MITIGATION OF NITROUS OXIDE AND METHANE EMISSIONS FROM RICE-WHEAT SYSTEM OF THE INDO-GANGETIC PLAIN

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ABSTRACT: Mitigation of methane (CH_4) and nitrous oxide (N_2O) emission from soil is important to reduce the global warming. Efficacy of six nitrification inhibitors i.e. neem cake, thiosulphate, coated calcium carbide, neem oil, hydroquinone and dicyandiamide (DCD) in mitigating N_2O and CH_4 emissions from fertilized soil in rice-wheat system, which occupies 13.5 million ha of the most productive lands in the Indo-Gangetic plains, was tested in field. The closed chamber technique was used for the collection of gas samples, which were analyzed using gas chromatography. Reduction in N_2O-N emission on the application of nitrification inhibitors ranged from 5% with hydroquinone to 31% with thiosulphate in rice and 7% with hydoquinone to 29% with DCD in wheat crop. Nitrification inhibitors also influenced the emission of CH_4. While application of neem coated urea, coated calcium carbide, neem oil and DCD reduced the emission of CH_4; hydroquinone and thiosulphate increased it when compared to urea alone. However, the total global warming potential (GWP) was lower with all the inhibitors (except hydroquinone) as compared to urea, suggesting that these substances could be used for mitigating greenhouse gas emission from the rice-wheat systems.

1.0 INTRODUCTION

Methane (CH_4) and nitrous oxide (N_2O) are the important greenhouse gases contributing 15% and 5%, respectively, towards the enhanced global warming (Watson *et al*. 1996). Methane concentration in the atmosphere is presently increasing at 3% per year (Prinn 1995) while the concentration of N_2O is increasing at 0.22% per year (Battle *et al*. 1996). Agricultural soils contribute significantly towards atmospheric CH_4 and N_2O (Mosier *et al.* 1998).

1.1 BACKGROUND

Rice-wheat (RW) cropping systems occupy 26 million ha of cultivated land in the Asian subtropics (Ladha *et al*. 2003). In the Indo-Gangetic plain (IGP) of South Asia the system occupies about 13.5 million ha of the most productive lands. In the RW system, the soil and water requirements of the two crops are drastically different. Rice seedlings are, traditionally transplanted in puddled and submerged soils, while wheat requires a well-pulverized and aerated soil to attain its potential yield. The alluvial soil (Ustochrept) of the region is sandy loam in texture with a high percolation rate and needs frequent irrigation in rice and soil moisture content many a times goes below the saturation level making the soil aerobic (Pathak *et al*. 2002). The drying of the soil at the end of the rice crop and during wheat also makes the soil aerobic. Thus a cycle of aerobic and anaerobic condition operates in the soil, which considerably influences CH_4 and N_2O emission. Moreover, the RW system consumes very high amount of N fertilizer, which also affects CH_4 and N_2O emission.

1.1.1 STATUS OF WORK TO DATE

Nitrification inhibitors, which slow down conversion of NH_4^+-N into NO_3^- –N, are reported to increase nitrogen use efficiency and crop yield (Prasad and Power 1995). Application of these inhibitors may also have considerable influence on N_2O and CH_4 emission in soil (Bronson and Mosier 1994; Wilson *et al*. 1995). For example, nitrification inhibitors like dicyandiamide (DCD), nitrapyrin (NP), acetylene, 2-amino-4-chloro–6-methyl-peyrimidine (AM) and 2-sulfanilamide-thiazole (ST) have been found to reduce N_2O emission from soil (Pathak and Nedwell 2001). Some new inhibitors like ATC (4-amino 1, 2, 4-triazole) (Aulakh *et al.* 2001) and DMPP (3,4-dimethylpyrazole phosphate) (Weiske *et al*. 2001) have also been reported to reduce N_2O emission. However, most of these compounds did not find popularity with the farmers in South Asia because of their higher cost and non-availability. There is a need to identify locally available and cheap materials to be used as nitrification inhibitor and study their efficacy in mitigating on greenhouse gas emission from soil. Previously studies have been carried out to evaluate the influence of nitrification inhibitors on the emission of either N_2O or CH_4. But as the inhibitors influences the emission of N_2O as well as CH_4, simultaneous measurement should be made for both the gases to evaluate the global warming potential (GWP) of a system.

The objectives of the study are to (i) measure N_2O and CH_4 emissions from soil in RW systems and (ii) evaluate the efficacy of some nitrification inhibitors on N_2O and CH_4 emission from soil.

2.0 MATERIALS AND METHODS

A field experiment was conducted in the farm of Indian Agricultural Research Institute, New Delhi in RW systems in 2001-02. The site is located in the Indo-Gangetic alluvial tract at 28°40’ N and 77°12’ E, at an altitude of 228 m above mean sea level. The alluvial soil of experimental site was loam in texture (46% sand, 33% silt and 21% clay) and had a bulk density of 1.38 g cm^{-3}, pH (1:2 soil:water) of 8.04, electrical conductivity of 0.42 dS m^{-1}, CEC of 7.3 C mol (p^+) kg^{-1}; and organic carbon, total N, Olsen P, and ammonium acetate extractable K contents of 4.2 g kg^{-1}, 0.30 g kg^{-1}, 0.008 g kg^{-1}, and 0.13 g kg^{-1}, respectively.

Efficacy of six nitrification inhibitors i.e. neem cake, thiosulphate, coated calcium carbide, neem oil, hydroquinone and dicyandiamide (DCD) in mitigating N_2O and CH_4 emissions from fertilized soil in rice-wheat system was tested in field with three replications in plots of 5 m long and 5 m wide. Nitrogen was applied through urea in three splits at 60, 30 and 30 kg N ha^{-1} at 7, 37 and 61 days after transplanting (DAT) of rice; while in wheat it was applied at 0, 27, and 66 days after sowing (DAS). Phosphorus (26.2 kg ha^{-1}) and K (50 kg ha^{-1}) were incorporated into the soil at the time of transplanting/sowing using single super phosphate (SSP) and muriate of potash (KCl), respectively, in all the plots.

Three, 30 days old rice seedlings (variety Pusa 44) were transplanted at 20 cm (row to row) by 15 cm (hill to hill) spacing. Wheat (variety HD 2687, 100 kg seed ha^{-1}) was sown in rows 22.5 cm apart. Irrigation in rice was given in 2-3 days interval while in wheat 5 irrigations were given. All the irrigations were of 5±1 cm depth. Weeds, pests, and diseases were controlled as required.

Collection of gas samples was carried out by the closed chamber technique (Pathak *et al*. 2002; 2003). Concentration of CH_4 and N_2O in the gas samples was estimated by gas chromatograph fitted with a flame ionization detector (FID) and electron capture detector (ECD), respectively.

Rice and wheat yields were determined from the total plot area by harvesting all the hills excluding the hills bordering the plot. The grains were separated from the straw, dried, and weighed. Grain moisture was determined immediately after weighing and subsamples were dried in an oven at 65 ^oC for 48 hours.

Soil samples from the 0-15 cm soil layer in 3 locations in each plot were collected using a core sampler. Physico-chemical properties of soil were determined following standard procedures (Page *et al*. 1982).

3.0 RESULTS AND DISCUSSION

3.1 EMISSION OF N_2O-N IN RICE

Emission of N_2O-N ranged from 0.3 to 19.5 g ha^{-1} day^{-1} during 112 days of the experiment (Fig. 1). Denitrification of nitrate in anaerobic soil condition was presumably responsible for the formation of N_2O. Moreover, soil submergence could not be maintained in this highly percolating loam soil. With irrigation applied at 2-3 days interval soil moisture dropped below saturation many times creating aerobic condition and favouring nitrification of ammonium formed by hydrolysis of urea to occur. A peak was observed in all the treatments following the addition of urea and inhibitors in combination with urea followed by a decline to reach a low level. Increased emission from all the plots after urea application could be due to nitrification. Considerable emission of N_2O on day 1 was due to formation of N_2O during denitrification of nitrate N already present in soil.

All the nitrification inhibitors except hydroquinone used in this study were effective in reducing N_2O emission (Table 1). Thiosulphate and Ca-carbide coated urea were found to be the most effective in reducing N_2O emission by 34 and 29%, respectively, over urea. Lower emission with inhibitors was due to availability of less amount of nitrate for denitrification due to the inhibition of the nitrification process. Lowest emissions with thiosulphate were due to the additional advantage of inhibition of hydrolysis of urea along with the inhibition of nitrification (Goos 1985). Thiosulphate also inhibits NH_4^+-N oxidation by heterotrophic nitrifiers and is interconverted with tetrathionate by many soil microorganisms which is a soil urease inhibitor (LeFaou *et al*. 1990).

3.2 EMISSION OF N_2O-N IN WHEAT

On day 1 emission of N_2O ranged from 11.2 to 12.8 g ha^{-1} day^{-1}, which reduced till the next dose of urea was applied. High emission of N_2O on day 1 in all the treatments was due to formation of N_2O during nitrification of ammonium N already present in soil as well as ammonium N produced by the hydrolysis of urea (Fig. 2). A peak was observed in all the treatments following the addition of urea and inhibitors in combination with urea which may be due to vigorous nitrification when sufficient NH_4^+- N was present in soil followed by a decline to reach a low level of N_2O emissions. Denitrification might also have taken place in some anaerobic microsites in the soil, resulting in N_2O-N flux. All the inhibitors used in this study were effective in reducing N_2O emission (Table 1) due to inhibition of nitrification (Pathak and Nedwell 2001). DCD and thiosulphate were found to be the most effective in reducing N_2O-N emission by 29 and 28%, respectively, over urea. The least effective was hydroquinone, which reduced the emission by 7%.

3.3 EMISSION OF CH_4 IN RICE

Flux of CH_4 varied between 0 to 0.6 kg $ha^{-1}day^{-1}$, however, no specific pattern of CH_4 flux was observed in any of the treatments. In some days the emission was very low because of intermittent drying of the soil. The soil moisture level went below saturation many times during the crop growth and thus anaerobic condition required for the formation of CH_4 in soil did not exist. Therefore, in this experiment flux of CH_4 was dictated by irrigation events.

Different inhibitors had significant influence on total emission of CH_4 during 112 days. Total emission of CH_4 was lowest (23.4 kg ha^{-1}) in the Ca-carbide treatment and the highest amount of emission (30.2 kg ha^{-1}) was recorded with application of urea plus hydroquinone (Table 1). The decrease in CH_4 emission seems to be direct result of slow release of acetylene, which inhibits CH_4 production by methanogenic bacteria (Knowles 1979) and the ability of wax coated calcium carbide to maintain low concentrations of CH_4 for extended periods. In case of DCD, since it has no effect on CH_4 oxidation it acts as a sink for CH_4 thereby lowering the emissions. Application of neem coated urea, coated Ca-carbide, neem oil and DCD reduced emission of CH_4 but hydroquinone and thiosulphate recorded 12 and 5% higher emission, respectively, compared to urea alone. There are conflicting reports regarding the influence of nitrification inhibitors on CH_4 emission. It has been suggested that nitrification inhibitors may have some inhibitory effect on CH_4 oxidation in soil probably due to higher conservation of ammonium in soil, leading to an increase in population of nitrifiers relative to methanotrophs and thus the overall reduction in CH_4 oxidation, as nitrifiers oxidize CH_4 less efficiently than methanotrophs (Bronson and Mosier 1994; Wilson *et al*. 1995). Thus there could be increase in CH_4 emission with application of nitrification inhibitors. In some other studies nitrification inhibitors either reduced the emission or had no effect (Weiske *et al.* 2001). In the present study the role of inhibitors was not conclusive and further studies are required.

In wheat no CH_4 emission was detected because of upland condition prevailing throughout the growing season.

The study revealed that nitrification inhibitors (except hydroquinone) are effective in reducing the GWP due to emission of N_2O and CH_4 from rice-wheat cropping systems. Some of the inhibitors like neem cake, neem oil, and calcium carbide are cheap and easily available and were able to reduce N_2O and CH_4 emissions as efficiently as DCD and thiosulphate. Therefore, the use of such materials by the farmers should be encouraged to mitigate the greenhouse gas emissions and combat the global warming.

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Table 1. Emission of nitrous oxide and methane from soil and their total global warming potential in the rice-wheat system

Treatment	N_2O-N emission in rice (kg ha^{-1})	N_2O-N emission in wheat (kg ha^{-1})	CH_4 emission in rice (kg ha^{-1})
Urea	0.76a†	0.66a	27.0b
Urea + hydroquinone	0.73a	0.62b	30.2a
Urea + neem cake	0.68b	0.52d	23.9c
Urea + thiosulphate	0.50d	0.48e	28.4b
Urea + coated Ca-carbide	0.54d	0.58c	23.4c
Neem oil coated urea	0.60c	0.56c	24.9c
Urea + DCD	0.63c	0.47e	23.8c

†In a column, values followed by the same letter are not significantly different at $P<0.05$ by Duncan's multiple range test.

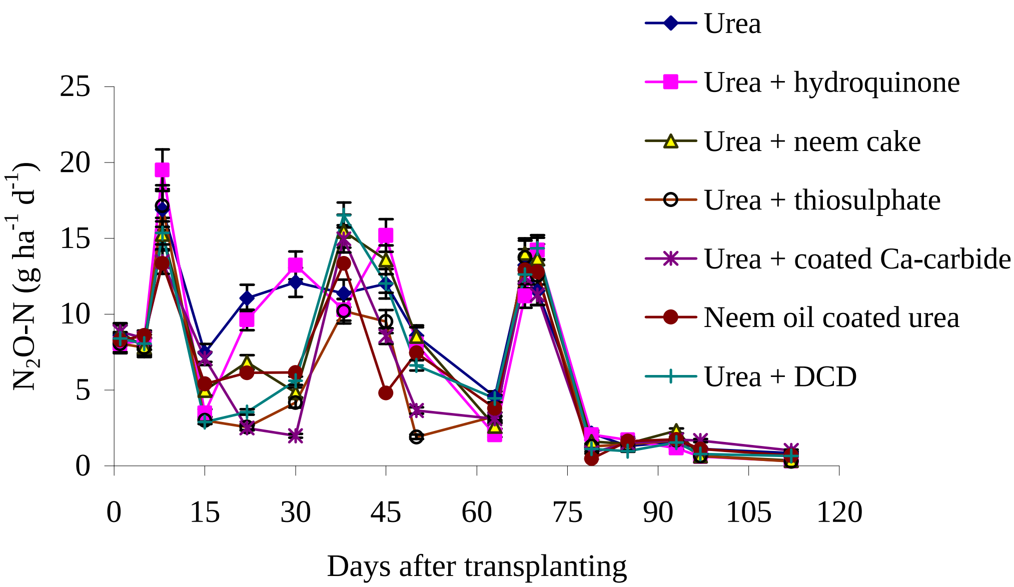

Fig. 1. Emission of nitrous oxide from fertilized soil with nitrification inhibitors in rice

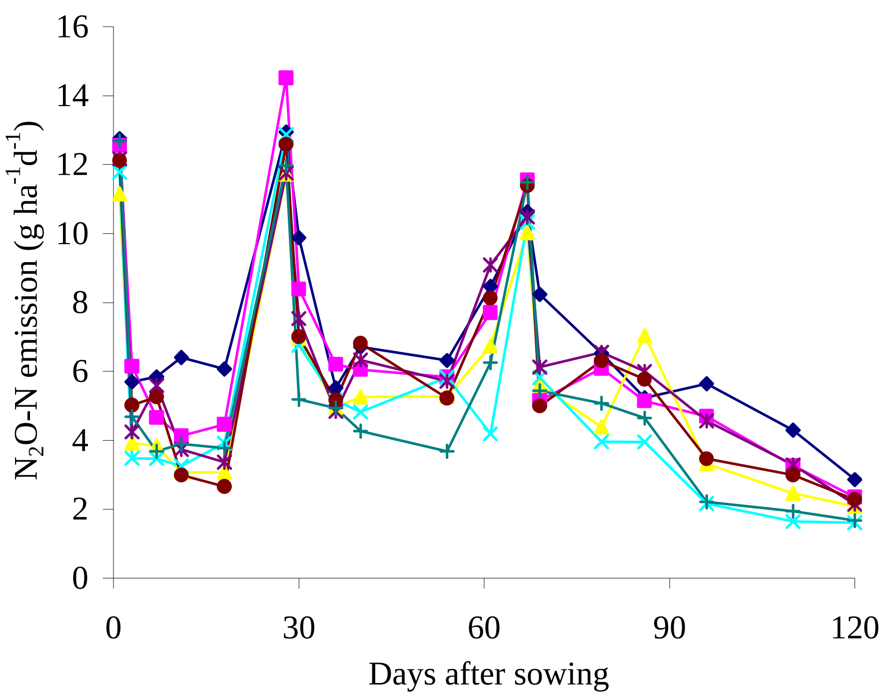

Fig. 2. Emission of nitrous oxide from fertilized soil with nitrification inhibitors in wheat (See Fig. 1. for the legends)