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N_2O Emissions under Different Moisture and Temperature Regimes

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Nitrous oxide (N_2O) is an efficient greenhouse gas. Its global warming potential is 340 times that of CO_2 when calculated for a time horizon of 100 years (Jain et al. 2000). N_2O also contributes to the destruction of stratospheric ozone by photochemical reaction (Rodhe 1990) N_2O emissions from soil are mainly a consequence of microbiological processes, i.e., nitrification and denitrification (IPCC 1992). These processes are largely controlled by a number of soil factors, such as soil moisture, temperature, and so on, which irregularly and substantially vary over time and space, and also interact with each other. Thus, incubation experiments have played a key role in recent decades (Hannu et al 2004; Wei et al 2004). However, few studies are found to focus on the simultaneous determination of N_2O emissions from nitrification and denitrification processes. Bai (2002) found that soil urease was a stable indicator of soil N_2O emissions in farmland of northwest China, which implied that soil microbiological processes responded positively to temperature or moisture shifts, but were stable and retained full activity within a certain condition range. Holtan (2002) firstly reported the kinetics of N_2O production and reduction under the conditions of low temperature in anaerobic slurries. These studies provide the possibility to simultaneously investigate soil N_2O emissions during the processes of nitrification and denitrification based on an assumption that soil enzymes involved in N_2O emissions are in a state of dynamic equilibrium within a range of temperature or moisture.

The objective of the present study is to investigate N_2O emissions under different moisture and temperature regimes in the dry land of northwest China; and, furthermore, to attempt to determine moisture and temperature parameters involved in N_2O emissions in farmland using the method of chemical reaction dynamics.

Materials and Methods

Soil samples were taken from the 1st farm experiment station of NAFU in the south of the Loess Plateau in China, located at 108°38′N, 35°42′E. This area has an annual mean temperature range of 11.0 to 14.0°C and an annual mean precipitation range of 415 mm to 630 mm, with an annual mean evaporation range of 800 to 900 mm. Crop systems are wheat-corn rotations. Soil was collected from the top 10 cm from the surface. Based on the Chinese classification system, the soil was classified as Earth-Cumuli-Qrthic Anthrosols (B2.4); having 490 $g \cdot kg^{-1}$ physical clay and 210 $g \cdot kg^{-1}$ clay, analyzed by the pipette method. The soil had 11.5 $g \cdot kg^{-1}$ organic matter, 92.9 $g \cdot kg^{-1}$ $CaCO_3$ and a pH (1:1) of 7.9.

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The soil samples were passed through a 1.0 mm sieve after being air-dried. Soil moisture was adjusted to 3% (moisture of air-dried soils), 10% (wilting coefficient), 16%, 22% (field moisture capacity), and 40% (saturation capacity) by carefully spraying water in the soils with a micro-sprayer. 80 g samples (air-dried weight) containing 1 mg C-glucose and 0.1 mg N-NO_3^- per gram dry soil were placed in 500-ml assay flasks and incubated at 10°C or 30°C. The flasks remained sealed throughout the incubation, except for 5 min aerations every 24 hours. Aeration ensured that the soils did not become anaerobic. Three replicates were performed for each moisture treatment. 1 ml samples of headspace atmosphere were taken with a gas-tight syringe after 1, 2, 3, 4, 5, 7, 11, 13, 16 and 19 day(s), and N_2O was measured using a gas chromatograph (Varian GC-3800) with an electron capture detector. The temperature of porapak Q column was 60°C, the electron capture detector (^{63}Ni) ran at 350°C. The injector temperature was 100°C. High-purity nitrogen with a flow velocity of 60 ml·min^{-1} was used as a carrier gas. The N_2O standard gas from Beijing was 9.6 $\mu l \cdot l^{-1}$, and was calibrated with 0.3282 $\mu l \cdot l^{-1}$ gas produced in Sweden. Samples were diluted with 99.999% nitrogen. The computer program had been set up to push out the vapor by a valve device before entering electron capture detector. Variance was less than 5%.

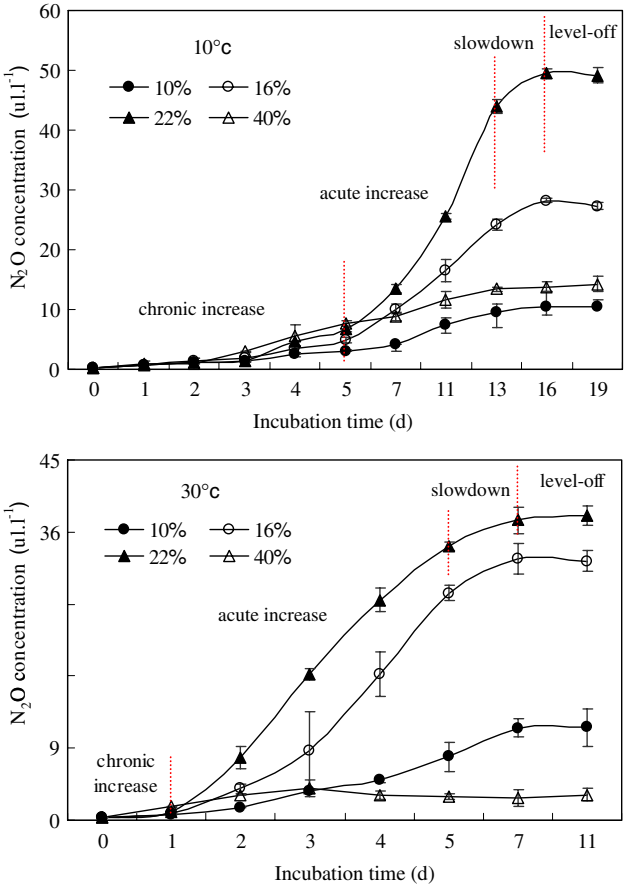

Fig. 1 Moisture effects on N_2O emissions at 10°C and 30°C

Results and Discussion

N_2O emissions of the different moisture treatments are shown in Fig. 1. N_2O concentrations over time were observed to follow S-shaped curves for both incubation temperatures, 10°C and 30°C. The similarity in the shape of these curves is a result of each comprising four stages, i.e., chronic increase, acute increase, slowdown and level-off, which are marked for the 22% moisture treatment (Fig. 1). Therefore, N_2O concentration was low and chronic at the onset of incubation and, thereafter, gradually increased with a higher rate. The rate then slowed down and finally reached a balanced state. At 30°C, the initiation points of the latter three stages were evidently earlier than at 10°C. This phenomenon exhibited the same temperature response of soil nitrifying and denitrifying bacteria. Guo (1999) reported that the optimum temperature of nitrification and denitrification processes in farmland soils were 25°C and 27–35°C, respectively, and both processes would be enhanced with the increase of temperature. Figure 1 also shows that N_2O emissions increased with the increase of moisture from 10% to 22%, and N_2O concentrations from samples containing 22% moisture were the highest throughout incubation. N_2O concentrations deceased sharply when the soil was saturated with 40% moisture.

The N_2O concentrations produced by soil with 10%, 16%, 22%, 40% moisture at the level-off stage were 10.4, 27.2, 49.1, 14.3 $\mu l \cdot l^{-1}$ at 10°C, and 11.6, 32.4, 38.0, 3.2 $\mu l \cdot l^{-1}$ at 30°C, respectively. This observation supported the findings of Galbally (1989), who thought nitrification and denitrification processes would adversely shift to the state of N_2O production and diffusion when soil moisture was beyond field capacity. In addition, Fig. 1 shows that N_2O emissions at 30°C were more lower than those at 10°C before field capacity, whereas the temperature response was reversed when the moisture content exceeded field capacity.

Figure 2 shows that N_2O emissions from the air-dried soils were very low. In the absence of moisture, the N_2O emissions followed a slow decreasing trend from the initial concentration of 0.312 $\mu l \cdot l^{-1}$ to the end concentration of 0.220 $\mu l \cdot l^{-1}$ at 10°C, and it was from 0.312 $\mu l \cdot l^{-1}$ to 0.296 $\mu l \cdot l^{-1}$ at 30°C. Based on this observation, we speculated that the air-dried soils at the low temperature would absorb the atmospheric N_2O, i.e., soils in some particular conditions could serve as the sinks of N_2O. However, we found that N_2O was partly desorbed with the increase of temperature from 10°C to

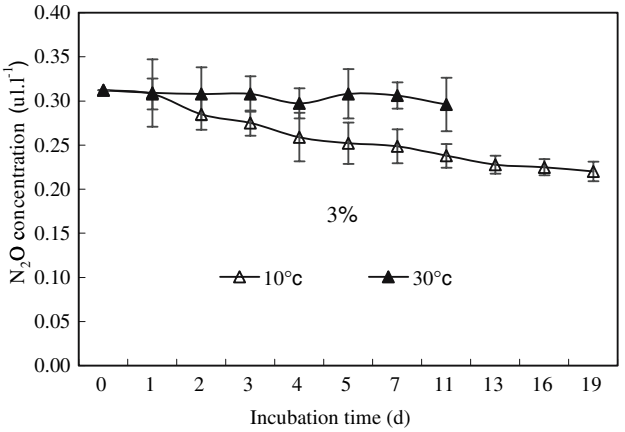

Fig. 2 N_2O emissions from air-dried soils 10°C and 30°C

30°C. This likely indicates that the air-dried soils could physically absorb the atmospheric N_2O, but not convert or consume it. Nevertheless, it was very essential for the evaluation of field N_2O emissions to take into account the absorption phenomenon.

Soil nitrification and denitrification processes were considered the two main sources of N_2O production. Shi (1999) reported that soil nitrate and nitrite reductase activities could distinguish the pathway of N_2O emission, and some researchers took the DEA (denitrifying enzyme activity) as an indicator to investigate N_2O emissions in anaerobic conditions using the C_2H_2 block technique (Holtan et al. 2002; Robert et al. 2004); few took measures to evaluate the two processes simultaneously. Our former study presented the schematic pathways of N_2O emissions in soil nitrification and denitrification processes (Jiang-gang et al. 2004). In the present study, we assumed the two processes involved in soil N_2O emissions to be one integrated biochemical reaction system. Simple linear regressions were performed to check the relationships between N_2O concentrations and incubation times under different moisture and temperature conditions (Table 1). It could be found that the equation $C = 1/[A + B\,exp\,(-t)]$ well expressed the S-shaped behavior of soil N_2O emissions. According to the above assumption, B was equivalent to the apparent chemical reaction rate constant of the integrated biochemical reaction system. B values increased with the increase of moisture from 10% to 22%, and it arrived the highest, 3.1622, at 10°C when soil moisture was 22%. In contrast, at 30°C, B values arrived the highest, 3.2056, when soil moisture was 16%. The findings indicate that the interaction of moisture and temperature strongly affected soil N_2O emissions. However, moisture was the dominant factor when it was beyond field capacity within a certain temperature range, e.g., 10°C to 30°C; the soil N_2O emissions rate decreased sharply (Table 1). Furthermore, the Arrhenius function

Table 1 Relationships between N_2O concentrations (C, $\mu l \cdot l^{-1}$)[a] and incubation time (t, day)

Temperature	Moisture	A	B	Determinant coefficient (R^2)[b]
10 °C	10%	0.2713	3.0413	0.9660 (n = 9)
	16%	0.1598	3.1311	0.9822 (n = 9)
	22%	0.1715	3.1622	0.9598 (n = 9)
	40%	0.1323	3.0439	0.9858 (n = 9)
30 °C	10%	0.1425	3.1404	0.9934 (n = 6)
	16%	– 0.0224	3.2056	0.9967 (n = 6)
	22%	– 0.0695	3.1988	0.9883 (n = 6)
	40%	0.1583	2.7978	0.9204 (n = 6)

[a] Calculated with the following equation: $C = 1/[A + B\,exp\,(-t)]$.

[b] With $n = 6$, the critical R^2 values at $p = 0.05$ and $p = 0.01$ are 0.4998 and 0.6956, respectively; and with $n = 9$, the critical R^2 values at $p = 0.05$ and $p = 0.01$ are 0.3624 and 0.5402, respectively; n, degrees of freedom.

was applied to calculate the apparent activation energies (Jiang et al. 1993). They were 1.12×10^3, 9.34×10^2 and 3.94×10^2 J · mol^{-1}, when moisture content was 10%, 16% and 22%, respectively. These values supported the results of Fig. 1. That was to say, field moisture capacity could be regarded as the optimum moisture for N_2O emissions because of its low apparent activation energy at the temperatures that N_2O emissions were not evidently inhibited. Therefore, the higher moisture content in soil did not imply better observations of N_2O emissions for these incubation experiments. In order to acquire the reliable thresholds and range of temperature, moisture and activation energies involved in soil N_2O emissions in the areas, our future work involves investigating the interactions of moisture and temperature at their optimal points. Moreover, the N_2O absorption of air-dried soils is a very interesting finding whose mechanics need further investigation. Hopefully this study will lead to further research in this field.

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