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N_2O emissions from a cultivated Andisol after application of nitrogen fertilizers with or without nitrification inhibitor under soil moisture regime

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Abstract: The aim of this work was to examine the emission of N_2O from soils following addition of nitrogen fertilizer with a nitrification inhibitor(+inh) or without the nitrification inhibitor(-inh) at different soil water regime. Higher soil moisture contents increased the total N_2O emissions in all treatments with total emissions being 7 times larger for the CK and >20 times larger for the fertilizer treatments at 85% WFPS(soil water filled pore space) than at 40% WFPS. The rates of N_2O emissions at 40% WFPS under all treatments were small. The maximum emission rate at 55% WFPS without the nitrification inhibitor(-inh) occurred later (day 11) than those of 70% WFPS (-inh) samples (day 8). The inhibition period was 4—22 d for 55% WFPS and 1—15 d for 70% WFPS comparing the rates of N_2O emissions treated (+inh) with (-inh). The maximum emission rates at 85% WFPS were higher than those at the other levels of soil water content for all treatments. The samples(+inh) released less N_2O than (-inh) samples at the early stage. Nevertheless, N_2O emissions from (+inh) samples lasted longer than in the (-inh) treatment. Changes in mineral N at 55%, 70% and 85% WFPS followed the same pattern. NH_4^+-N concentrations decreased while NO_3^--N concentrations increased from the beginning of incubation. NH_4^+-N concentrations from 40% WFPS treatment declined more slowly than those of the other three levels of soil water content. Nitrification was faster in the (-inh) samples with 100% NH_4^+-N nitrified after 22 d(50% WFPS) and 15 d(70% and 85% WFPS). N_2O emissions increased with soil water content. Adding N-fertilizer increased emissions of N_2O. The application of the nitrification inhibitor significantly reduced total N_2O emissions from 30.5%(at 85%WFPS) to 43.6%(at 55% WFPS).

Keywords: N_2O emission; nitrification inhibitor; soil water content; upland soil samples

Introduction

Nitrous oxide (N_2O) is one of the environmentally important trace gases, currently accounting for 2%—4% of total Greenhouse Warming Potential (GWP). It is also involved in the depletion of stratospheric ozone. Soil has been known as the major source of N_2O, accounting for 65% of total global emissions(Prather, 1995). Thus, reducing N_2O emissions from soils is a main task for the protection of the global atmosphere. N_2O is produced as the result of soil microbial processes, primarilly by nitrification, when the oxidation happens of NH_4^+ to NO_2^- or NO_3^-, and to a lesser extent through denitrification, when the sequential reduction happens of NO_3^- and NO_2^- to NO, N_2O and N_2. The magnitude of N_2O production depends on soil environmental conditions that favor nitrification or denitrification as the main process for N_2O emissions from soils. Denitrification may be the dominant mechanism influencing N_2O production in fertilized soils under oxygen-limited or anaerobic conditions. While nitrification may be the major mechanism responsible for N_2O production under moderately aerobic conditions (Klemedtsson, 1987).

Besides the soil moisture condition, other factors including the form of N-fertilizer applied, crop type, soil type and tillage practice can significantly affect N_2O emissions from soils(Granli, 1994; Mosier, 1996). For the last years, several approaches have been developed to reduce N_2O emissions after the application of mineral N-fertilizers. Among them, use of controlled release fertilizer nitrogen and nitrification inhibitors are of primary importance (Minami, 1994; Bronson, 1992; Mosier, 1996). Nitrification inhibitors can depress emissions of N_2O directly by reducing the fraction of NH_4^+-N oxidized to NO_3^--N and indirectly by reducing the amount of NO_3^--N substrate available for microbial denitrification processes. Many studies have been carried out on the efficiency of nitrification inhibitors to reduce soil born N_2O emissions after fertilization (Minami, 1994; McTaggart, 1997). However, little has been known of the joint effect of soil water content and nitrification inhibitors on N_2O emissions.

Therefore, the aim of this work was to examine the emission of N_2O from a local Andisol soil following fertilizer application at a range of soil moisture conditions. Two fertilizer treatments, with and without addition of nitrification inhibitor, were performed at four levels of soil water content by the laboratory way.

1 Materials and methods

An upland Andisol was collected from a field site cropland of vegetables at the National Institute of Agro-Environmental Sciences in Tsukuba, Japan. Soil samples from the upper soil horizon(0—15 cm) were sieved(2 mm mesh width) and air-dried. The soil pH(H_2O) was 6.0 and total N and C of the soil were 3.6 and 46 g/kg soil, respectively.

The three treatments are as follows: (1) nitrogen fertilizer(urea) with nitrification inhibitor (AM 0.42%)(+inh) or (F2); (2) nitrogen fertilizer (urea) without nitrification inhibitor (-inh) or (F1); (3) control (CK).

Each treatment was studied at 4 moisture contents corresponding to soil water filled pore space(WFPS) values of 40%, 55%, 70%, 85% with 15 replicates each. 80 g(dry wt.) of the sieved air-dried soil was weighed into a 350 ml

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conical flask. Then, 200 μg N/g dry soil corresponding to appropriate fertilizer treatment was added to each flask and mixed with the soil. The sieved soils had a bulk density of 0.7 g dry soil/cm^3 and the soil particle density was 2.65 g/cm^3. Based on these two parameters, the amounts of water were calculated that had to be added to the samples for the target WFPS. The samples were incubated at 28℃. Each flask was closed with a rubber stopper.

Three replicates per moisture level and treatment were randomly removed and analyzed for NH_4^+ and NO_3^- contents in 1, 8, 15, 22 and 36 incubation days after fertilization. Each flask was extracted with 300 ml 2 mol/L KCl solution for 1 h and then filtered. NH_4^+ and NO_3^- concentrations were analyzed by continous flow colorimetric analysis (FSA-802 autoanalyser). After every third or found day the headspace each was analyzed for N_2O. Following each gas sampling all flasks (including those not yet analyzed) were opened for approximately 20 min to aerate the flasks and then reasealed. N_2O analyses were carried out on a 14A gas chromatograph, with electron capture detector at 340℃.

2 Results

2.1 N_2O emissions during the incubation period

Total emission of N_2O (Fig. 1) increased with the soil water content. The total N_2O emissions for the CK treatment at 85% WFPS was 7 times higher than that at 40% WFPS, and the total N_2O emission for fertilizer treatments at 85% WFPS was 20 times higher than that at 40% WFPS.

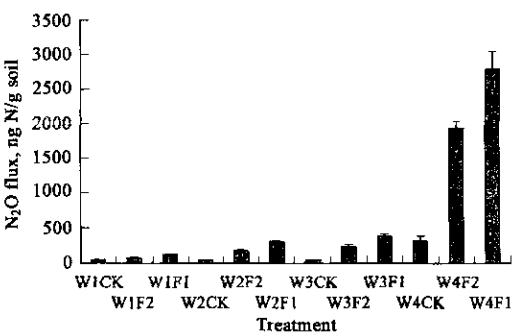

Fig.1 Total amount of N_2O emitted from soil samples with different treatment during 36 d incubation
W1, W2, W3, W4 are expressed as soil water filled pore space (WFPS) values of 40%, 55%, 70%, and 85% respectively. F2, F1, CK are expressed as (1) urea with nitrification inhibitor, (2) urea, and (3) control (no fertilizers) respectively. Bar: STDEV value

The rates of N_2O emissions are given for all sampling times in Fig. 2. The rates of N_2O emission from 40% WFPS (W1) soil samples were small (Fig. 2a). Only little differences could be observed among the three treatments. In addition, the dynamics of N_2O emissions were similar. The maximum emission rate occurred at the first day in all treatments, then the rate declined slowly during the experiment.

At 55% (W2) and 70% (W3) WFPS (Fig. 2b, 2c), for the treatment of urea, maximum emission rates of 55% WFPS (-inh) samples occurred later (day 11) than those of 70% WFPS (-inh) samples (day 8). This indicates that the nitrification activity was stronger at 70% WFPS than at 55% WFPS. After reaching the maximum emission, the rates decreased rapidly.

At the soil water content of 85% (W4) WFPS (Fig. 2d), maximum emission rates for all treatments were higher than at the other levels of soil water content. Maximum emission rates occurred at the first day and declined rapidly with the faster decline for the (-inh) treatment. (+ inh) samples released less N_2O than (-inh) samples at the beginning. Nevertheless, N_2O emissions from (+ inh) samples lasted longer than in the (-inh) treatment. The data of Fig. 1 and Fig.2 indicate that 85% WFPS is the most favorite soil water content for nitrification processes and for N_2O emission under the experimental conditions.

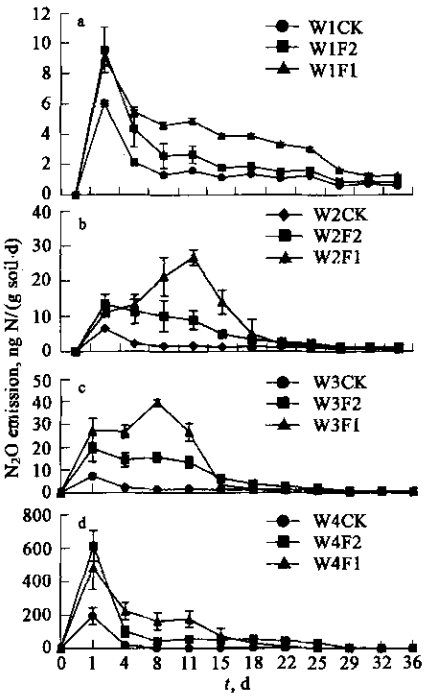

Fig.2 Rates of emissions of N_2O at soil moisture of (a) 40%, (b) 55%, (c) 70%, and (d) 85% WFPS

2.2 The change of mineral nitrogen

Mineral N concentration at 55%, 70% and 85% WFPS followed the same pattern (Fig. 3b, 3c, 3d), for 40% WFPS was different (Fig. 3a). NH_4^+-N concentrations decreased from the beginning of incubation while NO_3^--N concentrations increased. Nevertheless, some differences in the amounts of NH_4^+-N and NO_3^--N among the diffrent moisture contents could be detected. Increasing differences could be found concerning the dynamics of nitrification between the two fertilizer treatments with increasing soil water contents. In relation to increased soil water contents, decrease of NH_4^+-N in (-inh) samples was relatively faster than those of (+ inh) samples. For 40% WFPS treatment, NH_4^+-N concentrations declined more slowly than those of the other three levels of soil water content. Some NH_4^+-N fertilizer still existed in the soil even at the end of the incubation. After 36 days, only 60.1% NH_4^+-N of the (+ inh) specimen and 80.7% NH_4^+-N of the (-inh) specimen respectively were nitrified. At the other three moisture levels, almost all NH_4^+-N applied had been nitrified at the end of the incubation. But there were some differences in the nitrification rates among the different water content treatments. Nitrification rate was positively correlated to soil water content. Nitrification was faster in the (-inh) samples with 100% NH_4^+-N nitrified after 22 d (50% WFPS) and 15 d (70% and 85% WFPS). NH_4^+-N in the (+ inh) samples

was nitrified in the same pattern too, but the nitrification process still lasted until the end of the incubation. Thus, the application of the nitrification inhibitor reduced the nitrification rates significantly.

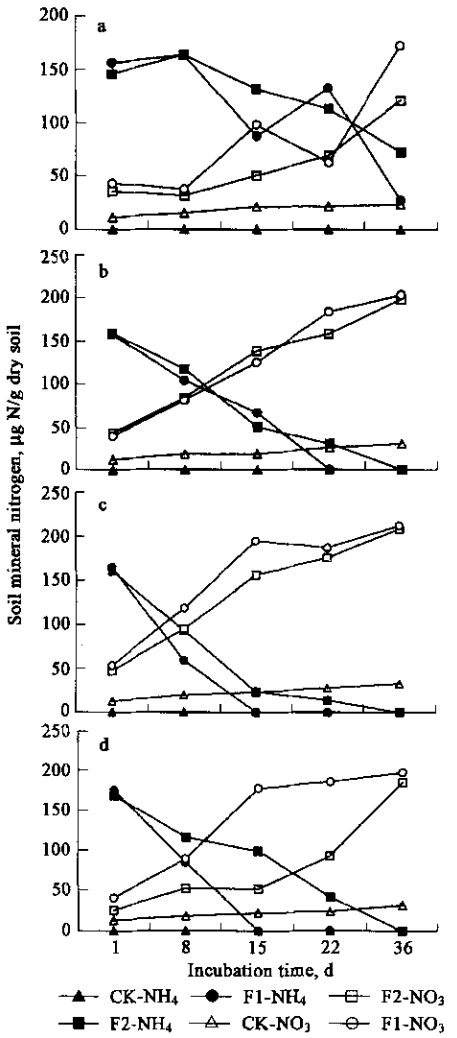

Fig.3 Soil mineral nitrogen at soil moisture of (a) 40%, (b)55%, (c)70%, and (d)85% WFPS

From above, adding N-fertilizer increased emissions of N_2O. Furthermore, a positive correlation between total N_2O emissions and soil water content could be detected, the correlation coefficient is 0.81 and 0.86 for (+inh) and (-inh) treatments respectively. The application of the nitrification inhibitor significantly reduced total N_2O emissions from 43.55% (55% WFPS) to 30.45% (85% WFPS) in comparisons to the respective (-inh) samples(Fig. 1). NH_4^+ concentrations of the soil decreased while NO_3^- contents increased during the whole experiment. Without respect to addition of nitrification inhibitor, nitrification activity was also positively related to soil water contents corresponding to higher amounts and rates of ammonia nitrification. For (-inh) samples the amount of nitrified ammonia ranged from 80.7% (40% WFPS) to 100% (85% WFPS) of total NH_4^+ in a duration of nitrification of 36 and 15 d respectively. Nitrification inhibitor reduced the nitrification rate significantly.

3 Discussion

Changes in the N_2O flux corresponded with the increase in soil moisture in our incubation experiment. These results were similar to the results which were obtained by other investigators (Linn, 1984; Mosier, 1986; Bronson, 1992; Granli, 1994; Kessavalou, 1998). N_2O emissions may be produced by nitrification process or denitrification process or both. Nitrification process and denitrification process were controlled by the nitrification and denitrification microbial activity. Linn (Linn, 1984) demonstrated the importance of soil/air/water balance upon aerobic and anaerobic microbial activities. Aerobic microbial activity increases with soil water content until a point that is reached where water displaces air and restricts the diffusion and availability of oxygen. The soil water content influenced the diffusion of oxygen and influenced nitrification process and denitrification process, finally influenced N_2O emission. From our data (Fig. 3), nitrate content increased with incubation time, the large amount of nitrate still remained in soil samples after 36 days incubation, so the possibility of NO_3^--N being denitrified was lower. N_2O emission may be mainly be produced by nitrification process in the experiment. The difference in N_2O produced from soil water content treatments was owing to that increasing soil water content increased nitrification rate.

Nitrification inhibitors can reduce emissions of N_2O directly by reducing the fraction of NH_4^+-N to NO_3^--N and indirectly by reducing the amount of NO_3^- substrate available for denitrification (Aulakh, 1984; Bronson, 1992; Minami, 1994; Mosier, 1996; McTaggart, 1997). In our experiment, the effect of nitrification inhibitors on N_2O emission was influenced by soil water content, because nitrification rate was affected by soil water content. As a consequence, nitrification inhibitors may play a positive role in the reduction of N_2O emissions from applied mineral N fertilizers. More attention should be drawn towards the importance of soil water regimes on design of sustainable strategies for the reduction of N_2O emissions from arable soils.

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