8) Tg N yr^{-1}, with a total from agricultural systems (including emissions from animal production and indirect emissions derived from N of agricultural origin) of 6.3 Tg N yr^{-1} (Mosier et al., 1998). Dobbie and Smith (2001), reported that emission of N_2O from grassland soil were always greater than those from arable soil although ratio narrowed with increasing temperature.

Yu et al. (2001) studied the N_2O and CH_4 mission under different soil redox potential, the results showed that the N_2O emission was regulated within a narrow redox potential range of +120 to +250 mV, due to the balance of N_2O production and its further reduction to N_2. In this study, N_2O and CH_4 emissions were found to occur at a distinctly different soil redox potential condition. The range of soil redox potential values where both N_2O and CH_4 emissions were low and was found to be different for different soils, but it ranged between +120 and –170 mV, this was a wide redox potential range enabling field management practices to minimize both N_2O and CH_4 emissions from wetland ecosystems.

Dobbie and Smith (2003) studied N_2O emissions from N-fertilised ungrazed grassland and arable land at sites widely distributed across Great Britain during 1999–2001. The closed static chamber method was used throughout. Emissions varied widely throughout the year at each site, and also between sites. Daily fluxes up to 1200 g N_2O–N ha^{-1} d^{-1} were recorded. The highest annual flux was 27.6 kg N_2O–N ha^{-1} at a grassland site in Wales, whereas the lowest, 1.7 kg N_2O–N ha^{-1} occurred on a soil overlying chalk in southern England. The key factors affecting N_2O emissions from agricultural soil were soil water-filled pore space (WFPS), temperature and soil NO_3^-–N content.

Maljanen et al., (2003) studied the N_2O emissions with a static chamber technique during 2 years from a drained organic soil in eastern Finland. After drainage, the soil was forested with birch (*Betula pendula* Roth) and 22 years later, part of the forest was felled and then used for cultivation of barley (*Hordeum vulgare* L.) and grass. The annual N_2O emissions from the cultivated soil (from 8.3 to 11.0 kg N_2O-N ha^{-1} yr^{-1}) were twice the annual emission from the adjacent forest site (4.2 kg N_2O-N ha^{-1} yr^{-1}).

Huang et al., (2004) investigated the influence of plant residues decomposition on N_2O emission, laboratory incubations were carried out for a period of 21 days using urea and five plant residues with a wide range of C: N ratios from 8 to 118. Incorporation of plant residues enhanced N_2O and CO_2 emissions. The two gas fluxes were significantly correlated (R^2=0.775, p<0.001). Cumulative emissions of N_2O and CO_2 were negatively correlated with the C: N ratio in plant residues (R^2=0.783 and 0.986 for N_2O, and 0.854 for CO_2, respectively). A negative relationship between the N_2O–N/NO_3^-–N ratio and the C: N ratio was observed (R^2=0.867) when residue plus urea was added. The N_2O emission fraction, defined as

N_2O–N emissions per unit N input, was not found to be a constant for either residue-N or urea-N amendment but dependent on C/N ratio when plant residue was incorporated.

Pilegaard et al., (2006) measured the soil emissions of NO and N_2O continuously at high frequency for more than one year at 15 European forest sites as part of the EU-funded project NOFRETETE. The highest NO emissions were observed from coniferous forests, whereas the lowest NO emissions were observed from deciduous forests. The NO emissions from coniferous forests were highly correlated with N-deposition. No significant correlation between N_2O emission and N-deposition was found. The highest average annual N_2O emission (20 g N_2O-N m^{-2} ha^{-1}) was found in an oak forest in the Mátra mountains (Hungary) receiving an annual N-deposition of 1.6 gm^{-2}. N_2O emission was significantly negatively correlated with the C/N ratio.

Ciarlo and Conti (2008) evaluated the effect of the chemical nature and application frequency of N fertilizers at different moisture contents on soil N_2O emissions and N_2O/ (N_2O+N_2) ratio. The research was based on five fertilization treatments: unfertilized control, a single application of 80 kg ha^{-1} N-urea, five split applications of 16 kg ha^{-1} N-urea, a single application of 80 kg ha^{-1} N–KNO_3, five split applications of 16 kg ha^{-1} N–KNO_3. Cumulative N_2O emissions for 22 days were unaffected by fertilization treatments at 32% water-filled pore space (WFPS). At 100% and 120% WFPS, cumulative N_2O emissions were highest from soil fertilized with KNO_3. The split application of N fertilizers decreased N_2O emissions compared to a single initial application only when KNO_3 was applied to a saturated soil, at 100% WFPS. Emissions of N_2O were very low after the application of urea, similar to those found at unfertilized soil. Average N_2O/(N_2O+N_2) ratio values were significantly affected by moisture levels ($p = 0.015$), being the lowest at 120% WFPS. The N_2O/ (N_2O+N_2) ratio averaged 0.2 in unfertilized soil and 0.5 in fertilized soil, although these differences were not statistically significant.

Measurement of N_2O emission from Indian soils started only in 1990s. Requirement of sophisticated laboratory facility for N_2O emission restricted such studies to a few laboratories. Some measurements of N_2O from grassland and wasteland in India have been done by Parashar et al., (1991). Studies in the Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi showed that the emissions of N_2O from rice fields fertilized with urea ranged from

0.06 per cent to 0.8 per cent of the applied fertilizers. Soils amended with urea emitted the highest amount of N_2O followed by ammonium sulphate and potassium nitrate amended soils of wheat crop. In case of paddy soils potassium nitrate applied plots emitted the maximum compared to ammonium sulphate (Ghosh et al., 1998).

Emissions of N_2O from anthropogenic activities in India have been estimated based on actual field measurements as well as available default methodologies. N_2O emissions from fertilizer application amount to 199-279 Gg N_2O yr^{-1}. Parashar et al., (1991) estimated N_2O emissions from irrigated and upland paddy fields in India ranging from 4 - 210 and from 2 - 10 Gg yr^{-1}respectively. The use of nitrification inhibitors like DCD, neem cake and nimin has been used by Majumdar et al., (2000) to reduce N_2O emission. The loss of nitrogen as N_2O was 0.010, 0.016, and 0.013 % of fertilizer nitrogen added when DCD, neem coated urea and nimin coated urea were used, respectively as compared to its loss when only urea was used (0.018%) , considering the sources of soil nitrogen and the role of soil moisture in influencing nitrification and denitrification processes.

A study was conducted to examine the effects of different nitrogenous fertilizers on emissions of N_2O from alluvial soil at submerged and field capacity moisture regimes (Majumdar et al., 2000). At submergence maximum amount of N_2O was emitted when urea was used followed by ammonium sulphate, ammonium chloride and potassium nitrate and the least in unfertilized control (Majumdar et al., 2000). The loss of nitrogen as N_2O was 0.001 - 0.2 % of the applied N at submergence while the value of the same at field capacity was 0.005-0.72%. This author also reported that at different levels of soil N ranging from 50 to 300 ppm nitrogen lost as N_2O was 0.06-0.15 % of the applied N. Pathak et al. (2002) reported that the emission from rice fields ranged from 0.16 to 0.93 kg N_2O-N ha^{-1} while from wheat fields it varied from 0.31 to 0.71 kg N_2O-N ha^{-1} depending upon the fertilizer and irrigation treatments. In rice-wheat system, typical of a farmer's field in Indo-Gangetic plains, where generally 240 kg N ha^{-1} yr^{-1} is applied through urea, N_2O-N emission is 1.57 kg ha^{-1} (0.38% of applied N). Malla et al. (2005) observed a reduction of N_2O emission on application of neem cake, thiosulphate, coated Ca carbide and DCD in wheat. Cameron et al, (2004) observed the high effectiveness of a nitrification inhibitor, dicyandiamide (DCD), in reducing N_2O emissions from animal urine patches in four different soils in New Zealand. Total N_2O emissions from animal urine patches ranged from 1 to 20.9kg N_2O-N ha^{-1} without DCD. These

were reduced to 0.31-5.7kg N_2O-N ha^{-1} by the use of DCD, representing 61-73% reductions (with an average of 70% reduction). Verma et al., (2007) found that with increasing concentration of DCD i.e. from 6 to 12% of nitrogen applied in the form of urea, decreased both average and peak N_2O emissions. However, from 14% DCD treated soil; there was a non-significant alteration in the N_2O emission. Duxbury et al. (1982) found that the annual emissions of N_2O-N from the mineral soils ranged from 0.9 kg N ha^{-1} to 0.42 kg N ha^{1}, whereas for the organic soils it ranged from 7 kg N ha^{-1} to 165 kg N ha^{-1}.

Based on the studies on N_2O emission in India, Bhatia et al., (2004) estimated that 79.9 Gg per annum of N_2O-N emission from Indian agricultural soil for the base year of 1994-95 using the IPCC (1996) methodology. Due to increased area under different crops, higher use of N fertilizers and also increase in animal population there was a linear increase in the emission of N_2O-N in India from 1980-81 onwards ranging from 38.2 to 107.9 Gg yr^{-1}. From agricultural perspective, N_2O emission from soil represents a loss of soil N.

2.1 Mechanism of N_2O emissions

Biological processes (denitrification, nitrification, dissimilatory nitrate reduction and assimilatory nitrate reduction) as well as abiological reactions (chemodenitrification) are the possible mechanisms of N_2O emissions from soil. However, it has been established that denitrification and nitrification are the most important mechanisms (Sharawat and Keeney, 1986) others contributing very little to this pool (Webster and Hopkins, 1996).

2.1.1 Denitrification

Denitrification occurs when nitrate is present in anaerobic micro sites developed wherever the microbial demand for O_2 exceeds the diffusion mediated supply (Arah and Smith, 1989). This may well occur where O_2 diffusion is impeded by water, either at the centers of soil (Smith 1980) or in water saturated regions (Arah, 1988) or wherever the local O_2 demand is exceptionally high (Parkin, 1987). Denitrification in soils also consumes N_2O through the reduction of N_2O to N_2 (Firestone et al., 1980). Hence this bacterial process may serve either as a source or as a sink for N_2O. Studies suggest that denitrification is the dominating process that leads to N_2O emissions (Thornton et al., 1997).

2.1.2 Nitrification

Nitrification also contributes to N_2O emissions following ammonium fertilizer or ammonia forming fertilizer addition to soils during the oxidation of NH_4^+ or NH_2OH to NO_3^- (Bremner and Blackmer, 1981) Definitive evidences are available on N_2O release from even aerobic soils treated with ammoniacal fertilizers (Bremner and Blackmer, 1978).

The relative importance of either of these processes in N_2O emissions from soil is difficult to assess and is likely to vary appreciably with the type of N fertilizer, land management, climate and other factors affecting soil conditions (Vermoesen et al., 1996). At present there are no laboratory manipulations, which permit delineation of these two processes as sources of N_2O. However, Dendooven et al. (1998) have made an attempt by differentially ^{15}N-labeling the NO_3^- and NH_4^+ pools in soils. They proposed that by periodically measuring and comparing the enrichments of the N_2O, NH_4^+ and NO_3^- pools, the relative importance of the two processes could be quantified. Dendooven et al. (1998) found that N_2O produced through nitrification was 33% of the total N_2O emitted after pig slurry application to a loamy soil.

2.1.3 Other microbial processes

Nitrous oxide production is reported in micro-organisms with dissimilatory NO_3 reduction, with respiratory NO_3 reduction to N_2O and with assimilatory NO_3 reduction to NH_4. All these metabolic pathways typically produce N_2O but not N_2 and they do not gain energy by producing N_2O. They have thus been named non-respiratory N_2O producers in contrast to respiratory N_2O producing denitrifiers (Tiedje, 1988). N_2O seems to be produced also by nitrate reductase acting on NO_2. However, this evidence is still restricted to *E.Coli* (Smith, 1983) and to bean leaves (Klepper, 1987).

2.1.4 Chemical formation of N_2O

Nitrous oxide can also be formed by chemical reactions when NO_2 or NH_2OH are decomposed in acid soils, producing N_2O.

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

However, the formation of N_2O by chemical reaction of NO_2 and hydroxylamine does not seem to be important since there was no significant increase of the rate of N_2O production by the addition of NO_2^- or NH_2OH in soils (Yoshinari ,1990) also reported

that the chemical production of N_2O in soil and other ecosystems is of minor importance as a source of N_2O since the reaction becomes significant only in the presence of relatively high NO_2 concentration (>1 mM), which is not commonly found in natural environments.

In spite of lot of work on the mechanism of N_2O emissions, the primary source of observed soil emissions is often uncertain. It is generally assumed that the majority of N_2O production occurs in the proximity to the surface (Conrad et al., 1983). However, Burton and Beauchamp (1997) observed a significant sub-surface N_2O production. They emphasized the need to examine the soil as a three dimensional body for the production, transport and storage of N_2O. Seiler and Conrad (1981) concluded that N_2O produced at depths are likely to be consumed in the upper soil layer during the upward transport by a diffusive process. This process of N_2O reduction to N_2 during diffusion would be enhanced if the soils were wet, since the diffusion coefficient of N_2O is much less than that of N_2 (Letey et al., 1980).

2.1.5 Factors affecting the emissions of nitrous oxide

A range of soil, climate and management factors affect the emissions of N_2O from soils (Sharawat and Keeney, 1986; Webster and Hopkins, 1996). Some of the important findings are presented here.

2.1.5.1 Moisture regime

Soil water can directly and indirectly influence denitrification through 1) provision for suitable conditions for microbial growth and activity; 2) restricting supply of O_2 to micro-sites by filling soil pores 3) release of available C and N substrates through wetting and drying cycles and 4) providing a diffusion medium through which substrates and products are moved to and away from soil microorganisms. However, the primary effect of water on N_2O production in aerobic and partially aerobic soils is to restrict O_2 levels by reducing the air-water interfacial area within air-filled pores thus producing the anaerobic condition (Davidson, 1992). Generally, an increase in denitrification rates following irrigation and precipitation is commonly observed (Ryden and Lund, 1978). Soil water content was a key factor controlling continuously aerobic samples produced small amounts of N_2O, whereas alternate anaerobic and aerobic cycles of varying duration increased the emissions of N_2O by several folds. Drying soils increases the capacity of soil to denitrify by increasing the amount of

readily available organic C. Hysteresis was observed whereby a decrease in denitrification occurred when moist soils were dried, whereas wetting dry soils resulted in an increase in the amount of N denitrified and the amount of N was dependent upon the antecedent moisture conditions.

2.1.5.2 Oxygen

Oxygen is considered to be inhibitory for denitrifying enzymes (Knowels, 1982) although the critical limit of O_2 varied among different species of denitrifying bacteria. The N_2O yield during nitrification activity is inversely correlated with the concentration of dissolved O_2 (Anderson and Levine, 1986). Firestone et al. (1980) found that increased O_2 content enhanced the production of N_2O relative to N_2 during denitrification. Under anaerobic conditions, -N_2O production was initially found to increase, but this was followed by N_2O consumption in the system and its conversion to N_2 by N_2O reductase. This was also confirmed by Firestone et al. (1980) who reported that the soil could act as a N_2O sink under anoxic conditions. They also reported that N_2O emissions were higher in soils with fluctuating redox potential established by alternate wetting and drying cycles.

2.1.5.3 Soil pH

The optimum pH for N_2O emissions via denitrification varies with species and age of organisms and NO_3 concentration but most denitrifiers have optimum pH for growth between 6 and 8. Although the process is favoured at slightly alkaline pH, it proceeds to pH as low as 3.5 and can account for significant N losses in acid soils. Soil acidity through various mechanisms may modulate the emissions of nitrous oxide. Firstly, increased soil acidity may lower the decomposition rate of soil organic matter (Perrson et al., 1989), hence reducing the availability of N substrate for N_2O production. Secondly, higher soil acidity directly reduces nitrification and denitrification (Bramley and White, 1989). Thirdly, acidification may severely inhibit N_2O reductase with the result that denitrification yields more N_2O than N_2 (Weir and Gillam 1986). Fourthly, decreasing pH reduces the availability of molybdenum that in turn may reduce the synthesis of NO_3 reductase, a molybdo-protein enzyme. Fifthly, with decreasing pH, NO_2 formed by NO_3 reduction would become toxic and solubilization of aluminium or manganese might cause toxicity effects (Firestone, 1982). Finally, severe acidification may induce chemical production of N_2O from NO_2. However, the actual mechanism of

controlling NO_2 emissions in acid soils is still unknown. Firestone et al., (1980) reported that the influence of soil acidity is exerted through or to be interacted with the effect of NO_3 or NO_2 concentration. Sitaula et al., (1995) reported that N_2O fluxes was significantly reduced at pH 3, it increased when the pH was increased to 4 but at pH 5.5 it decreased with no fertilizer as well as with the application of 90 kg N ha^{-1}. It is generally accepted that evolution of N_2O relative to N_2 increases with increase in pH (Webster and Hopkins, 1996; Firestone, 1982).Some worked done by scientist on factors affecting N_2O emission is given below

2.1.5.4 Soil texture

The effect of soil texture on N_2O emissions likely results from physical variations in air and water proportions. Water infiltration rate and gas diffusion rates are greatly influenced by soil texture and hence N_2O emissions. Mosier et al. (1998) reported greater rates of N_2O emissions in finer textured soils. Small N additions did not result in an immediate increase in N_2O emissions from sandy loam soil but did significantly increase N_2O flux from clay loam soil (Mosier et al., 1998). Conversely, highest flux was observed from sandy soil followed by loamy and clayey soil from rice paddy fields (182.2, 82.8, 68.7 $\mu gm^{-2}h^{-1}$ respectively. The estimate of N_2O production rates at several depths demonstrated that sites of N_2O production was only near the soil surface.

2.1.5.5 Temperature

Temperature plays a significant role in the process of N_2O emissions. The N_2O emissions increased with increase in soil temperature from up to 40^oC (Blackmer et al., 1980) however, the optimum temperature for denitrification to be in the range of 60 - 70^oC (Keeney et al., 1979). It is argued that the high optimum temperature for denitrification is actually due to a combination of biological and chemical reactions. As thermophilic temperature approached, thermophilic nitrate respirers and chemodenitrification reactions dominate (Keeney et al., 1979). The thawing of frozen soil can lead to a temporal increase in N_2O production (Broadbent and Clark, 1965). Christensen and Tiedje (1990) reported brief and vigorous N_2O fluxes during rapid thaw events in the spring in a sandy loam. Peak flux rates of 486g N ha^{-1} d^{-1} as N_2O were observed in NO_3 amended soils. They observed that field production of N_2O was two orders of magnitude higher at thaw in the spring than at any time during the rest of

the year. This may be due to changes in solubility, production near the soil surface and diffusion from depth.

2.1.5.6 Fertilizer Application

Global emission of N_2O from cultivated land is estimated to be 3.5 Tg N per year out of which synthetic nitrogenous fertilizer contributes 1.5 Tg annually. Plants grown on normally aerated soil can release significant amounts of N_2O into the atmosphere. N_2O dissolved in water is taken up by the plant roots and conveyed to the leaves through the transpiration stream (Chang et al., 1998). Production of N_2O from soil during denitrification and nitrification increased in N-fertilized systems (Mosier et al., 1986). However, Blackmer et al., 1980 reported that the amount of N_2O evolved from plots treated with $(NH_4)_2SO_4$ or urea markedly exceeded those from plots receiving the same amount of N as Ca $(NO_3)_2$. These are the evidence that most of the N_2O evolved from soils is generated by nitrifying microorganisms (Brietenbeck et al., 1980). It has also been observed that the N_2O emissions are larger from soils fertilized with anhydrous NH_3 than those of fertilizers with NO_3 and NH_4 sources (Duxbury et al., 1982) and also reported that on an average, the emissions of N_2O-N induced by anhydrous ammonia was 13 times more than that induced by aqueous ammonia or urea and represented 1.2% of the anhydrous ammonia-N applied. They attributed this to the fact that the customary method of applying anhydrous ammonia by injection into soil produces highly alkaline zones and results in high N_2O emissions. Bremner and Blackmer (1978) observed that the emissions of N_2O was more with the application of urea followed by ammonium sulphate and nitrate fertilizers at 60 per cent water holding capacity. Rice paddy field applied with ammonium sulphate emitted more N_2O than with urea and N_2O -N losses of applied ammonium sulphate and urea ranged from 0.038 to 0.28% and 0.033 to 0.16%, respectively. On the other hand, urea, which is widely used nitrogenous fertilizer in the country has been reported to contribute to maximum amount of N_2O emission followed by ammonium sulphate, ammonium chloride and potassium nitrate from alluvial soil at submerged and field capacity moisture regimes (Majumdar et al., 2000) and observed no unique dependence of N_2O emissions on fertilizer N application that was applied in ammonium form. Lindau et al., (1990) reported that the emissions of N_2O due to fertilizer addition were low in lowland rice and there was no increase of N_2O emissions with urea addition above control. In maize field, however, the emissions of N_2O with urea was about two times as that of

$Ca(NO_3)_2$ (Duxbury and McConnaughey, 1986). Eichner (1990) summarized the data from 104 field experiments and estimated that 2.7% of anhydrous ammonia, 0.44% of ammonium nitrate, 0.25% of ammonium type, 0.11% of urea and 0.05% of nitrate were lost as N_2O. However, his estimation differed significantly from that of Galbally (1985), who estimated that 0.5 % of anhydrous ammonia, 0.1% of ammonium nitrate, 0.1% of ammonium type, 0.5% of urea and 0.05% of nitrate were emitted as N_2O. IPCC currently assume an N_2O emission factor of 1.25 ± 1% of fertilizer N applied. Nitrous oxide emission not only depends on the type of fertilizer N used but also on the mode of application of fertilizer N. The fertilizer derived N_2O-N losses from 250 Kg N ha^{-1} of urea incorporated in the plough layer was less than (0.15%) than band application of lower rate of N applied through urea (0.27%) (Xiaoyuan Yan et al., 2001).

The form of N fertilizer affected N_2O emissions with higher emissions in case of NH_4NO_3 and NH_4SO_4. The proportion of applied N lost as N_2O varied 0.42% to 0.55% with the form of N applied suggesting that controlling this factor would not be an efficient way of limiting N_2O emissions under certain climatic and pedological conditions (Henault et al., 1998). Coating of urea with polyolefin did not have any influence on N_2O emission (Xianoyuan Yan et al., 2001). The effects of urea, ammonium sulphate, potassium nitrate and ammonium nitrate on nitrous oxide emission from soil at field capacity and submerged condition were studied during 120 days in the laboratory. Total emission of nitrous oxide was higher at submergence as compared to field capacity regardless of fertilizer type. At field capacity soil fertilized with urea emitted highest amount of N_2O while under submerged condition the emission was highest in soils with ammonium nitrate (Pathak and Nedwell, 2001).

Addition of nutrients such as P and liming materials such as $CaCO_3$ can also affect N_2O evolution from soils in some situations. Lindau et al., (1990) found that application of P or $CaCO_3$ increased emissions of N_2O under aerobic conditions. However, P induced emissions were larger than those obtained with $CaCO_3$. Lindau et al., (1990) also observed that addition of $CaCO_3$ increased emissions but P addition had no effect.

2.1.5.7 Amendment with organic manure

Denitrifiers use organic C compounds as electron donors for energy and synthesis of cellular constituents. Plant residues, green manure and farm yard manure have been reported to increase rates of denitrification (Aulakh 1988). Cabrera (1994) observed

that maximum rates of N_2O emissions occur within the first 4 days after poultry litter application. The highest emission rate occurred with fine poultry litter particle followed by palletized litter. N_2O emissions have been shown to be directly correlated with BOD content of slurry applied to the soil. The available microbial organic carbon seems to determine the amount of N_2O emitted shortly after slurry application (Clemens and Huschka 2001). These emissions originate from rapid nitrification and denitrification induced by manure, since they contain considerable amounts of ammonium and readily available organic carbon (Granli and Bockman, 1994).

Soils receiving industrially and biologically fixed N contribute to these emissions during denitrification and nitrification (Bremner and Blackmer, 1978). Due to advent of modern agriculture, consumption of nitrogenous fertilizer has risen sharply all over the world. This is expected to increase every year as the third world countries and developing countries are using more amount of fertilizer to meet their food demand. Consequently, the emissions of N_2O from soil will also increase. Any attempt to reduce its emissions will be of great significance as it not only will reduce the atmospheric pollution but also increase fertilizer use efficiency. The prerequisite of developing management practices to minimize N_2O emissions from managed ecosystems is an understanding of the source and factors controlling N_2O emissions.

2.2 Nitrous oxide emission inventory

Earlier some attempts have been made to estimate N_2O emission from Indian soils. Parashar et al. (1998), for example, estimated 199-279 Gg N_2O yr^{-1} emissions from agricultural soils in India. In another study, N_2O emission from Indian agricultural soils was estimated to be 240 Gg yr^{-1} (ALGAS, 1998). Garg et al. (2001) using the IPCC methodology and emission coefficients (IPCC, 1996) have given an estimate of 170 Gg N_2O from Indian soils. Bhatia et al. (2004) estimated 126 Gg N_2O emissions for the base year 1994-95 from Indian agricultural soils using some measured emission coefficients. However, using the IPCC default emission coefficients the emission was 228 Gg N_2O yr^{-1}. Recently, Pathak et al. (2010), showed that the direct and indirect N_2O emissions from Indian agricultural soils was 186.4 Gg and 30.61 Gg, respectively. Agricultural N_2O emissions are projected to increase by 35-60% up to 2030 due to increased nitrogen fertilizer use and increased animal manure production (FAO, 2003).

3

MATERIAL AND METHODS

For estimation of nitrous oxide emission from different soils of India a laboratory incubation study was conducted during 2010-11 at the Division of Environmental Science, IARI, New Delhi. Regular soil temperature measurement and soil moisture monitoring were done. Initial and final soil physicochemical parameters were analysed. Estimation of nitrous oxide flux was done by sampling and analysis with gas chromatograph. The details of material and methodology adopted are given below:

3.1 Soil collection sites

On the basis of heterogeneity of soil and climatic conditions, nine states of India were selected for the collection of soil samples (Figure 3.1). The selected states were

1) West Bengal 2) Punjab 3) Andhra Pradesh 4) Kerala 5) Karnataka 6) Jharkhand 7) Jammu & Kashmir 8) Himachal Pradesh and 9) Maharashtra

The soil samples were collected from the following districts of the above states (Table: 3.1)

Table 3.1 List of soil collection site

S. No.	State	District	Site of Sampling	Soil type	Soil Order
1.	Punjab	Ludhiana	Ludhiana	Alluvial	Inceptisol
2.	Himachal Pradesh	Solan	Solan	Alluvial	Inceptisol Entisol
3.	Andhra Pradesh	Nizamabad	Mallaram	Black	Vertisol
4.	Karnataka	Bagalkot	Mudhol	Red	Alfisol
5.	Kerala	Palakkad	Kottoppadam	Latrrite	Oxisol
6.	Maharashtra	Ahmednagar	Astagoan	Black	Vertisol
7.	Jharkhand	Ranchi	Kanke	Red & Lateritic	Alfisol Oxisol
8.	Jammu & Kashmir	Srinagar	Kallar	Alluvial	Inceptisol
9.	West Bengal	Howrah	Dakshin Maju	Alluvial	Inceptisol

3.1.1. Description of soil collection sites

Solan (Himachal Pradesh)

Solan is located at 30.92°N 77.12°E. It has an average elevation of 1467 metres. The town is surrounded by high hills. The eastern side of the town is covered by Matiul peak which is approximately 1,986 metres (6,516 ft) high. The 2,000 metres (6,562 ft) high Karol peak is located on the Northern side of the town. Since Solan town has abundance of hill formations, only some 30 to 40 percent area is suited for building activity. Steep slopes, forested area, nallah formations, loose and sinking

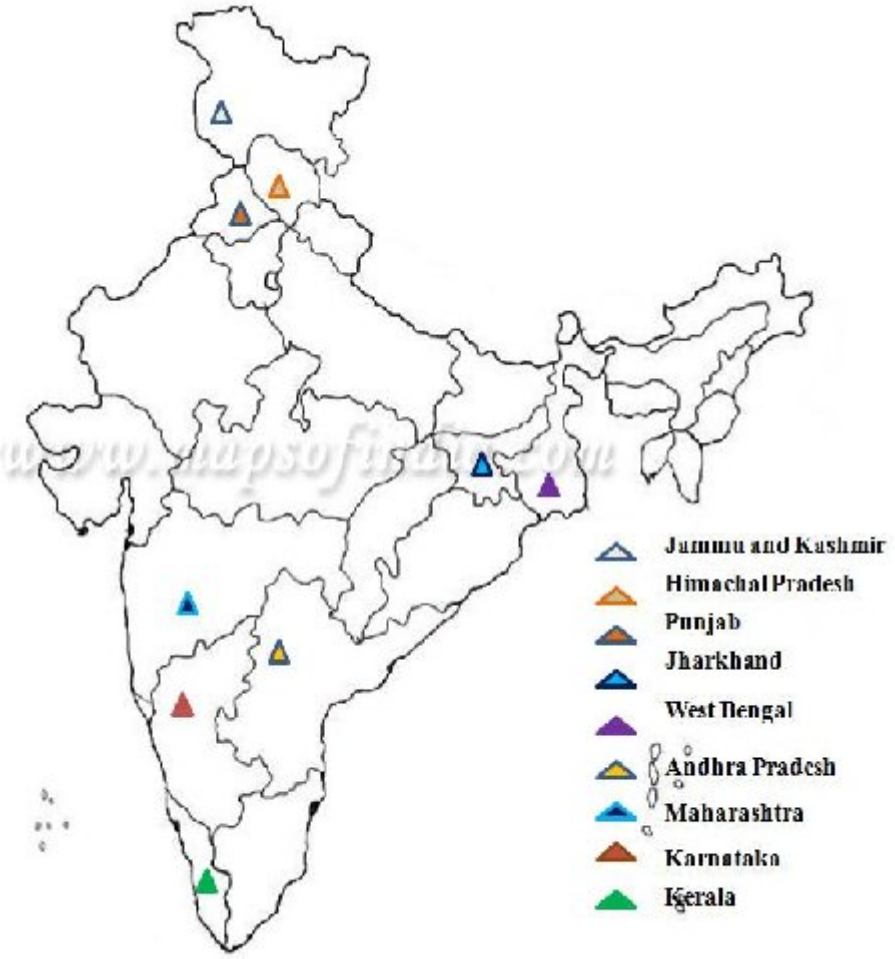

Figure 3.1: Location of soil sampling sites in different states of India

sites forms rest of the area. Soil is generally sandy loam in valley areas of the district and in rest of the hilly and mountainous areas soil is skeletal, soil depth is generally shallow except in areas having good vegetative cover. It is generally dry, shallow and deficient in organic matter. Landslides are the common features in mountainous terrain. Soils are rich in nutrients and thus are fertile. The soil of the area was alluvial.

Palakkad (Kerala)

Palakkad district is situated in the South West Coast of India. It lies between 10'21 and 11'14 North latitude and 76'02 and 76'54 East longitude. The total geographical area of the district is 4480 km^2 representing 11.53 % of the State's geographical area. Based on the physical features, the district is divided into two natural divisions - midland and highland. The midland region consists of valleys and plains. It leads up to the highland which consists of high mountain peaks, long spurs, extensive ravines, dense forests and tangled jungles. Midland is thick with coconut, areca nut, cashew, pepper, rubber and paddy cultivation. The soil is laterite in the hill and mid land regions. The soil of Palakkad district is mainly of four types, namely, peaty (kari), laterite, forest and black. Peaty soil is found only in Thrithala firka of Ottappalam taluk. Laterite is seen in the major portions of all taluks. Forest soil is confined to Mannarghat and Ottappalam taluks, the narrow strip of land along the western boundaries of Palakkad and Alathur taluks and along the southern boundary of Chittur taluk. Black soil is seen mostly in the eastern sector of Chittur taluk and a small portion of Palakkad taluk. Soil of the area was laterite.

Ahmednagar (Maharashtra)

The district of Ahmednagar lying between 18°2' and 19°9' north latitudes and 73°9' and 75°5' east longitudes is situated partly in the upper Godavari basin and partly in the Bhima basin, the interfluve in between forming the extensive Ahmednagar plateau. The chief soils of the entire basin are kali or black with a variety of gradations depending upon the local terrain conditions and slope. The soils, by and large derived from weathering of basalts under tropical semi-arid climatic conditions, are *regurs* (black cotton soil), a type of clay loam that is moisture-retentive. In this region the soil is more suited to wheat than to cotton, excessively sticky and hard to

work during rains and full of cracks in the hot weather. Soil of the site was black cotton soil.

Ranchi (Jharkhand)

This city of Jharkhand is located at 23.23º N latitude and 85.23ºE longitude. The total area covered by Ranchi is 35 square kilometres. This city is located at a height of 2,140 feet above sea level. Geographically, Ranchi is located in the Chota Nagpur plateau. The climate of Ranchi can be broadly classified into three main seasons vize summer, winter and monsoon. The temperature of Ranchi during summer varies from a minimum of 20.6º Centigrade to a maximum of 37.2º C. During winter the temperature varies from a minimum of 10.3ºC to a maximum of 22.9ºC. Ranchi receives an annual rainfall of about 1530 mm. The entire district of Ranchi is covered by Red soil except for a small portion in the south east which contains red and black soil. Sampled soil was red lateritic type.

Srinagar (Jammu and kashmir)

District falls under the temperate to mediterranean type of climate and is characterized by mild summers and chilling winters. Due to altitude variation from 1,600 meters to 5,000 meters above mean sea level. There is a wide variation in climatic conditions in different parts of the district experiencing a typical temperate climate in high altitude which experience snowfall and severe cold in the winter and tropical climate at low altitude. Precipitation takes place in the form of rainfall as well as snow with occasional hailstorms. The average rainfall in the district is about 680 mm. About 60 to 70% of the precipitation is received in the form of snow during December to February. March to April is the months of heavy rainfall. The soils of the Kashmir Valley are broadly divided into two types viz, Hapludalfs & Ochraqualfs and the same is true for the Srinagar district also. Hapludalfs soils are found on Karewa tops & uplands with a slope variation of 1-3%. These are very deep, well drained with moderate permeability. Surface texture varies from clay loam to silty clay loam and are mostly used for cultivation of wheat, maize and pulses. Ochraqualfs soils are found in plain to mid upland topography. These soils are moderately fine textured with clay loam as the predominant surface texture. These soils are mostly used because of their low permeability for the cultivation of paddy, mustard & at places wheat. Soil of the location was alluvial in nature.

Howrah (West Bengal)

Howrah is an industrial city, a municipal corporation in the Howrah district, West Bengal, India.. Located on the west bank of the Hooghly River, it is a twin city of Kolkata. Howrah is the second small district after Kolkata. Howrah is located at 22.59°N 88.31°E. It has an average elevation of 12 metres (39 feet). It has mainly alluvial type of soil.

Nizamabad (Andhra Pradesh)

Nizamabad district is in the slot of agricultural districts in the state of Andhra Pradesh. Though the district is situated away from the sea, the climate is tropical. The annual rainfall in the district is around 1000 mm. The same is very intensive during the period June to September. Normal minimum temperature is 13.7^0C and maximum is 39.9 ^{0}C. At times the temperature falls as low as 6^0C in December-January and touches as high as 47 ^{0}C in May. The soils of the district are primarily of Red, Black cotton and Sandy loams. The soils of the district are primarily Red, Black cotton and Sandy loams. Sampled soil was red soil.

Bagalkot (Karnataka)

The district of Bagalkot is situated entirely on the north Karnataka plateau, which is part of the larger Deccan plateau. It is positioned at 16°12′N 75°45′E and covers an area of 6593 km². The average elevation in this area reaches approximately 610 m. The climate is warm and dry throughout the year and rainfall is scarce. Bagalkot district receives the lowest rainfall annually in Karnataka. The months of September and December account for about 52% of the total annual rainfall. Bagalkot is devoid of large canopy tree vegetation. The region is semi-arid. The Krishna and Malaprabha River flow through the region but are non perennial. Soil in the area can be categorised as either the majority black or minority red. Black soil retains moisture and is often used for the cultivation of cotton. Rabi and jowar are main crop cultivated in Bagalkot while other important crops grown are groundnut, cotton, maize, bajra, wheat, sugarcane and tobacco. The district is also rich in mineral wealth. Iron ore also exists in the southern part of the district. Like much of Karnataka, the gneiss is the most common rock family. Common rock types in the region include greenstone, quartzite, sandstone and limestone. The dry climate makes

the region susceptible to drought and crop failure. The average rainfall in the region is approximately 318 mm annually. The area from where sample was taken was dominant in red soil.

Ludhiana (Punjab)

Ludhiana district falls in central part of Punjab. The Satluj forms the border of the district in the north with Jalandhar and Hoshiarpur districts. Ropar and Fatehgarh sahib districts mark the eastern and south eastern boundaries. The western border is adjoining Moga and Ferozpur districts. The geographical area of the district is 3790 km^2. The climate of Ludhiana district can be classified as tropical steppe, hot and semi-arid which is mainly dry with very hot summer and cold winter except during monsoon season when moist air of oceanic origin penetrates into the district. The district area is occupied by Indo-Gangatic alluvium. The district soil characteristics are influenced to a very limited extent by the topography, vegetation and parent rock. The variations in soil profile characteristics are much more pronounced because of the regional climatic differences. The soil of this zone has developed under semi-arid condition. The soil is sandy loam to clayey.

2.2. Soil sample collection and analysis

Representative samples of all soils (2-3 kg) were drawn randomly from 0-15 cm depth with the help of tube auger from the selected locations. The samples were collected in polythene bag sealed and transported to the laboratory for the study. The soils were air dried, grounded and passed through 2mm sieve, mixed and stored in sealed plastic jars. Initial soil samples were analyzed to determine the physico-chemical properties (Table 3.2). Soil samples were collected after incubation and were also analyzed for pH, Electrical Conductivity (EC) soil organic carbon (SOC) content total N, ammonical N and nitrate N.

Table 3.2: Methods used for the analysis of different soil parameters

Parameters	Methods of analysis	References
Electrical conductivity	Conductivity meter	Jackson (1973)
Total Nitrogen	Kjeldahl apparatus method	Bremmer and Sulvany (1982)
Available NO^-_3 Nitrogen	1M KCl method	Bremmer and Kenny(1963)
Available NH^+_4 Nitrogen	Devarda's alloy	Subhai & Asija (1956)
Organic Carbon	Walkley & Black method	Walkley and Black(1934)
Cation exchange capacity	$BaCl_2$ method	Jackson (1967)
Moisture at Saturation	Keen Box	Keen et al.(1921)
Moisture at F.C. (%)	Pressure plate apparatus	Richards and Fireman (1943)
Soil pH	pH meter	Jackson (1967)

3.3 Experimental setup for the estimation of N_2O emission from soil

Incubation studies were undertaken in a BOD incubator maintained at a temperature of 30^0C.250 ml capacity spout less borosil glass beakers were used for the incubation experiment. 100 gm of each of sieved soil was taken for the experiment in above-mentioned beakers. Distilled water was added to bring the soil moisture content to field capacity (18% w/w). Each beaker was stoppered with 3 opening rubber cork and made airtight with sealing grease. Soil thermometer was inserted in each beaker touching the soil and it is fixed in one of cork hole with silicon seal. In other two holes with glass tube in each rubber septa is fitted to the outer end of tube to ensure gas inlet and outlet (Figure: 3.2 A & B). Initial N_2O emission determinations from all beakers at room temperature (24^0C) were done. All beakers were maintained at 30^0C in BOD incubator. Moisture loss was compensated by adding distilled water to maintain the moisture content at field capacity.

A

B

Figure 3.2: Experimental setup for measurement nitrous oxide emission from soil

Figure 3.3: Gas chromatograph used for quantitative analysis of nitrous oxide emission

3.4 Collection of gas samples

The gas samples from headspace were periodically drawn at regular interval throughout the experiment. Samples from each beaker was drawn with the help of 5 ml disposable syringes fitted with a 24 gauze needle and 3- way cork to prevent diffusion of gas sample (Figure: 3.3). The gas sampling ports of the beakers were closed by rubber septa during the periods of gas sampling while the sampling ports were kept open during the rest of the incubation period. Care was taken to mix the headspace thoroughly by pushing plunger up and down for at least 10 minutes. Gas samples were collected at an intervals of 3 days during 30 days, at 0 h (0 time) 1/2 h and 1 h (final time) on each sampling day by gas tight syringes (5 ml). Headspace volume and soil temperature was recorded at the time of sampling.

3.5 Gas sample analysis

Nitrous oxide concentration in the gas samples collected were estimated by Gas Chromatograph (Hewlett Packard 5890 Series II) fitted with an electron capture detector (ECD) and 6' x 1/8" stainless steel column (Porapak N). Column, and detector temperatures were 50°C, and 350°C, respectively. The carrier gas was N_2

with a flow rate of 14 ml min^{-1}. A GC-computer interface was used to plot and measure the peak area. N_2O standard of 500 ppbv and 1 ppm obtained from Spectra gases (NIST standards) were used for calibration.

Calculation of N_2O flux

Cross sectional area of the chamber	=	A m^2
Headspace	=	H m
Volume of headspace	=	AH m^3 = 1000 x AH l
N_2O concentration at 0 time	=	Co
N_2O concentration after time t	=	Ct
Change in concentration in time t	=	$(C_t - C_o)$ ppbv
	=	$(C_t - C_o)$ nl l^{-1}
Volume of N_2O evolved in time t	=	$(C_t - C_o)$ nl l^{-1} x 1000 AH L
	=	$(C_t - C_o)$ x AH µl

When t is in hours, then flux is

$$F = [(C_t - C_o) \times AH)/ (A \times t)\ \mu l m^{-2} h^{-1} = Y\ \mu l\ m^{-2} h^{-1}$$

Now 22.4µl of N_2O is 44 µg at STP

So, Y µl of N_2O is (44xY/22.4) µg at STP

Therefore, Flux = Y x 44/22.4 µg $m^{-2}h^{-1}$

Hence, Flux = $[(C_t-C_o)/t] \times H \times 44/22.4$ µg $m^{-2}h^{-1}$

3.6 Data analysis

Various statistical methods like correlation matrix, standard deviation were used for the analysis and interpretation of the data using SPSS (ver. 10) statistical package.

4

RESEARCH PAPER

Estimation of Nitrous Oxide Emission from different Soils of India

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Abstract:

A laboratory experiment was conducted at the Division of Environmental Science, IARI, New Delhi to estimate the emission N_2O and its emission pattern from nine different type of soil sample collected from nine different state (Punjab, Himachal Pradesh, Andhra Pradesh, Kerala, Maharashtra, Jharkhand, J & K and West Bengal) varying widely in their soil characteristics, vegetation and climatic condition of India. The incubation experiment was carried out at 30^{o} C in BOD incubator for 30 days. The gas samples were collected at regular intervals and immediately analyzed for N_2O using a gas chromatograph (Hewlett Packard, series 5590) fitted with a Porapak-N column and electron capture detector. All the soil samples showed almost similar pattern of N_2O emission i.e. initial emission was negligible but with advent of time emission increased and attained maximum value between 10 to 13^{th} day after incubation followed by rapid decline. The soils of Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana showed early peak of N_2O flux than soils of Ahmednagar, Srinagar and Solan. The soil samples of Ludhiana emitted highest amount of N_2O (39.74 ± 0.64 µg/100 g) over 30 days of incubation followed by Howrah (37.28 ± 0.68 µg/100 g) and Ahmednagar (32.78 ± 0.17 µg/100 g) while lowest emission was recorded in soil samples of Ranchi (18.13 ± 0.46 µg/100 g). N_2O emission showed significant positive correlation with pH of soil and total nitrogen content while significant negative correlation with C/N ratio. Present study showed that the soil of Punjab, West Bengal and Maharashtra contribute a significant amount of N_2O to the atmosphere and soil pH, C/N ratio, total N content, NO_3-N content and extent of agricultural practices are some of the key factors for controlling the N_2O emission from the soil.

Key words: Nitrous oxide, Soils, Emission, C/N Ratio, Field capacity

1. Introduction

India, the second most populous country in the world and is one of the major fertilizer consuming countries along with the USA, the former USSR and China. With increasing population food production has to be increased. Increased application of N fertilizer might lead to an increase in the emissions of nitrous oxide. This will impact the nitrogen balances and the environment. Soils are the most important sources of N_2O emission, contributing at least 60% of the global gross N_2O emission (Prather et al., 1995). Nitrous oxide (N_2O) is an important greenhouse gas (GHG) contributing 5% of the enhanced greenhouse effect. Agriculture and associated sectors produce about 58% of the total anthropogenic N_2O emission (Carlo et al., 2007). Despite its low concentration in the atmosphere of about 316 ppb, its global warming potential is about 298 times than that of CO_2 in a 100-year time frame (IPCC, 2007). Considerable amounts of N_2O gas are emitted from natural and cultivated soils through microbial processes, the most important being nitrification and denitrification (Xing, 1998). Present annual emission of N_2O-N from agricultural system amounts to 0.63Tg (direct emission through losses of N to aquatic systems each emitting $0.21Tgy^{-1}$ (Mosier et al., 1998). Future N_2O emissions in 2030 are projected to reach 0.81 Tg (reference scenario), 0.69 Tg (medium mitigation scenario) and 0.6 Tg (strong mitigation scenario). Along with indiscriminate use of fertilisers for increasing food production, N_2O is also produced naturally from denitrification and nitrification processes in soils, and contributes to global warming and stratospheric ozone depletion. Due to the advent of modern agriculture, consumption of nitrogenous fertilizer has risen sharply all over the world. This is expected to increase every year as the third world countries are using larger amounts of fertilizer to meet their food demand. Consequently, emission of N_2O from the soil will also increase. Increase by about 8% since then and the current increase (approximately 0.2– 0.4% annually) are attributed mainly to anthropogenic processes in the last 2 decades, atmospheric concentrations of N_2O continue to increase at a rate of 0.25 percent per year. There has been a significant multiyear variance in observed growth of N_2O concentrations, but the reasons for these trends are not fully understood yet (IPCC, 2001b). From agricultural perspective, N_2O emission from soil also represents a loss of N from soil system and decreasing N use efficiency. However, N_2O emission capacities vary from soil to soil. Soils receiving industrially and biologically fixed N contribute to this emission during denitrification

and nitrification. Many abiotic factors have been recognized as regulators for the variations, namely soil pH (Hu¨tsch et al., 2001), oxygen availability (Bollmann and Conrad, 1998), redox potential (Yu et al., 2001), organic carbon (Azam et al., 2002), temperature (Godde and Conrad, 1999), fertilization (Kumar et al., 2000), water regime (Websterand Hopkins, 1996), and land management (He´nault et al., 1998).

Although substantial research has been done on CH_4 and N_2O emission from tropical soils, only a few studies have reported N_2O emission from Indian soils. In terms of nitrous oxide emission, the contribution of Indian agriculture as a fraction of the world agriculture is miniscule. In earlier estimates, emission of 243 Gg of N_2O was ascribed to Indian agriculture. Out of this, 240 Gg was contributed by Indian agricultural soil and 3 Gg was due to burning of agricultural residues. For the year 1994–95 using the IPCC default emission coefficients, the value of nitrous oxide emissions was found to be 145 Gg. Bhatia et al., 2004 using indigenous emission coefficients estimated that the Indian agricultural soil is contributing only 79.94 Gg of nitrous oxide. Based on these estimates, the contribution of Indian agriculture would be revised to 120 Gg of N_2O–N annually. There are uncertainties in the estimation of nitrous oxide emissions from Indian agriculture because of its diverse soil, climate, land-use types and socio economic conditions. The real assessment of contribution of Indian agriculture to greenhouse gas emissions and subsequent climate change can only be answered by preparing a national inventory. This will not only improve estimates of emissions and related impact assessments, but also provide a baseline from which we may develop our future emission trajectories to identify and evaluate mitigation strategies. Present study was conducted to prepare an estimate of N_2O emission from different heterogeneous soils found in different part of India.

2. Material and Methods

2.1. Study Area

On the basis of heterogeneity of soil and climatic condition, total nine state of the India was selected for the collection of soil samples which vary widely in their soil characteristics, vegetation and climatic condition. The selected site were (1) West Bengal (2) Punjab (3) Andhra Pradesh (4) Kerala (5) Karnataka (6) Jharkhand (7) Jammu & Kashmir (8) Himachal Pradesh and (9)

Maharashtra. The brief description of sites and the types of soils is given below:
a) Ludhiana district of Punjab: it has tropical steppe, hot and semi-arid climate which is mainly dry with very hot summer and cold winter except during monsoon season. The area is mainly occupied by Indo-Gangetic alluvium.

b) Solan district of Himachal Pradesh: it is located at latitude 30.92°N and longitude 77.12°E. Soil is generally sandy loam in valley areas of the district and in rest of the hilly and mountainous areas soil is skeletal, soil depth is generally shallow except in areas having good vegetative cover. The area from where sample was taken was alluvial.

c) Nizamabad district of Andhra Pradesh: The annual rainfall in the district is around 1000 mm with maximum intensive during the period June to September. Normal minimum temperature is 13.7^0C and maximum is 39.9^0C. The soils of the district are primarily of two kinds, Black cotton and Sandy loams. Sampled soil was red soil.

d) Bagalkot district of Karnataka: It is positioned at 16°12′N 75°45′E. The months of September and December account for about 52% of the total annual rainfall. This region is semi-arid and devoid of large canopy tree vegetation. Soil in the area can be categorised as either the majority black or minority red. The area from where sample was taken was dominant in red soil.

e) Palakkad district of Kerala: It lies between 10’21 and 11’14 North latitude and 76’02 and 76’54 East longitude. The soil is mainly of four types, namely, peaty (kari), laterite, forest and black. Soil type used in experiment was red soil.

f) Ahmednagar district of Maharashtra: lying between 18°2' and 19°9' north latitudes and 73°9' and 75°5' east longitudes is situated partly in the upper Godavari basin and partly in the Bhima basin. The soils, by and large derived from weathering of basalts under tropical semi-arid climatic conditions, are *regurs* (black cotton soil), a type of clay loam that is moisture-retentive. Soil type used in experiment was black soil.

g) Ranchi district of Jharkhand: located at 23.23º N latitude and 85.23ºE longitude. Ranchi receives an annual rainfall of about 1530 mm. The entire district of Ranchi is

covered by Red soil except for a small portion in the south east which contains red and black. Sampled soil was red lateritic type.

h) Srinagar district of J & K: it has Temperate to Mediterranean type of climate and is characterized by mild summers and chilling winters. The average rainfall in the district is about 680 mm with 60 to 70% of the precipitation in the form of snow during December to February. Soil has been broadly divided in two categories viz. Hapludalfs and Ochraqualfs soils. Hapludalfs soils are very deep, well drained with moderate permeability; surface texture varies from clay loam to silty clay loam are mostly used for cultivation of Wheat, Maize & pulses. Ochraqualfs are moderately fine textured with clay loam as the predominant surface texture. Soil type used in experiment was alluvial in nature.

i) Howrah district of Kolkata: Located on the west bank of the Hoogli River and geographically is located at 22.59°N 88.31°E. It has an average elevation of 12 metres (39 feet). It has mainly alluvial type of soil.

2.2 Soil Sample Collection and Analysis

Representative samples of all soils (2-3 kg) were drawn from 0-15 cm depth with the help of tube auger from the selected locations. The samples were collected in polythene bag, sealed and transported to the laboratory for the study. The soils were air dried, grounded by wooden mortar & pestle and passed through 2mm sieve, mixed and stored in sealed plastic jars. Physical and chemical parameters of soil samples before and after incubation were analyzed by standard methods.

2.3 Experimental setup

Incubation studies were undertaken in a BOD incubator maintained at a temperature of 30^0C, 250 ml capacity spout less borosil glass beakers were used for the incubation experiment. 100 gm of each of sieved soil was taken for the experiment in abovementioned beakers. Distilled water was added to bring the soil moisture content to field capacity (18% w/w).Each beaker was stoppered with 3 opening rubber cork and made airtight with sealing grease. Soil thermometer was inserted in each beaker with touching the soil and was fixed in one of cork hole with silicon seal. Initial N_2O emission determinations from all beakers at room temperature

(24^0c) were done. Then all beakers were maintained at 30^0c in BOD incubator. Moisture loss was compensated by adding distilled water to maintain the moisture content at field capacity.

Gas Sampling and Analysis

The gas samples from headspace were periodically drawn at regular interval throughout the experiment samples from each beaker was drawn with the help of 5 ml disposable syringes fitted with a 24 gauze needle and 3- way cork to prevent diffusion of gas sample. The gas sampling ports of the beakers were closed by rubber septa during the periods of gas sampling while the sampling ports were kept open during the rest of the incubation period. Care was taken to mix the headspace thoroughly by pushing plunger up and down for at least 10 minutes. Gas samples were collected at an intervals of 3 days during 30 days, at 0 h (0 time), 1/2 h and 1 h (final time) on each sampling day by gas tight syringes (5 ml). Headspace volume and soil temperature was recorded at the time of sampling. Nitrous oxide concentration in the gas samples collected were estimated by Gas Chromatograph (Hewlett Packard 5890 Series II) fitted with an electron capture detector (ECD) and 6' x 1/8" stainless steel column (Porapak N). N2O standard of 500 ppbv and 1 ppm obtained from Spectra gases (NIST standards) were used for calibration. Estimation of total N2O emissions during the crop season was done by successive linear interpolation of average emission on the sampling days assuming that emission followed a linear trend during the periods when no sample was taken.

3. Results

3.1 Physico-Chemical Properties of Soils

The physic chemical parameters of soils are given in Table 4.1. The result showed that the pH of soils varied from acidic to slightly alkaline. The soil sample of Palkkad (Kerala) showed lowest value of pH i.e. 4.87 while soil of Ludhiana (Punjab) had highest pH value i.e. 7.05. The soils of Palkkad (Kerala), Ranchi (Jharkhand), Solan (H. P.), Srinagar (J &K) and Bagalkot (Karnataka) falls under acidic to slightly acidic class while that of Howrah (WB), Nizamabad (A. P.), Ludhiana (Punjab), and Ahmednagar (MH) comes under near neutral to slightly alkaline class (Figure 4.1). Texture of soils sample ranged from sandy loam to clayey soil and highest bulk density 1.39 g cm^{-3} and lowest 1.12 g cm^{-3} was observed in

Ahmednagar (Mha) and Ludhiana (Punjab) respectively. Highest electrical conductivity 0.53 dS/m was observed in soil samples of Ludhiana (Punjab) and soil sample of Srinagar (J &K) showed lowest value 0.15 dS/m. Total N content varied from 260 mg/kg in Bagalkot (Karnataka) soil sample to 720 mg/kg in Solan (H. P.) while C:N ratio ranged from 7.5 in Howrah (WB) sample to 13.46 in Bagalkot (Karnataka) soil sample (Figure 4.2). Highest NO_3-N (6.3 mg/kg) and NH_4-N (8.367 mg/kg) content was reported in soil samples of Ludhiana (Punjab) and Ahmednagar (MH) respectively while lowest in Srinagar (1.8 mg/kg) and Bagalkot (1.68 mg/kg) respectively.

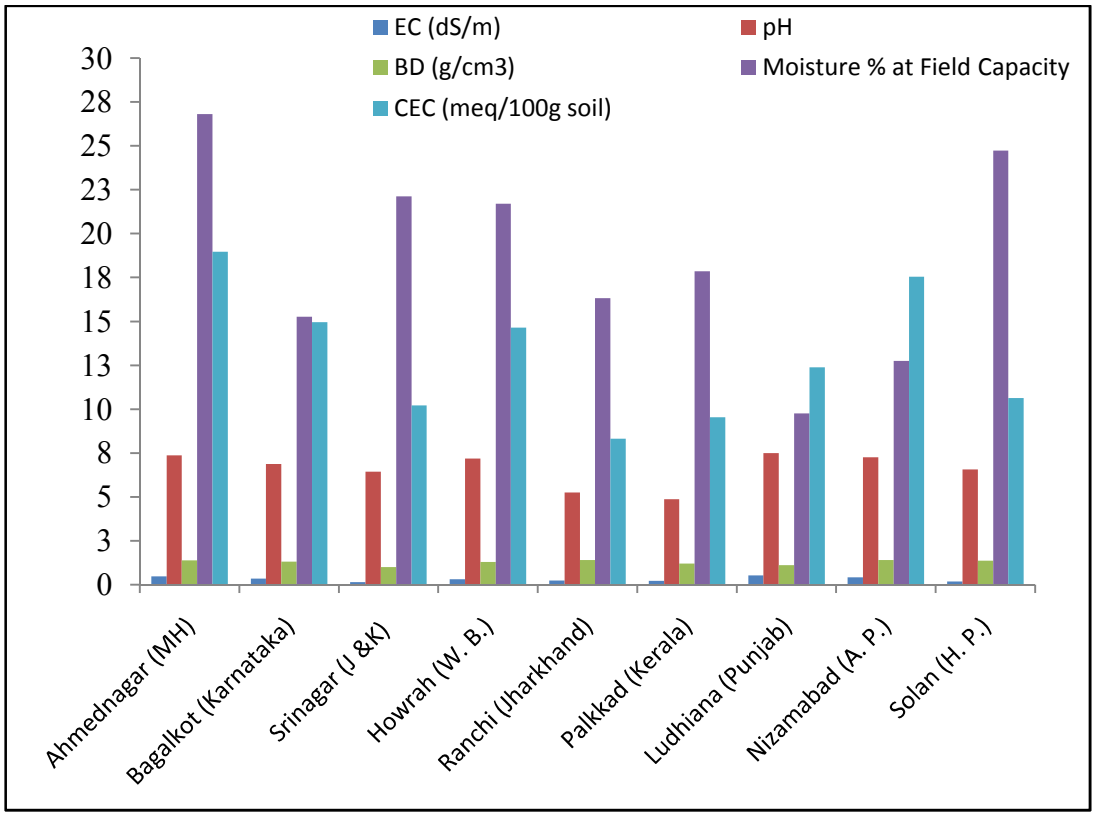


Figure: 4.1 Comparison of soil physical parameters of different states of India

Table 4.1 Physico-chemical properties of different soils of India

State	E.C. (dS/m) (1:1)	Soil pH (1:2)	Organic-C (%)	P (ppm)	K (ppm)	Total N (mg/kg)	C:N Ratio	NH_4^+-N (mg/kg)	NO_3-N (mg/kg)	Moisture % at Field Capacity	B.D. (g/cm^3)	CEC (meq/100g)	Soil Texture
Ahmednagar (Maharashtra)	0.47	7.36	0.35	8.16	91.46	350	10.11	8.367	4.184	26.80	1.39	18.97	clayey
Bagalkot (Karnataka)	0.35	6.87	0.35	16.82	89.36	260	13.46	1.680	2.700	15.26	1.32	14.95	silt clay loam
Srinagar (J &K)	0.15	6.44	0.58	13.28	119.37	690	8.43	6.000	1.800	22.13	1.01	10.21	clay loam
Howrah (West Bengal)	0.32	7.19	0.48	14.27	119.85	640	7.50	6.960	5.200	21.71	1.30	14.65	clay loam
Ranchi (Jharkhand)	0.24	5.25	0.37	11.97	86.56	320	11.56	5.229	2.615	16.32	1.41	8.32	sandy loam
Palkkad (Kerala)	0.21	4.87	0.74	12.12	93.79	580	12.76	5.889	2.945	17.85	1.21	9.54	sandy clay loam
Ludhiana (Punjub)	0.53	7.50	0.46	9.65	112.00	420	10.95	3.336	6.300	9.75	1.12	12.39	sandy loam
Nizamabad (Andhra Pradesh)	0.42	7.25	0.71	8.76	92.37	623	11.40	5.940	2.970	12.75	1.41	17.54	sandy clay loam
Solan (H. P)	0.18	6.57	0.81	9.24	121.68	720	11.25	7.350	2.100	24.73	1.37	10.64	silty loam

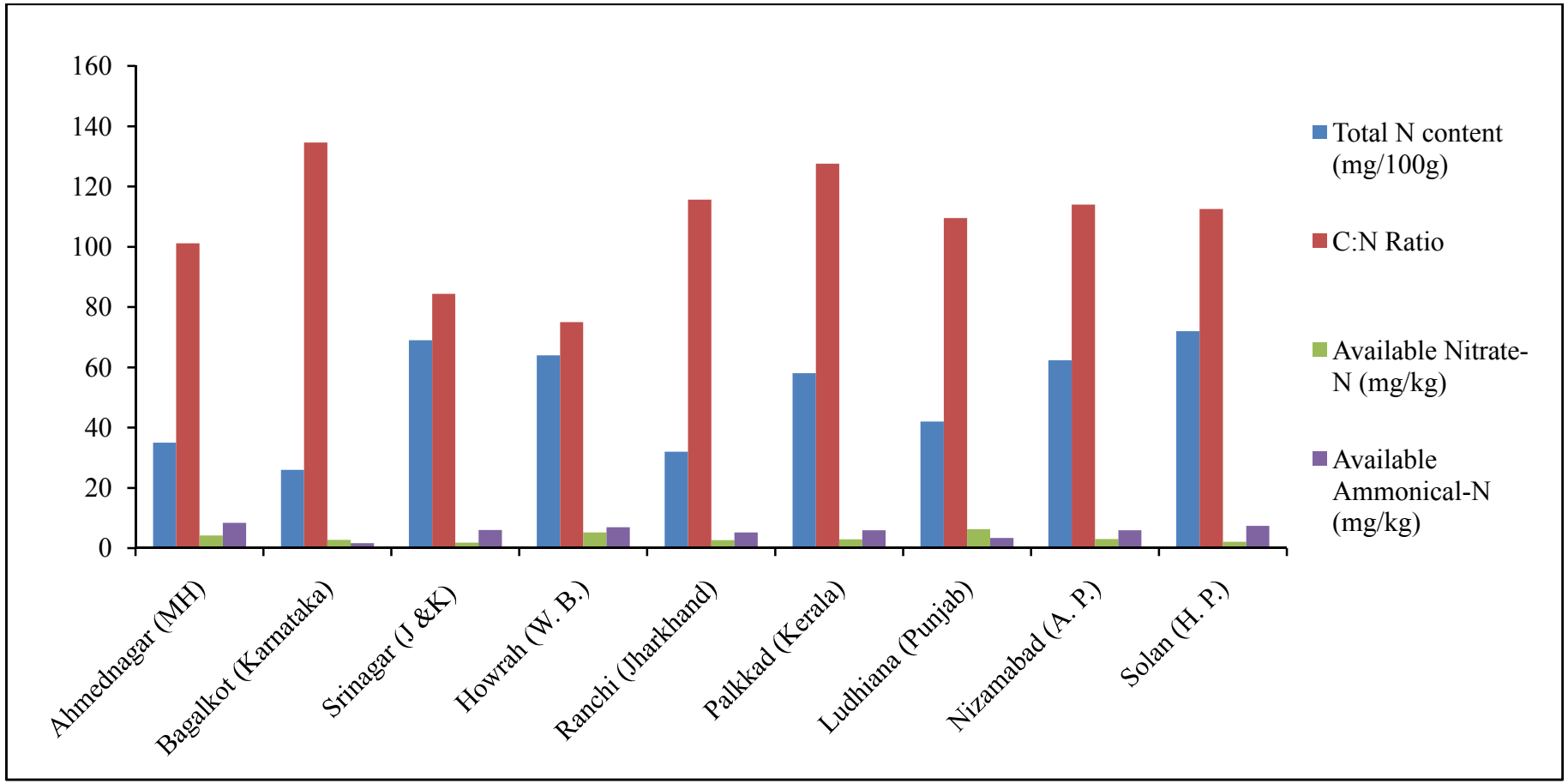


Figure: 4.2 Comparison of soil chemical parameters of different states of India

No significant change in soil pH and EC was observed before and after incubation for 30 days. A significant loss of total N, NO_3-N and NH_4-N was observed in all the soil types it was mainly due to mineralization and emission of N_2O (Figure: 4.5).

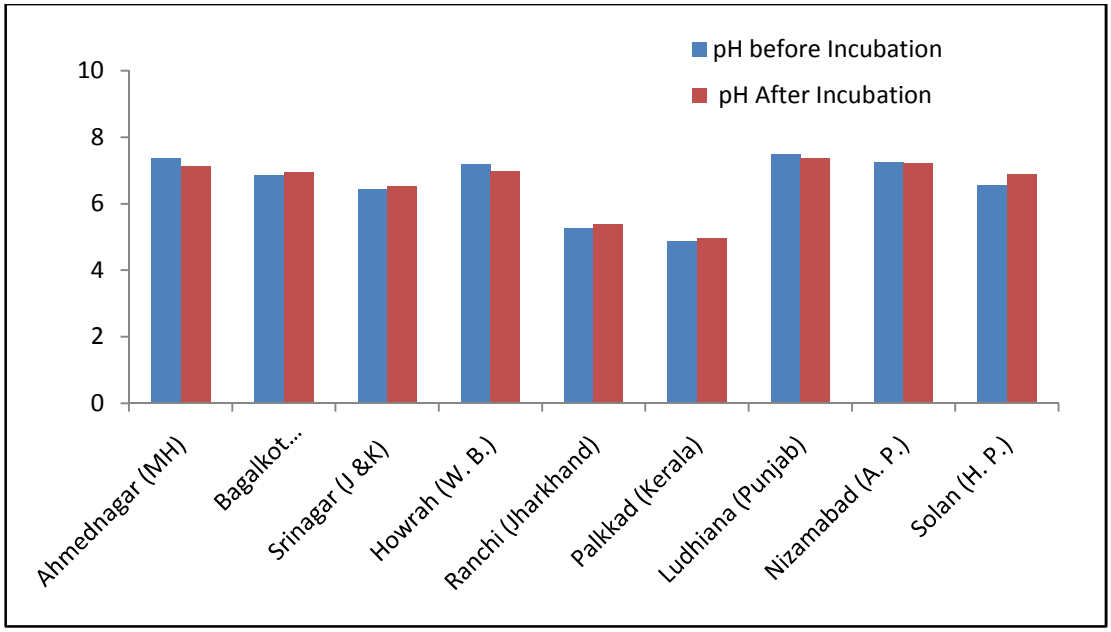


Figure: 4.3 Change in the pH of soils of different states of India

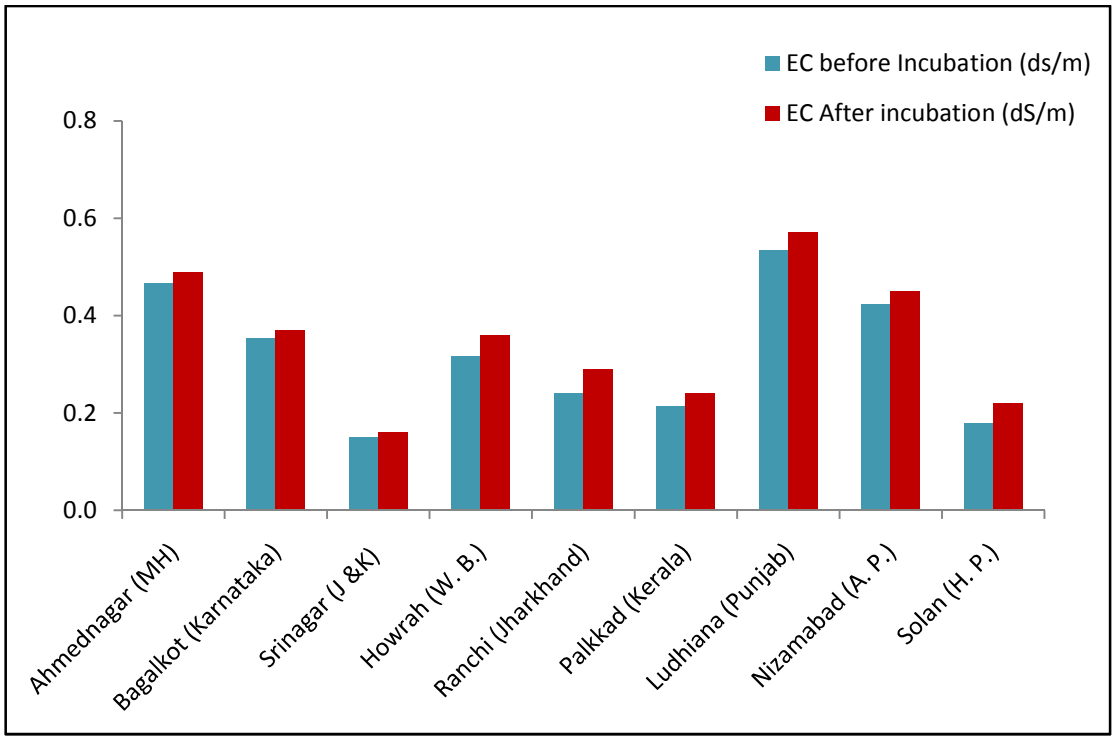


Figure: 4.4 Change in the electrical conductivity of soils of different states of India

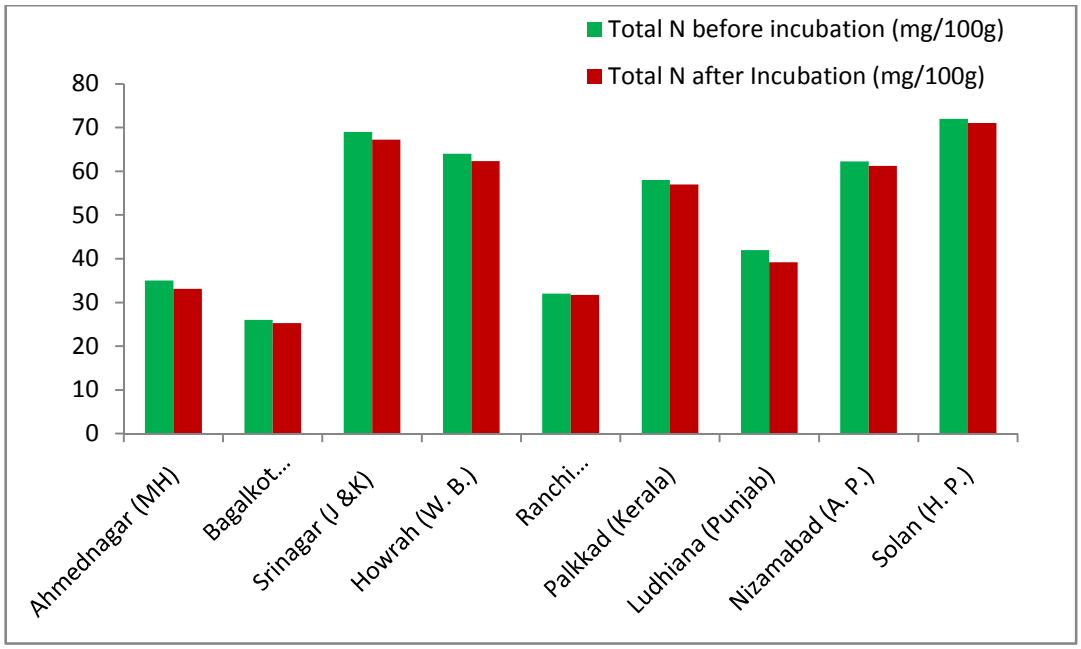


Figure: 4.5 Change in the total N content of soils of different states of India

3.2 Emission of nitrous oxide

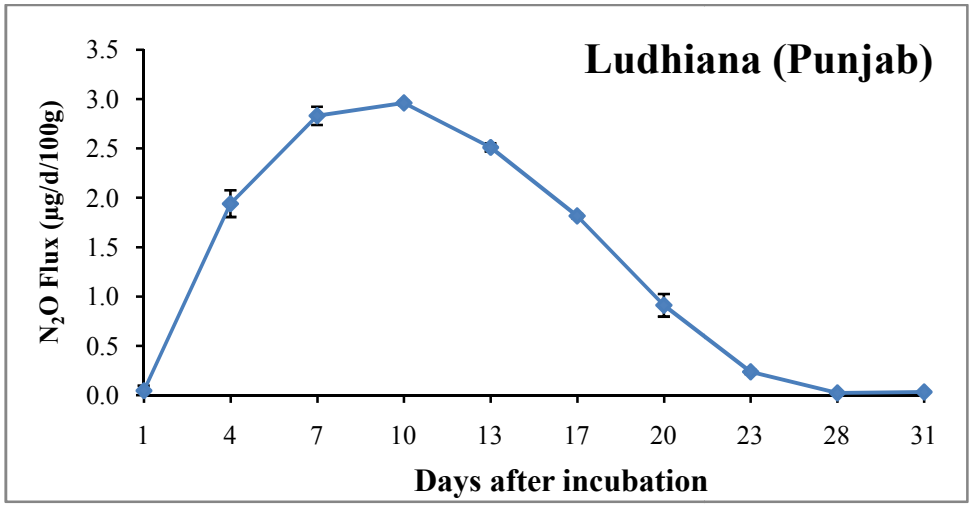
The result of N_2O emission from different soil types are given in table 4.2

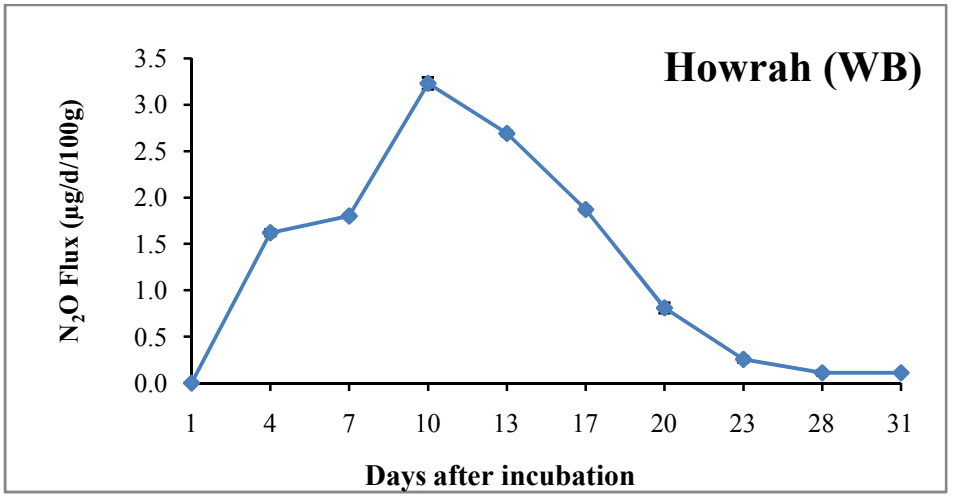
3.2.1 Ludhiana (Punjab)

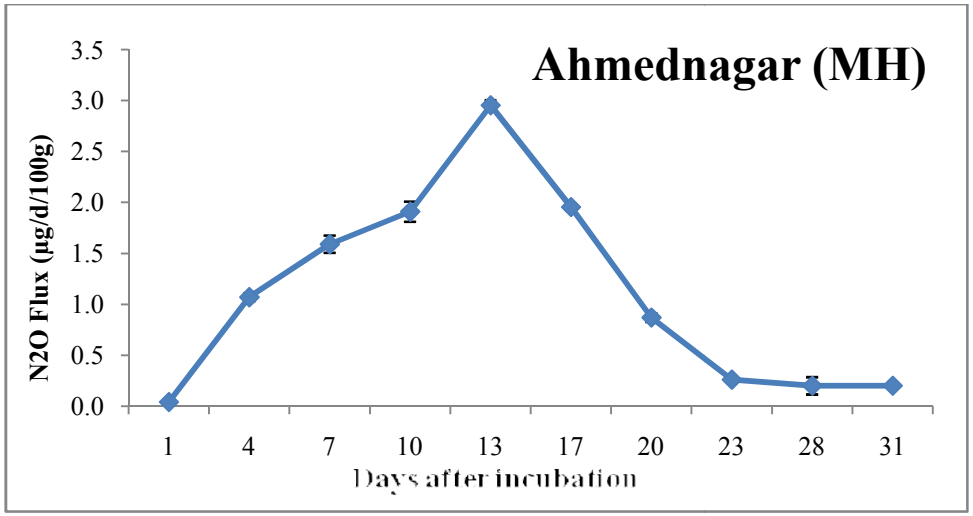
The initial N_2O emission was negligible and increased rapidly at later stage. It attained maximum value 2.96 µg/day/100g soil on 10^{th} day of incubation followed by gradual decrease in flux to negligible value on 29^{th} day after incubation (Figure: 4.6). The cumulative flux of nitrous oxide for 30 days was 39.75 (±0.64) µg/100g soil.

3.2.2 Howrah (W. B.)

The soil samples of Howrah showed total 38.78 (±0.68) µg/100g cumulative emissions over 31 days of incubation. On 1^{st} day of incubation the emission within one hour was zero and it rapidly increased and attained maximum emission flux (3.23µg/day/100g soil) on 10 day after incubation followed by rapid decline (Figure: 4.6).







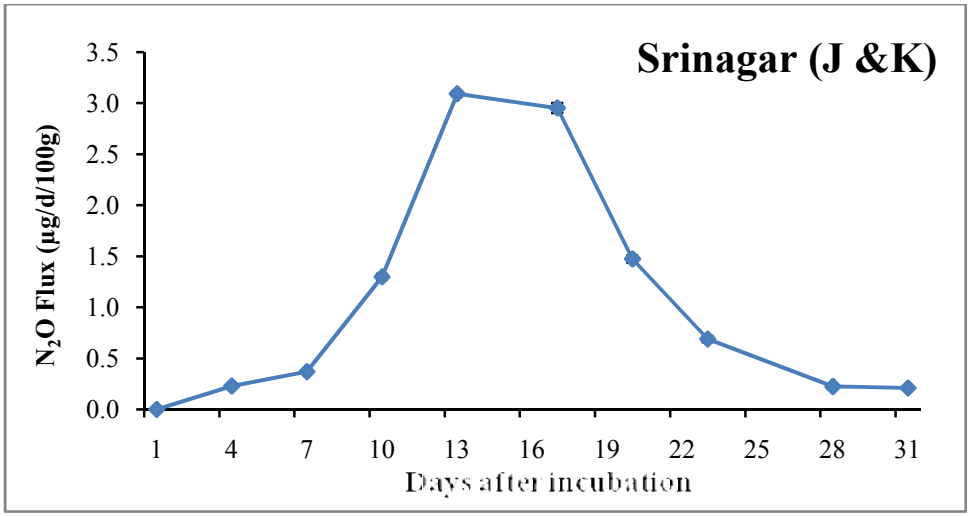


Figure: 4.6 Temporal emission of N_2O from the soils of Ludhiana, Howrah, Ahmednagar and Srinagar

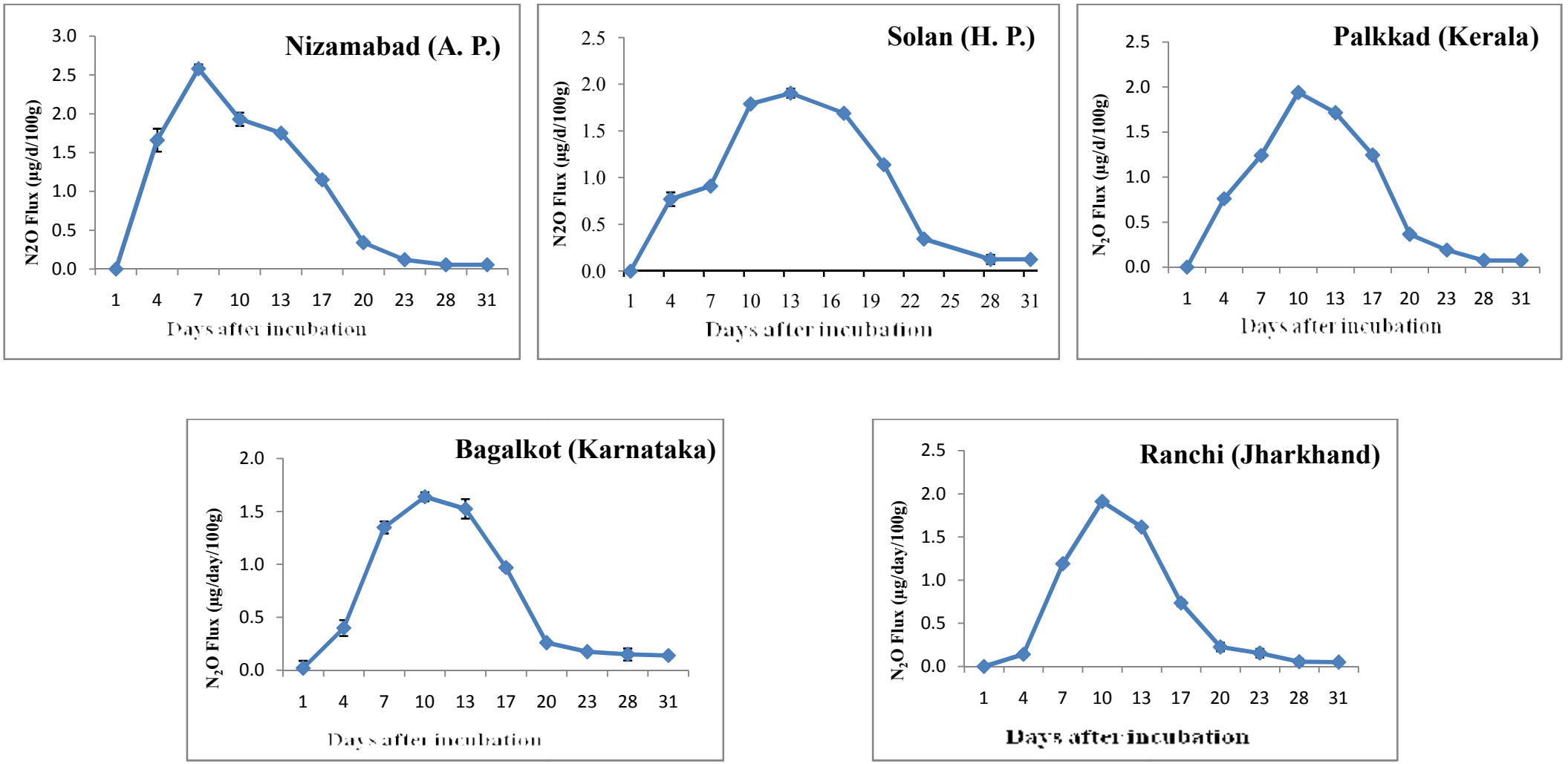


Figure: 4.7 Temporal emission of N_2O from the soils of Nizamabad, Solan, Palkkad, Bagalkot and Ranchi

Table 4.2: Temporal emission of N_2O from Soils of nine states of India

	N_2O Emission Flux from soil (µg/d/100g soil)									
State /Day after Incubation	1	4	7	10	13	17	20	23	28	31
Ahmednagar (MH)	0.04 (0.01)	1.07 (0.04)	1.59 (0.09)	1.91 (0.10)	2.96 (0.05)	1.96 (0.04)	0.87 (0.04)	0.26 (0.01)	0.20 (0.09)	0.20 (0.09)
Bagalkot (Karnataka)	0.02 (0.07)	0.40 (0.08)	1.35 (0.06)	1.64 (0.04)	1.53 (0.09)	0.97 (0.03)	0.26 (0.01)	0.18 (0.01)	0.15 (0.06)	0.14 (0.06)
Srinagar (J &K)	0.00 (0.00)	0.23 (0.00)	0.37 (0.01)	1.30 (0.03)	3.10 (0.02)	2.96 (0.05)	1.48 (0.04)	0.69 (0.03)	0.23 (0.02)	0.21 (0.02)
Howrah (WB)	0.00 (0.00)	1.62 (0.04)	1.80 (0.02)	3.23 (0.06)	2.69 (0.03)	1.87 (0.03)	0.81 (0.06)	0.26 (0.04)	0.11 (0.03)	0.11 (0.03)
Ranchi (Jharkhand)	0.00 (0.00)	0.14 (0.03)	1.19 (0.01)	1.91 (0.02)	1.62 (0.02)	0.74 (0.04)	0.23 (0.05)	0.16 (0.05)	0.06 (0.04)	0.05 (0.04)
Palkkad (Kerala)	0.00 (0.00)	0.76 (0.03)	1.24 (0.03)	1.94 (0.01)	1.72 (0.04)	1.25 (0.04)	0.37 (0.04)	0.19 (0.03)	0.08 (0.02)	0.08 (0.02)
Ludhiana (Punjab)	0.05 (0.05)	1.94 (0.14)	2.83 (0.09)	2.96 (0.02)	2.51 (0.04)	1.82 (0.02)	0.91 (0.11)	0.24 (0.02)	0.02 (0.01)	0.03 (0.01)
Nizamabad (A. P.)	0.00 (0.00)	1.66 (0.15)	2.58 (0.06)	1.93 (0.09)	1.75 (0.03)	1.15 (0.04)	0.34 (0.01)	0.12 (0.01)	0.06 (0.02)	0.06 (0.02)
Solan (H. P.)	0.00 (0.00)	0.77 (0.07)	0.91 (0.03)	1.79 (0.01)	1.91 (0.05)	1.69 (0.03)	1.14 (0.03)	0.35 (0.02)	0.13 (0.05)	0.13 (0.05)

- Values in parenthesis indicate the S.dev

3.2.3 Ahmednagar (MH)

The soil samples of Ahmadnagar showed peak emission rate 2.96 μg/100g on 13th day after incubation followed by declined flux rate (Figure: 4.6). The total cumulative emission was 32.72 ±0.14 μg/100g.

3.2.4 Srinagar (J &K)

The result revealed that the initial N_2O emission flux in incubated soil samples of Srinagar was zero and it increased gradually up to 7th day and after that increased at rapid rate. The maximum N_2O emission flux 3.1 μg/day/100g was attained on between 13th and 16th day of incubation after that declined in emission was observe with faster pass. The total cumulative emission 31.36 ± 0.14 μg/100g soil was recorded within the incubated time period of 31 days (Figure 4.6).

3.2.5 Nizamabad (A. P.), Solan (H. P.), Bagalkot (Karnataka), Palkkad (Kerala) and Ranchi (Jharkhand)

Figure 4.7 represents the temporal emission pattern of N_2O during the period of 30 days from Nizamabad, Solan, Bagalkot, Palkkad and Ranchi soils. It was observed that maximum value of flux was 1.93, 1.91, 1.64, 1.94, 1.91 μg/day/100g for Nizamabad, Solan, Bagalkot, Palkkad and Ranchi soils respectively. The result showed that cumulative total of N_2O emission was 28.85 (±0.12), 26.21 (± 0.21), 19.73 (±0.1), 22.69 (± 0.10) and 18.13 (± 0.46) for Nizamabad, Solan, Bagalkot, Palkkad and Ranchi soils respectively.

3.3 N_2O Emission Pattern

All soil samples showed similar pattern of N_2O emission. Initially the emission was negligible but with advent of time emission increased and attained maximum value between 10 to 13th day after incubation followed by rapid decline (Figure 4.9). In case of soils of Ahmednagar, Srinagar and Solan the maximum peak of N_2O emission was obtained after 13th day of incubation where as soils from Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana attained maximum peak on 10th day of incubation period. Nizamabad soil showed maximum emission on 7th day of incubation. The highest cumulative N_2O Emission over 31 days of incubation was recorded in soil samples of Ludhiana (39.74 ± 0.64 μg/100 g) followed by Howrah

(37.28 ± 0.68 µg/100 g) and Ahmednagar (32.78 ± 0.17 µg/100 g) while lowest value was observed in soil samples of Ranchi (18.13 ± 0.46 µg/100 g) (Figure: 4.10). Analysis of data showed significant positive correlation of N_2O emission with pH of soil and total nitrogen content while significant negative correlation with C/N ratio (Figure 4.8).

Cumulative N_2O Emission	1								
Soil E. C.	- 0.115	1							
Soil pH	0.704*	0.219	1						
Soil Bulk density	- 0.542	0.192	-0.027	1					
Soil water at Field Capacity	0.021	0.259	- 0.023	0.230	1				
CEC of soil	0.368	0.515	0.761*	0.321	0.091	1			
NO_3^- N content	0.752*	- 0.412	0.527	- 0.375	- 0.298	0.344	1		
Total N content	0.309	- 0.119	- 0.015	- 0.185	0.300	- 0.195	- 0.225	1	
C:N Ratio	- 0.691*	- 0.069	- 0.368	0.242	- 0.445	- 0.115	- 0.282	- 0.477	1
	Cumulative N_2O Emission	**Soil EC**	**Soil pH**	**Soil BD**	**Soil water at Field Capacity**	**CEC of soil**	**NO_3^- N content**	**Total N content**	**C:N Ratio**

***** Correlation is significant at the 0.05 level (2-tailed).

Figure 4.8 Correlation Matrix of N_2O emissions with soil physico-chemical properties

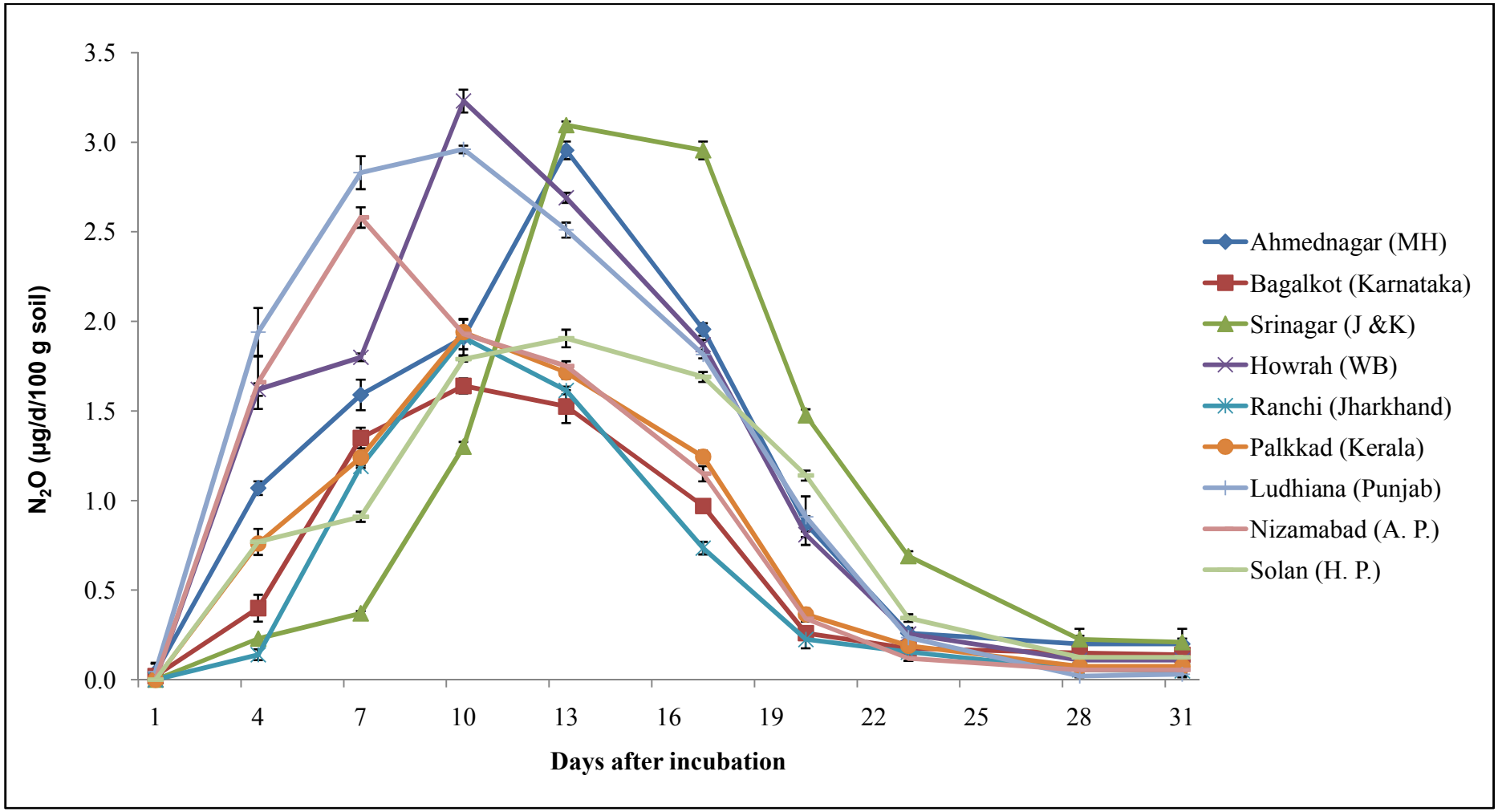


Figure: 4.9 Temporal N_2O emission patterns of different soils

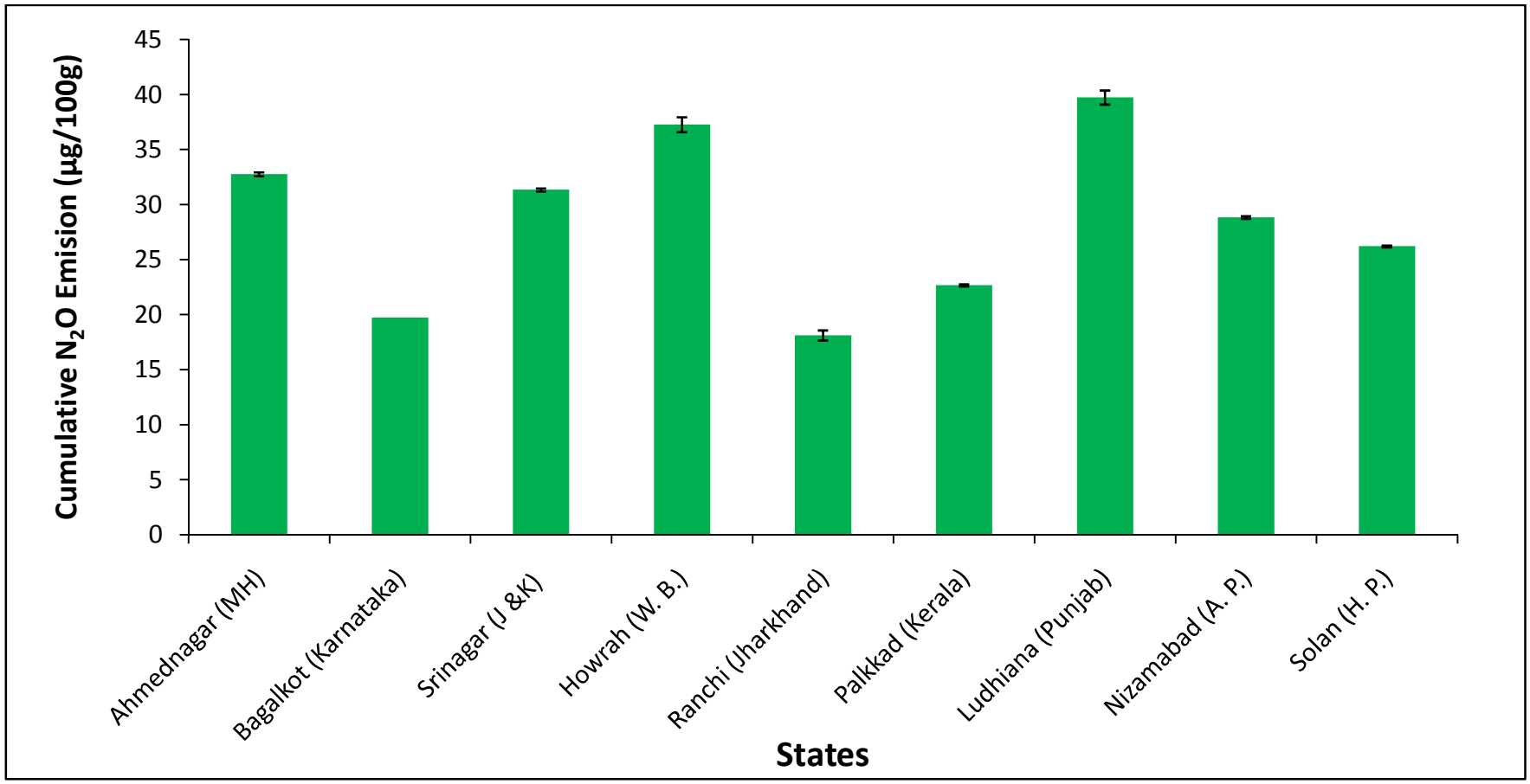


Figure: 4.10 Cumulative N_2O emissions from soils of different states of India.

4. Discussion

It has been well established that biological process of denitrification and nitrification are the most important mechanisms for the emission of N_2O from the soil (Sharawat and Keeney, 1986). During field capacity almost all the micro pores remain field with water that make soil partially unsaturated that favours the denitrification. Subsequent drying of soil for period of 72 hours after the addition of distilled created the aerobic process. Thus alternate partial anaerobic and aerobic condition may be resulted into the production of N_2O and subsequent emission from the soil. It was also reported that, the primary effect of water on N_2O production in aerobic and partially aerobic soils is to restrict O_2 levels by reducing the air-water interfacial area within air-filled pores thus producing the anaerobic condition (Davidson, 1992). Soil water content was a key factor controlling continuously aerobic samples produced small amounts of N_2O, whereas alternate anaerobic and aerobic cycles of varying duration increased the emissions of N_2O by several folds. Majumdar et al., (2000) also reported that, the loss of nitrogen as N_2O was 0.001 - 0.2 % of the applied N at submergence while the value of the same at field capacity was 0.005-0.72%. Maag and Vinther, (1996) also reported that percentage of N_2O-N produced by nitrification increased with increased soil moisture (0.49% at 40% FC and 0.93% at 100% FC).

Present study observed that the initial emission of N_2O emission was low followed by rapid increase, it might be due to gradual activation of microorganism responsible for denitrification and nitrification. Decrease in emission after attaining peak value is due to loss of limited microbial food (carbon) and nitrogen with time from the soil it can sported by decrease in total nitrogen and carbon content of incubated soil sample.

The soil sample of Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana showed early peak of N_2O emission than soil samples of Ahmadnagar, Srinagar and Solan. It is due to higher NO_2-N content in soils of Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana and higher organic-N content in soil samples of Ahmadnagar, Srinagar and Solan. Dobbie and Smith (2003), also reported that, the key factors affecting N_2O emissions from agricultural soil were soil water-filled pore space (WFPS), temperature and soil NO_3^-–N content.

In the present study the highest cumulative N_2O emission was from the soil samples of Ludhiana (39.74 ± 0.64 µg/100 g) followed by Howrah (37.28 ± 0.68 µg/100 g) and Ahmednagar (32.78 ± 0.17 µg/100 g) while lowest value was

observed in soil samples of Ranchi (18.13 ± 0.46 μg/100 g). It was due to higher nitrogen content, low C/N ratio, higher pH value and intensive agricultural practices in former soil than later. Statistical analysis also sported the fact by showing significant positive correlation of N_2O emission with pH of soil and total nitrogen content while significant negative correlation with C/N ratio. It is also reported that the optimum pH for N_2O emissions via denitrification varies with species and age of organisms and NO_3 concentration but most denitrifiers have optimum pH for growth between 6 to 8 and process is favoured at slightly alkaline pH (Aulakh, 1992). It is generally accepted that evolution of N_2O relative to N_2 increases with increase in pH (Webster and Hopkins, 1996; Firestone, 1982). Maljanen et al., (2003) reported that, the annual N_2O emissions from the cultivated soil were twice the annual emission from the adjacent forest site. It supports the statement; area with high agricultural activity has higher N_2O emissions than less agricultural activity area. Pilegaard et al., (2006) reported in their study that N_2O emission from European forest was significantly negatively correlated with the C/N ratio. Huang et al., (2004) investigated the influence of plant residues decomposition on N_2O emission by laboratory incubations and reported that, cumulative emissions of N_2O and CO_2 were negatively correlated with the C/N ratio in plant residues. Discussion on present study suggests that, the soil pH, C/N ratio, total nitrogen content and NO_3-N content and extent of agricultural practices are some of the key factors for controlling the N_2O emission from the soil.

5. Conclusions

Present study showed that the soil of Punjab, West Bengal and Maharashtra contribute a significant amount of N_2O to the atmosphere. Soil pH, C/N ratio, total N content, NO_3-N content and extent of agricultural practices are some of the key factors for controlling the N_2O emission from the soil.

5

SUMMARY AND CONCLUSION

Nitrous oxide (N_2O) is an important greenhouse gas (GHG) contributing 5% of the enhanced greenhouse effect. Agriculture and associated sectors produce about 58% of the total anthropogenic N_2O emission (Carlo et al., 2007). With its current concentration of 315ppbv, N_2O is also responsible for the destruction of the stratospheric ozone (IPCC, 2007).The concern of N_2O emission is greater because of its long atmospheric lifetime of 114 ± 16years and higher global warming potential (298 times that of CO_2). In the last 2 decades, atmospheric concentrations of N_2O continue to increase at a rate of 0.25 percent per year.

Soil is considered to be one of the major sources, contributing 65% to the global nitrous oxide emission. The soil receiving chemical fertilizer and biologically fixed nitrogen contributes to nitrous oxide emission during the processes of nitrification and denitrification. A range of soil and climatic factors can influence N mineralization in soils thereby affecting direct emissions.There are uncertainties in estimation of nitrous oxide emissions from Indian agriculture because of diverse soil, climate, land-use types, socio-economic conditions and non-availability of reliable region specific emission coefficients for nitrous oxide. To capture Indian circumstances, we need to generate data for emission of nitrous oxide from different soil types. The present study was therefore undertaken to estimate the emission of nitrous oxide from different soil types of India.

A laboratory experiment was conducted at the Division of Environmental Science, IARI, New Delhi to estimate the emission N_2O and its emission pattern from nine different type of soil sample collected from nine different state (Punjab, Himachal Pradesh, Andhra Pradesh, Kerala, Maharashtra, Jharkhand, J & K and Kolkata) varying widely in their soil characteristics, vegetation and climatic condition of India. The incubation experiment was carried out at 30^{o} C in BOD incubator for 30 days. The gas samples were collected at regular intervals and immediately analyzed for N_2O using a gas chromatograph (Hewlett Packard, series 5590) fitted with a Porapak-N column and electron capture detector. Initial and final soil samples were analysed for their physic chemical properties.

The salient findings of this investigation are listed below:

- The pH of all soil samples collected from site present in nine different states of India varied from acidic to slightly alkaline with lowest value of pH i.e. 4.87 in Palkkad (Kerala) while soil of Ludhiana (Punjab) had highest pH value i.e. 7.05.
- Total N content varied from 260 mg/kg in Bagalkot (Karnataka) soil sample to 720 mg/kg in Solan (H.P.) while C:N ratio ranged from 7.5 in Howrah (WB) sample to 13.46 in Bagalkot (Karnataka) soil sample. Highest NO_3-N (6.3 mg/kg) and NH_4-N (8.367 mg/kg) content was reported in soil samples of Ludhiana (Punjab) and Ahmadnagar respectively while lowest in Srinagar (1.8 mg/kg) and Bagalkot (1.68 mg/kg) respectively.
- All the soils showed almost similar pattern of N_2O emission i.e. initialy emission was negligible but with advent of time emission increased and attained maximum value between 10 and 13th day after incubation followed by rapid decline.
- The soil of Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana showed early peak of N_2O emission than soil samples of Ahmadnagar, Srinagar and Solan.
- The soil of Ludhiana emitted highest amount of N_2O (39.74 ± 0.64 µg/100 g) followed by Howrah (37.28 ± 0.68 µg/100 g) and Ahmadnagar (32.78 ± 0.17 µg/100 g) while lowest emission was recorded from soil of Ranchi (18.13 ± 0.46 µg/100 g).
- The analysis showed a significant positive correlation of N_2O emission with pH of soil and total nitrogen content and significant negative correlation with C/N ratio was found.
- A significant loss of total N, NO_3-N and NH_4-N in all soil samples was observed.

The present study showed that the soil of Punjab, West Bengal and Maharashtra emitted higher amount of N_2O to the atmosphere as compared to the other soils. Soil pH, C/N ratio, total N content, NO_3-N content are some of the key factors for controlling the N_2O emission from the soil.

NITROUS OXIDE EMISSION FROM DIFFERENT SOILS OF INDIA

ABSTRACT

A laboratory experiment was conducted at the Division of Environmental Science, IARI, New Delhi to estimate the emission N_2O and its emission pattern from nine different type of soil sample collected from nine different state (Punjab, Himachal Pradesh, Andhra Pradesh, Kerala, Maharashtra, Jharkhand, J & K and Kolkata) varying widely in their soil characteristics, vegetation and climatic condition of India. The incubation experiment was carried out at 30^o C in BOD incubator for 30 days. The gas samples were collected at regular intervals and immediately analyzed for N_2O using a gas chromatograph (Hewlett Packard, series 5590) fitted with a Porapak-N column and electron capture detector. All the soil samples showed almost similar pattern of N_2O emission i.e. initial emission was negligible but with advent of time emission increased and attained maximum value between 10 to 13^{th} day after incubation followed by rapid decline. The soils of Bagalkot, Howrah, Ranchi, Palkkad and Ludhiana showed early peak of N_2O flux than soils of Ahmednagar, Srinagar and Solan. The soil samples of Ludhiana emitted highest amount of N_2O (39.74 ± 0.64 µg/100 g) over 30 days of incubation followed by Howrah (37.28 ± 0.68 µg/100 g) and Ahmednagar (32.78 ± 0.17 µg/100 g) while lowest emission was recorded in soil samples of Ranchi (18.13 ± 0.46 µg/100 g). N_2O emission showed significant positive correlation with pH of soil and total nitrogen content while significant negative correlation with C/N ratio. Present study showed that the soil of Punjab, West Bengal and Maharashtra contribute a significant amount of N_2O to the atmosphere and soil pH, C/N ratio, total N content, NO_3-N content and extent of agricultural practices are some of the key factors for controlling the N_2O emission from the soil.

भारत की विभिन्न मृदाओं से नाइट्रस ऑक्साइड का उत्सर्जन

सारांश

भारत के नव विभिन्य राज्यों के चुने हुए स्थान जो की मिट्टी, वनस्पति तथा जलवायु के विशेषता में व्यापक रूप से अलग हैं इसलिए पंजाब, हिमाचल प्रदेश, आंध्र प्रदेश, केरल, महाराष्ट्र, झारखंड, जम्मू एवं कश्मीर और वेस्ट बंगाल राज्यों की मृदा से निकलने वाले एक महत्वपूर्ण ग्रीन हाउस गैस N_2O का कुल संचयी उत्सर्जन और उत्सर्जन के तरीकों के अध्यन के लिए आई.ए.आर. ई, न्यू दिल्ही के पर्यावरण विज्ञानं संभाग में एक प्रयोगशालिय प्रयोग किया गया। ऊष्मायन प्रयोग बीओडी इनक्यूबेटर में 30 दिनों के लिए 30 डिग्री सेल्सियस पर किया गया। गैस के नमूने नियमित अंतराल पर एकत्र किए गए और तुरंत पोरपाक - एन कोलुम्न तथा इलेक्ट्रॉन कब्जा डिटेक्टर से सज्जित गैस क्रोमैटोग्राफ (हेवलेट पैकार्ड 5590, श्रृंखला) का उपयोग कर N_2O का विश्लेषण किया गया। इन्क्युबेटेड मिट्टी के नमूनों के विश्लेषण से पता चला की सभी मिट्टी से N_2O उत्सर्जन का प्रतिमान लगभग समान है यानि प्रारंभ में उत्सर्जन नगण्य थी लेकिन समय के साथ उत्सर्जन में वृद्धि हुई और ऊष्मायन 10वें से 13वें दिन के बिच अधिकतम उत्सर्जन हुई उसके बाद तेजी से गिरावट आई। बागलकोट, हावड़ा, रांची, पलक्कड़ और लुधियाना की मिट्टी, अहमदनगर श्रीनगर, और सोलन की मिट्टी से पहले हिं N_2O प्रवाह का शिखर दिखाएँ। लुधियाना की मिट्टी के नमूने से 31 ऊष्मायन दिन की अवधि में सर्वाधिक (39.74 ± 0.64 µg/100g) N_2O का उतसर्जन हुआ, इसके बाद हावड़ा (37.28 ± 0.68 µg/100g) और अहमदनगर में तथा सबसे कम उत्सर्जन 18.13 (± 0.46 µg 100 /g) रांची की मिट्टी के नमूने में दर्ज की गई। N_2O उत्सर्जन, मिट्टी के पी.एच. और कुल नाइट्रोजन मात्रा के साथ महत्वपूर्ण सकारात्मक सहसंबंध तथा सी / एन अनुपात के साथ महत्वपूर्ण नकारात्मक सहसंबंध दिखाया। वर्तमान अध्ययन से पता चला कि पंजाब, पश्चिम बंगाल और महाराष्ट्र की मिट्टी, वातावरण में N_2O का एक मत्वपूर्ण मात्रा का योगदान करती है। मिट्टी पी एच., सी / एन अनुपात, कुल नाइट्रोजन, NO_3-N और कृषि पद्धतियां मिट्टी से N_2O उत्सर्जन को नियंत्रित करने के लिए महत्वपूर्ण कारकों में से कुछ हैं।

BIBLIOGRAPHY

Adhya, T.K., Bharti K., Mohanty, S.R., Ramakrishnan, B., Rao V.R., Sethunathan N., Wassmann R. (2000) Methane emission from rice fields at Cuttack, India. *Nutrient Cycling Agroecosystem* **58**: 95-106.

Aderson, Joels.L.(1986) Relative ratios of nitric oxide and nitrous oxide production by nitrifiers, denitrifier and nitrate respires. *Applied environmental microbiology* **51**(5):938-945.

Aggarwal, P.K., Kalra, N., Chander, S. and Pathak, H. (2006) InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agriculture Systems*. **89**(1):1-25.

Ahuja, D.R. (1990) Estimating Regional Anthropogenic Emissions of Greenhouse Gases, US-EPA Climate Change Technical Series, Washington DC. p. 20.

ALGAS. (1998) Asia Least-cost Greenhouse gas Abatement Strategy: National Report on Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS), Ministry of Environment and Forest, Government of India, New Delhi.

Arah and smith(1989) Steady state denitrification in segregated soils: a mathematical model. *European journal of soil science*.**40(1)**:139-149.

Andreae MO and Merlet P. (2001) Emission of trace gases and aerosols from biomass burning. *Global Biogeochem. Cycles* **15**: 955– 966.

Aulakh, M.S.(1988): Recent advances in Biotechnology and applied Biology. In: *Chang, S., Chan, K. and Woo, N.Y.S (eds.), Chinese University, Hong Cong. pp.* 691-702.

Azam,F.,Miller.C.,Wieske.A.,Benckisier,G.,Ottoo,J.C.G.(2002)Nitrification and denitrification sources of atmospheric nitrous oxide role of oxidisable carbon and applied nitrogen. *Biology and fertility of soils*.**35(1**):54-61.

Bandibas, J.,Vermoesen, A., De Groot, C.J., Cleemput, O.Van (1994): The effect of different moisture regimes and soil characteristics on nitrous oxide emission from different soils. *Soil Science*, **152(2);** 106-114.

Bandyopadhyay S.K., H. Pathak, N. Kalra, P.K. Aggarwal, R. Kaur, H.C.Joshi, R. Choudhary, and R.P. Roetter.(2001)Yield estimation and agro-technical

description of production systems. In Aggarwal P.K., Roetter, R.P. Kalra, N., Van Keulen, H., Hoanh, C.T. and Van Laar, H.H. (eds.) Land use analysis and planning for sustainable food security: with an illustration for the state of Haryana, India. New Delhi: Indian Agricultural Research Institute; Los Banos: International Rice Research Institute; Wagningen: Wagningen University and Research Center. pp.61-89.

Beauchamp, E.G. (1997): Nitrous oxide emission from agricultural soils. *Canadian Journal of Soil Sciience,* **77**; 113–123

Bharati, K., Mohanty, S.R., Singh, D.P., Rao, V.R., Adhya, T.K. (2000a) Influence of incorporation or dual cropping of *Azolla* on methane emission from a flooded alluvial soil planted to rice in eastern India. *Agri. Eco. Env.* **79**: 73-83.

Bharti K, Mohanty S R, Padmavati P V L, Rao V R & Adhya T K.(2000b) Influence of six nitrification inhibitors on methane production in a flooded alluvial soil, *Nutrient Cycling Agroecosystem*. **58**:389-394.

Bhat, A.K. and Beri, B. (1996) Methane emission in irrigated rice soils of Punjab. Current Science. **70(3**): 154-155.

Bhatia A, Aggarwal PK, and Pathak H. (2007) Simulating greenhouse gas emissions from Indian rice fields using the InfoCrop Model. Intern. Rice Res. Notes. 32:38-40.

Bhatia A, Pathak H Aggarwal PK, and Jain N. (2010) Trade-off between productivity enhancement and global warming potential of rice and wheat in India. *Nutr. Cycling Agroecosys*. 86:413-424.

Bhatia A, Pathak H, Jain N, Singh PK and Singh AK. (2005) Global warming potential of manure amended soils under rice-wheat system in the Indo-Gangetic Plains. Atmosphere Environment. 39: 6976–6984.

Bhatia A, Sasmal S, Jain N, Pathak H, Kumar R and Singh A. (2010) Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. Agric. Ecosys Environ. DOI: 10.1016/j.agee. 2010.01.004

Bhatia, A., Pathak, H. and Aggarwal, P.K. (2004) Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential. *Current Science*. 87(3): 317-324.

Bhatia, A., Pathak,H., Agrawal, P.K.(2004): Inventory of methane and nitrous oxide emission from agricultural soils of India and their global warming potential.*Current Science*.**87(3);** 317-324.

Bhattacharya S and Mitra AP. (1998) Greenhouse gas emission India for the base year 1990. Center on Global Change, National Physical Laboratory, New Delhi. pp 118.

Bøckman, O.Chr., Olfs, H.W.(1998): Fertilizers, agronomy and N_2O. *Nutrient Cycling in Agroecosystems.* **52**; 165-170.

Bolmann, A. and Conrad,R.(1998) Influence of O_2 availability on NO and N_2O release by nitrification and denitrification in soils.*Global change biology and biochemistry*.**12(3):**263-269.

Breitenbeck, G.A., Blackmer, A.M., Bremner, J.M. (1980): Effects of different nitrogen fertilizers on emission of nitrous oxide from soil. *Journal of Geophysical Research,* **7**; 85-88.

Bremmer,J.M.(1965):Total nitrogen. In :Black C.A.et.al.(eds).Methods of soil analysis. .*American Society of Agronomy ,Madison, Wis, Part 2.Agron* **9**;1149-1176

Bremner, J.M., Blackmer, A.M. (1981): Terrestrial nitrification as a source of atmospheric nitrous oxide. In*: Delwiche, C.C (eds.) Biochemistry of ancient and modern environments. Canberra, Australia. pp. 279-291.*

Bremner, J.M., Blackmer, A.M. (1978): Nitrous oxide: Emission from soils during nitification of fertilizer nitrogen. *Science*, **199**; 295-297.

Bramley and White (1989) The effect of PH , liming, moisture and temperature on activity of nitrifiers in a soil under pasture.*Australian Journal of soil research.***27(4)**:711-724.

Broadbent, F. E., Clark, F. (1965): Denitrification.**In**: Bartholomew, W.V. andCalrk, F.E. (eds.) Soil nitrogen. Agronomy*, American Society of Agronomy*, **10**; 344-359.

Burton, D.L., Bergstrom, D.W., Covert, J.A., Wagner Riddle, C. and Beauchomp, E.G. (1997). Three methods to estimate N_2O fluxes as impacted by agricultural management.*Canadian journal of soil science* **77**:125-134.

Cao, M., Gregson, K., Marshall, S., Dent, J.B. and Heal, O. (1996) Global methane emissions from rice paddies*. Chemosphere.* **55(5),** 879-897.

Ciarlo, E, Conti., Bartoloni, M., Rubio, N. (2008):Soil N_2O emissions and $N_2O/(N_2O+N_2)$ ratio as affected by different fertilization practices and soil moisture, Biology and fertility of soils.**44(7):**991-995.

Conrad,R., Bak,F., Seitz,H.J.,Thebrath,B.,Mayer,H.P., Schutz,H.,(1983) Hydrogen turnover by Psychotropic homoacetogenic and mesophilic methanogenic bacteria in anoxic paddy soil and lake sediment ,*FEMS microbiology letters*.**62(5):**285-293.

Clemens,J.and Huschka,A.(2001)The effect of biological oxygen demand of cattle slurry and soil moisture on nitrous oxide emission.*Nutrient cycling in agroecosystem*.**59(2):**193-198.

Daji,H.J., Cameron, K.C.(2004): Effect of temperature and application rate of nitrification inhibitor,dicyandiamide(DCD), on nitrification rate and microbial biomass in a grazed pasture soil. *Australian Journal Of Soil Research,* **42(8)**; 927-932.

Das Kaushik, Baruah KK. (2008) Agriculture, *Ecosystems and Environment*.**124 (1):** 105-113.

Davidson, E.A. (1992): Sources of nitric oxide and nitrous oxide following wetting of dry soil. *Soil Science Society of American Journal*, **56**; 95-102.

Debnath G., M.C. Jain, Sushil Kumar, K. Sarkar and S.K. Sinha. (1996) Methane emission from rice fields amended with biogas slurry and farmyard manure. Climatic Change 33:97-109.

Dendooven, L., Bonhomme, E., Merckx, R., Vlassak, K. (1998): Injection of pig slurry and its effect on dynamics of nitrogen and carbon in a loamy soil under laboratory conditions. *Biology and fertility of Soil*, **27**; 5-8.

Dobbie, K.A., Smith, K.E.(2001): The effect of temperature, water filled pore space and land use on N_2O emission from an imperfectly drained gleysol, *European Journal of Soil Science,***52**; 667-673

Dobbie, K.E., McTagggart, L.P., Smith, K.A. (1999): Nitrous oxide emission from intensive agricultural system: Variation between crops and seasons, key driving variables, and mean emission factors. *Journal of Geophysical Research ,* **104**; 26891–26899

Dobbie., Karen, E., Smith, Keith, A. (2003): Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling Variables. *Global Change Biology*, **9(2)**; 204–218

Duxbury, J.M. and McConnaughey, P.K.(1986): Effect of fertilizer source on denitrification and nitrous oxide emissions in a maize-field. *Soil Science Society of American Journal,* **50**; 644-648.

Duxbury, J.M., Bouldin, D.R., Terry, R.E., Tate, R.L. (1982): Emissions of nitrous oxide from soils. *Nature,* **275;** 602-604

Ebrayi, K.N., Pathak, H., Kalra, N., Bhatia, A. and Jain, N. (2007) Simulation of nitrogen dynamics in soil using InfoCrop model. Env. Monit. Assess. 131:451-465.

Ehhalt, D., Prather, M., Dentener, F., Derwent, R., Dlugokencky, E., Holland, E., Isaksen, I., Katima, J., Kirchho, V., Matson, P., Midgley, P. and Wang, M. (2001): Atmospheric Chemistry and Greenhouse Gases. In: *Houghton, J. T., Ding, Y., Griggs, D. J. (eds.) Climate Change: The Scientific Basis. Cambridge University Press, Cambridge.* pp. 881.

Eichner, M.J. (1990): Nitrous oxide emission from fertilized soils: Summary of available data. *Environmental Quality Journal,* **19;** 272-280.

FAO, Agriculture and Consumer Protection Department (2003): Fertilizer and future. *Spotlight* (Magazine)

Fertiliser Statistics (2000) Fertilizer Association of India, New Delhi.

Firestone, M. K., Davidson, E.A.(1989): Microbiological basis of NO and N_2O prod.and consumption in soil. **In** :*Andreae, M. O. and Schimel, D. S. (eds) Exchange of trace gases between terrestrial ecosystem and the Atmosphere John Willy and sons ltd. pp. 7-21.*

Firestone, M.K., Firestone, R.B., Tiedje, J.M.(1980): Nitrous oxide from soil denitrification: factors controlling its biological production. *Science* **28**; 749-750.

Gadde B, Christoph MC and Wassmann R. (2009) Rice straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation, Biomass Bioenergy 33: 1532-1546.

Galbally,I.E.,Frenzy,J.R.,Muirhead,W.A.,Simpson,J.R.,Trevitt,A.C.F.,Chalk P.M.,(1986) Emission of nitrogen oxide(NOx) from a flooded soils fertilized with urea relation to other nitrogen loss processes.*Journal of atmospheric chemistry* **5(3):**343-365.

Garg, A. and Shukla, P.R. (2002) Emission inventory of India. Tata McGraw-Hill Publishing Co., New Delhi 278 p.

Garg, A., Bhattacharya, S., Shukla, P. R. & Dadhwal, V. K. (2001). Regional and sectoral assessment of greenhouse gas emission in India. Atmos. Environ. 35, 2679–2695.

Ghosh, S., Jain, M.C. and Sinha S.K. (1995) Estimates of global methane production from rice paddies based on substrate requirement. Current Science. 69(11): 937-939.

Ghosh, S., Majumdar, D. and Jain, M.C. (2002) Nitrous oxide emissions from kharif and rabi legumes grown on an alluvial soil. *Biology Fertility Soils*. 35(6): 473-478.

Ghosh, S., Majumdar, D., Jain, M.C.(2003) :Methane and nitrous oxide emissions from an irrigated rice of north India , *Chemosphere* ,**51(3)**; 181-195.

Gogoi N., Baruah K.K. , Gogoi B., Gupta P.K. (2005) Methane emission characteristics and its relations with plant and soil parameters under irrigated rice ecosystem of northeast India. *Chemosphere* 59: 1677–1684

Granli, T., Bockman, O.C. (1994): Nitrous oxide from agriculture.*Norwegian*

Gupta PK, Gupta V, Sharma C, Das SN, Purkait N, Adhya TK, Pathak H, Ramesh R, Baruah KK, Venkatratnam L, Singh G and Iyer CSP. (2009) Development of methane emission factors for Indian paddy fields and estimation of national methane budget. *Chemosphere* 74: 590-598.

Gupta, Prabhat K., Sharma, C., Bhattacharya, S. and Mitra, A.P. (2002) Scientific basis for establishing country greenhouse gas estimates for rice-based agriculture: An Indian case study. *Nutrient Cycling Agroecosys*., 64: 19–31.

Gupta, Raj K. and Rao, D.L.N. (1994). Potential of wastelands for sequestering carbon by reforestation. Curr. Sci. 66, 73-75.

Hao, W.M., Scgraffe, D., Crutzen, P.J., Sanhueza (1988) *Journal of Atmospheric Chemistry,* **7**; 93-105.

Henault, C., Devis, X., Lucas, J.L., Germon, J.C.(1998): Influence of different agricultural practices (type of crop form of N fertilizer) on soil nitrous oxide emissions. *Biology and Fertility of Soils,* **27**; 299-306

Huang, Y., Jianwen, Z., Xingkai, Xu.(2004): Nitrous oxide emissions as influenced by amendment of plant residues with different C:N ratios. *Soil Biology and Biochemistry, **36**; 973-981.*

Huke RE and Huke EH. (1997) Rice Area by Type of Culture: South, Southeast, and East Asia. IRRI, Los Baños, Philippines, 59 pp.

Hutchinson, G.L., Mosier, A.R. (1981): Nitrous oxide emissions from cropped fields. *Journal of Environment Quality*, **10**; 169-173.

Hutchinson,J.J.,Grant,B.B.,Smith,W.N.,Desjardins,R.L.,Campbell,C.A.,Wrath,D.E. Verg,X.P.,(2007) Estimates of direct nitrous oxide emission from Canadian agroecosystem and their uncertainties. *Canadian journal of soil science*.87:141-152.

IFPRI. (2009) Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen. The International Food Policy Research Institute (IFPRI).2020 Vision for Food .*Agriculture and the Environment*, p. 29.

IINC. (2004) India's Initial National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment and Forests, Government of India, p 392.

INCCA. (2010) Assessment of the Greenhouse Gas (GHG) Emission 2007, Indian Network for Climate Change Assessment (INCCA).The Ministry of Environment & Forests, Govt. of India.

IPCC (1996): Guidelines for national greenhouse gas inventories.

IPCC (2001): Climate Change 2001: The Scientific Basis. *Cambridge University Press, New York, p. 12.*

IPCC (2001): Climate change: The scientific basis. *Working group I third assessment report, Cambridge Press.,U.K.*

IPCC (2007): Climate change:Impacts, Adaptation & Vulnerability. *Inter-Governmental Panel on Climate Change. Report of the Working group II. Cambridge, UK.*

IPCC, (2007): Climate change 2007: Impacts, adaptation and vulnerability. Inter Governmental Panel on climate change. *Report of the Working Group II. Cambridge, UK.*

IPCC. (1996) Intergovernmental Panel on Climate Change, Climate Change (1995), Scientific Technical Report Analyses, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Eds. Watson, R. T. et al.) Cambridge University Press, Cambridge, p. 880.

IPCC. (2006) Intergovernmental Panel on Climate Change, Guidelines for National

Greenhouse Gas Inventories, IGES, Japan (www.ipcc.ch).

IPCC. (2007) The Physical Science Basis. In: Solomon, S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds.) Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IRRI (2008) World Rice Statistics, International Rice Research Institute, Los Baños, Philippines.

Jackson, M.L (1967) Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd, New Delhi.

Jackson, M.L. (1973): Soil Chemical Analysis .Prentice Hall of India Pvt. Ltd, New Delhi.

Jain, M. C., Kumar, S., Wassmann, R., Mitra, S., Singh, S., Singh, J.P., Singh, R.L Yadav, A.K. and Gupta, S. (2000) Methane emission from rice field in northern India (New Delhi). *Journal Nutrient Cycling Agroecosystem*. 158: 75-83.

Kasimir-Klemedtsson, A., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. Oenema, O. (1997): Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management* **13**; 245-250.

Keen, B.A., Raczkowski, H. (1921): Determination of Bulk density. *Journal of Agriculture science*, **11**; 5131-5144.

Keeney, D.R., Fillery, I.R., Marx, G.P. (1979): Effect of temperature on the gaseous nitrogen products of denitrification in silt loam soil. *Soil Science Society of American Journal,* **43;** 1124-1128

Keeney, D.R., Nelson, D.W.(1982): Nitrogen-Inorganic Forms. In: Page et al. (eds), Methods of Soil Analysis (Part 2). *ASA-SSAC, Madison, WI, USA*; 643-698.

Khalil, M.A.K. and Shearer, M.J. (1993) Methane emissions from rice agriculture. Cited in Shearer, M.J., Khalil, M.A.K. 1993, Rice agriculture: emissions. In: Atmospheric Methane: Sources, Sinks, and Role in Global Change. Berlin, Springer-Verlag, 113: 250-253.

Klepper, L.A,(1987). Nitric oxide emission from soybean leaves during in vivo nitrate reductase assays. *Plant Physiol*., **85**; 96–99.

Knowels, R.(1982): Denitrification. *Microbiological Reviews,* **46;** 43-45

Kumar, U, Jain, M.C., Kumar, S., Pathak, H. and Majumdar, D. (2000a) Role of nitrification inhibitors on nitrous oxide emissions in a fertilized alluvial clay loam

under different moisture regimes. Curr. Sci. 79: 224-228.

Kumar, U., Jain, M.C., Pathak, H., Kumar, S. and Majumdar, D. (2000b) Nitrous oxide emissions from different fertilizers and its mitigation by nitrification inhibitors in irrigated rice. *Biology Fertility Soils.* **32**: 474-478.

Lal, R. (2004) Soil carbon sequestration in India. Climatic Change 65: 277-296.

Lal, R. (2005) Soil carbon sequestration for sustaining agricultural production and improving the environment with particular reference to Brazil. *Journal Sustainable Agriculture*. **26**: 23-42.

Lal, R. (2007) Soil Science and the Carbon Civilization. *Soil Science Society America Journal*. **71**: 1425-1437.

Letey, J., Hadas, A., Valoras, N. and Focht, D.D.(1980): Gas diffusion as a factor in laboratory Lett., **3**; 157-160.

Lindau, C.W., DeLaune, R.D., Patrick., Jr, W.H., Bollich, P.K. (1990): Fertilizer effects on dinitrogen, nitrous oxide and methane emissions from lowland rice. *Soil Science Society of American Journal,* **54**; 1789-1794.

Maag, M. and Vinther, F.P. (1996): Nitrous oxide emission by nitrification and denitrification in different soil types and at different soil moisture contents and temperatures*, Applied Soil Ecology*, **4(1)**; 5-14

Majumdar D, Kumar S, Pathak H, Jain MC and Kumar U. (2000) Reducing nitrous oxide emission from rice field with nitrification inhibitors. Agric. Ecosys. Environ. 81:163-169.

Majumdar, D., Dutta, A., Kumar, S., Pathak, H. and Jain, M.C. (2001) Mitigation of N_2O emission from an alluvial soil by application of karanjin. Biol. Fertil. Soils 33: 438-442.

Majumdar, D., Pathak , H., Kumar, S., Jain, M.C. (2002): Nitrous oxide emission from a sandy loam inceptisol under irrigated wheat in India as influenced by different nitrification inhibitors . *Agricultural Ecosystem Environment*, **91**; 283-293.

Majumdar, D., Pathak, H. Kumar, S. and Jain, M.C. (2002) Nitrous oxide emission from a sandy loam Inceptisol under irrigated wheat in India as influenced by different nitrification inhibitors. *Agricultural Ecosystem Environment*. 91:283-293.

Majumdar, D., Rastogi, M., Kumar, S., Pathak, H., Jain, M.C. and Kumar, U. (2000): Nitrous oxide emissions from an alluvial soil with different nitrogenous

fertilizers and nitrogen levels. *Journal of Indian Society of Soil Science,* **48**; 732-741.

Majumder, B., Mandal, B., Bandyopadhyay, P. 2008. Soil organic carbon pools and productivity in relation to nutrient management in a 20-year-old rice–berseem agroecosystem. *Biology Fertility of Soils* **44:** 451-461.

Maljanen, M., Liikanen, A., Silvola, J., and Martikainen, P. J.(2003): Measuring N2O emissions from organic soils with closed chamber or gas gradient methods. *European Journal Soil Science*. **54**; 625–631.

Maljanen, M., Liikanen, A., Silvola. J., and Martikainen, J.P. (2003)**:**Nitrous oxide emissions from boreal organic soil under different land-use. *Soil Biology and Biochemistry***, 35(5)**; 689-700.

Malla G, Bhatia A, Pathak H, Prasad S, Jain N, Singh J and Kumar V. (2005) Mitigating nitrous oxide and methane emissions from soil under rice-wheat system with nitrification inhibitors. *Chemosphere* **58**: 141–147.

Malla, G., Bhatia, A., Pathak , H., Prasad, S., Jain, N., Singh, J.(2004) : Mitigating nitrous oxide and methane emissions from soil in rice-wheat system of Indogangetic plain with nitrification and urease inhibitor ,*Chemosphere*,**52(2**); 141-147

Mandal, B., Majumder, B., Adhya, T.K. et al. 2008. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. *Global Change Biology*. **14**: 2139-2151.

Manna, M.C., Swarup, A., Wajari., R.H. et al. (2005) Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Res*. **93**: 264-280.

Matthews, E., Fung, I., and Lerner, J. (1991) Methane emission from rice cultivation: geographic and seasonal distribution of cultivated areas and emissions. *Global Biogeochem. Cycles* **5**: 3-24.

McKenney, D.J., Wang, S.W., Drury, C.F., Findlay, W.I. (1995): Denitrification, immobilization and mineralization in nitrate limited and non-limited residue amended soil. *Soil Science Society of America Journal*, **59;** 118–124

Mosier, A., Kroeze ,C., Nevison, C,, Oenema, O., Seitzinger, S., Cleemput, O van .(1999): An overview of the revised 1996 IPCC guidelines for national

greenhouse gas inventory methodology for nitrous oxide from agriculture. *Environmental Science Pollution.* **2**; 35–333.

Mosier, A.R., Guenzi, W.D. and Schwezer, E.E. (1986). Soil losses of dinitrogen and nitrous oxide from irrigated crop in Northeastern Colorado. *Soil Science Society of American Journal.***50:** 344-348.

Mosier, A.R., Hutchinson, G.L.(1981): Nitrous oxide emission from crop fields. *Journal of Environmental Quality.* **10**; 169-173

Mosier,A.R,Parton,W.J.and Phangpan,S(1988) Long term large N and immediate small N addition effects on trace gas fluxes in the Colorado shortgrass steppe, *Biology and fertility soils*.**28**:44-50.

Olsen, S.R., Cole, C.V., Watanable, F.S. and Dean, L.A. (1954): Estimation of available phosphorus in soils by extraction with sodium bicarbonate.*Circulation of U.S. Department of Agriculture*, **939.**

Page, A.L., Miller, R.H., Keeney, D.R. (1982): Methods of soil analysis.Part 2, Chemical and microbiological properties, *2nd edition, Agronomy No. 9, ASA-SSSA Madison, WI, USA.*

Parasher, D.C., Gupta, P.K., Rai, J., Sharma, R.C., Singh, N., Reddy, B.M.(1991) : Measurement of greenhouse gas in India of the Indo-US Workshop, New Delhi; 625-640.

Parkin, T.B. (1987): Soil microsites as source denitrification variability. *Soil Science Society of American Journal,* **51**; 1194-1199.

Pathak, H. (1999): Emissions of nitrous oxide from soil. *Current Science*,**77(3)**; 359-369

Pathak, H. and Nedwell, D.B. (2001): Nitrous oxide emission from soil with different fertilizers water levels and nitrification inhibitors. *Water Soil Air Pollution,* **129**; 217-228.

Pathak, H. and Rao, D.L.N. (1998): Carbon and nitrogen mineralization from added organic matter in saline and alkali soils. *Soil Biology Biochemistry*, **30(6)**; 695-702

Pathak, H., Bhatia, A., Prasad,S., Jain, M.C., Kumar, S., Singh,S. (2002): Emission of nitrous oxide from soil in rice-wheat systems of Indogangetic plains of India*. Environ. Monitoring Assessment*, **77(2**); 163-178

Pilegaard, K., Skiba, U., Ambus, P., Beier, C., Bruggemann, N.,Butterbach-Bahl, K., Dick, J., Dorsey, J., Duyzer, J., Gallagher,M., Gasche, R., Horvath, L., Kitzler, B., Leip, A., Pihlatie, M.K., Rosenkranz, P., Seufert, G., Vesala, T., Westrate, H., andZechmeister-Boltenstern, S. (2006): Nitrogen load and forest type determine the soil emission of nitrogen oxides (NO and N2O). *Biogeosciences* .**3**: 837–869.

Piper, C.D. (1966): Soil and Plant Analysis, *Hans Publishers, Bombay*.

Plant and Soil, **181**; 153-162

Ryden, J.C., Lund, L.J., Focht, D.D.(1978):Direct in-field measurement of denitrification loss from soil. *Soil Science Society of American Journal*, **42**; 731-738

Schindlbacher, A., Zechmeister-Boltnstern, S., Butterbach-Bahl, K.(2004) Effect of Soil moisture and temperature on NO, NO_2 and N_2O emission from European forestsoil. *Journal of Geophysical Research,* **109**; 217-302.

Seiler, W., Conrad, R. (1981): Field measurements of natural and fertilizer induced N_2O release rates from soils. *Journal of Air Pollution and Contamination Association,* **31**; 767-772.

Sahrawat K L and Keeney D R (1986) Nitrous oxide emission from Nitrous oxide emission from soil. *Advances in Soil Science*. **4**: 103–148

Smith, K.A., Patrick, W.H. Jr. (1983): Nitrous oxide emission as affected by alternate anaerobic and aerobic conditions from soil suspensions enriched with ammonium sulphate. Soil Biology and Biochemistry **15**: 693-697

Smith,K.A.,Dobbie,K.E.(1980) The effect of temperature , water filled pore space and land use on N_2O emission from imperfectly drained gleysol.*European Journal of soil science*.52(4):667-673.

Subbaih, B.V and Asija, G.L(1965) A rapid procedure for the estimation of available nitrogen in soils. *Current Science*.25:259-260.

Thornton, P.E., Running, S.W., White, M.A. (1997) Generating surfaces of daily meteorological variables over large regions of complex terrain. *Journal of Hydrology* **190**: 214-251.

Tiedje, J.M. (1988): Ecology of denitrification and dissimilatory nitrate reduction to ammonium. *Zehnder, A.J.B. (eds.) Environmental Microbiology of Anaerobes Wiley, New York*; 199-244.

Verma, A., Tyagi, L., Singh, S.N.(2008): Attenuation of N_2O emission rates from agricultural soils at different dicyandiamide concentrations. *Environmental monitoring and assessment*. **137;** 287-293.

Walkley, A and Black,C.A.(1934) An examination of the Degjareff method for determining soils organic matter and a proposed modification of chromic acid titration method .*Soil Science*.**37**:27-38.

Webster, A. and Hopkins,D.W.(1996) Nitrogen and oxygen isotope ratios of nitrous oxide emitted from soil and produced by nitrifying and denitrifying bacteria. *Biology and fertility of soils.* **22 (4):**326-330.

Weier, K.L., Gillam, J.W. (1986): Effect of acidity on nitrogen mineralization and nitrification in Atlantic coastal plain soils. *Soil Science Society of American Journal,* **50;** 1210-1214.

Williams, E.J., Hutchinson, G.L., Fehsenfeld, F.C. (1992): NOx and N_2O emissions from soils. *Global Biogeochem Cycle,***6**; 351-388.

Xiaoyuan, Y., Hosen, K., Yagi. (2001). Nitrous oxide and nitric oxide emissions from maize field plots as affected by n fertilizer type and application method. *Biology and Fertility of Soils,* **34**; 297-303.

Xing, G.X.,(1998): N_2O emission from cropland in China. *Nutrient Cycling Agroecosyst*, **52**; 249–254.

Yoshinari, T.(1990): Denitification in Soil and Sediment (edsRevsbech, N. P. and Sorenson, J.), *Plenum, New York*. ;129–149.

Yu, K.W., Wang, Z. P., Vermoesen, A., Patrick, W.H. Jr., Van Cleemput, O. (2001): Nitrous oxide and methane emissions from different soil suspensions: effect of soil redox status. *Biology Fertility of Soil.* **34**:25-30.

Zechmeister-Boltenstern, S. (2006): Factors controlling regional differences in forest soil emission of nitrogen oxides (NO and N_2O). *Biogeosciences*, **3(4)** ; 651-661