Vol.10 No.4 **Advances in Atmospheric Sciences** November 1993

Studies of Nitrous Oxide Emission from Farmlands in North China

Wang Shaobin (王少彬), *Su Weihan* (苏维瀚), and *Song Wenzhi* (宋文质)
Research Center for Eco-environmental Sciences, Chinese Academy of Sciences, Beijing 100085
Zeng Jianghai (曾江海) and *Zhang Yuming* (张玉铭)
Institute of Agricultural Modernization, Chinese Academy of Sciences, Shijiazhuang 050021, Hebei Province

ABSTRACT

Measurements of nitrous oxide emission from agricultural lands were conducted. The results show that nitrous oxide fluxes on several soils are at the range of 2–60 $\mu g \cdot N / m^2$ h. Factors influencing the production rates of nitrous oxide from the soils, such as soil temperature, soil moisture and fertilization, are discussed. The calculated amount of nitrous oxide emission from China farmlands is 9.8×10^7 Kg · N per year, which accounts for about 10% of the total source strength in China areas.

Key words: Nitrous oxide, Agricultural lands

I. INTRODUCTION

Nitrous oxide is a long lived and radiatively active trace gas in the atmosphere, which partly contributes to the global warming effect. In addition, through atmospheric transport and diffusion, nitrous oxide can reach the stratosphere and photodissociate to produce odd-nitrogen compounds (NO, NO_2) which react with stratospheric ozone molecule, leading to ozone layer depletion. Due to the above effect of nitrous oxide, its emission, variation and role in the atmosphere have been widely studied in the last decade.

Since the industrial revolution, concentration of nitrous oxide in the atmosphere has been increasing dramatically, and in recent years the increasing rate is of about 0.2–0.3% annually (Houghton et al., 1990). It is commonly known that nitrous oxide in the atmosphere comes from various sources—natural and anthropogenic emissions. Biological processes in the soil, land use change and agricultural activities account for 80% of the order of nitrous oxide sources (Bouwman, 1990).

So, China as a large agricultural country, nitrous oxide emitting from farmlands is an important contributor to the sources in China regions. Understanding of this source is helpful to study its regional budget and its effects on the future climate change in China area and the world.

II. EXPERIMENTAL

This work takes several fields as experimental plots for N_2O flux measurements. These plots are situated at Luancheng Ecological Experimental Station, Institute of Agricultural Modernization in Shijiazhuang (37°54′N, 114°42′E), Chinese Academy of Sciences. Closed chamber technique is used for N_2O flux measurements (Fig.1). Sampling device is a sealed box (1 m × 1 m × 1 m) set on the field. The frame is made of wood. The walls and the top of the box are covered by teflon film (Do Pont Company, USA). There is a sampling vent on the side column of the box. When experiment is conducted, the box is set on the field. In other

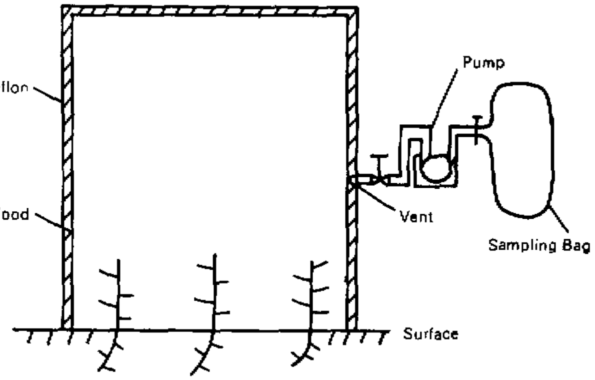

Fig.1. Diagram of the system for N_2O flux measure ment.

time, it is opened. The experimental time is about 1–2 hours. Gas sample is drawn into sampling bag from sampling vent by a miniature air pump (Sibata Company, Japan). Sampling bags are made of aluminum-plated film with the volume of 1 litre (Guangming Institute of Chemical Industry, Dalian). The gas samples are analyzed on a SP-3410 gas chromatography with Ni^{63} electron capture detector (Beijing Analysis Instrumental Factory, China). More detailed analyses of N_2O can be found elsewhere (Su et al., 1992). Meteorological data and soil temperature are also recorded during the experiments. In this paper soil temperature always means the temperature at 10 cm below the surface.

III. RESULTS AND DISCUSSION

1. *Fluxes of* N_2O *on Several Farmlands*

Since the microenvironments inside the aggregates differ from the bulk of the soil, there is high spatial and temporal variability of N_2O emissions from soils (Bouwman, 1990). We carried out experiments on four fields such as vegetation, winter wheat, corn and alfalfa plots in 1989–1990 to determine the diurnal and seasonal variation of N_2O fluxes. On vegetation field, N_2O flux variation during two successive fertilization periods with 15 g/m^2 urea scattered every six days were observed (Fig.2a). It can be seen that N_2O production rate is small (5 $\mu g \cdot N/m^2$ h) before fertilization, after that the rate increases to reach the maximum at the fourth day, then it decreases to normal value. In the second fertilization period, the N_2O fluxes are higher than the corresponding values in the first period. This is due to higher N material in the soil. The N_2O fluxes on winter wheat field show similar variation (Fig.2b). The fertilization and irrigation increase the flux of N_2O emission (40–50 $\mu g \cdot N/m^2$ h). Fig.2c and Fig.2d illustrate diurnal variation of N_2O flux on alfalfa and corn fields, respectively. Without the activities of fertilization and irrigation, the variation of N_2O flux is small. Generally, a diurnal rhythm of N_2O flux coincides with the diurnal variation of the soil temperature, that is, the higher the temperature is, the greater the emission flux exists.

In conclusion, N_2O fluxes on four types of agricultural lands are different, though particular in fertilization and irrigation events when the flux is 40–60 $\mu g \cdot N/m^2$ h, production rates at normal condition are at the same level of about 10 $\mu g \cdot N/m^2$ h.

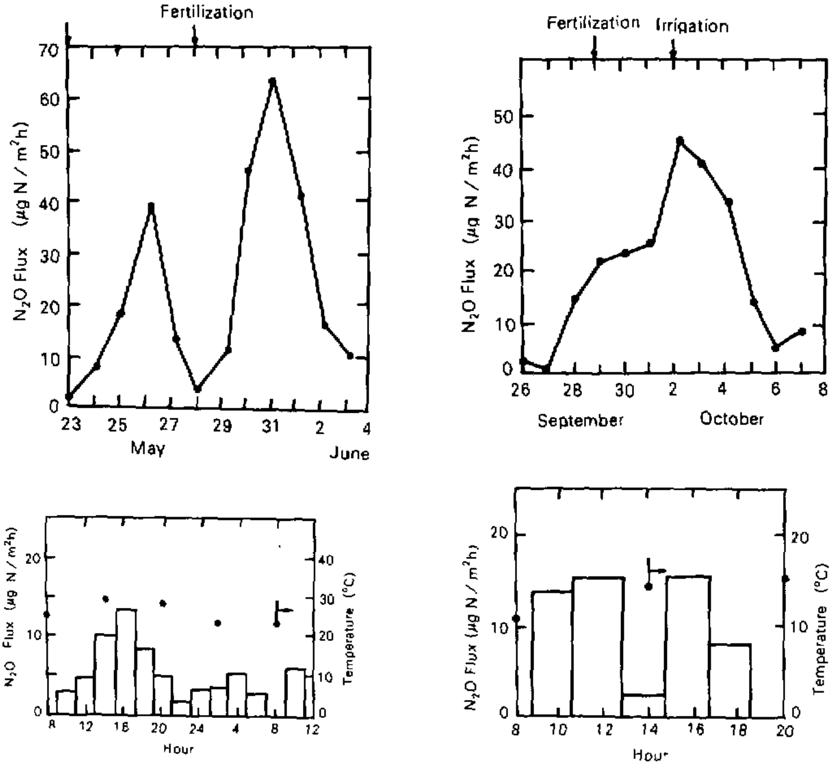

Fig.2. N_2O fluxes observed on several agricultural lands.

2. *Factors Influencing the Production of* N_2O

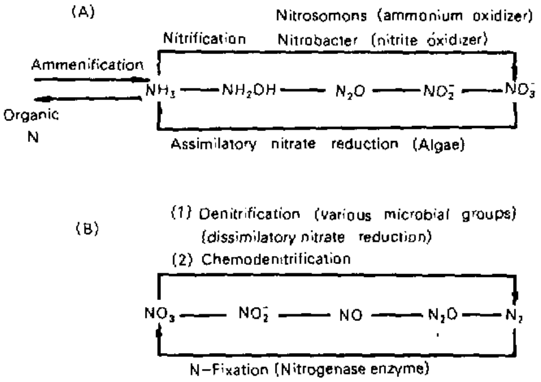

Fig.3. Pathways of nitrification and denitrification processes in the soils, (A) the nitrification sequence, (B) the denitrification sequence.

The release of nitrous oxide from soils is known to occur during biological denitrification, chemical denitrification and nitrification (Bouwman, 1990; Firestone and Davidson, 1990). The general pathways of the processes are illustrated in Fig.3. Nitrification is the biological oxidation of ammonium (NH_4^+) to nitrite or nitrate (NO_2^-, NO_3^-), respectively, or a biologically induced increase in the oxidation state of nitrogen. Biological denitrification is the dissimilatory reduction of nitrate or nitrite to gas forms of nitrogen by essentially anaerobic bacteria producing molecular N_2 or oxides of nitrogen when oxygen is limiting. Chemical denitrification is the reduction of nitrite or nitrate through chemical reductants producing N_2 or oxides of nitrogen (Bouwman, 1990). Since the pathways that lead to N_2O production are complex and there are many parameters affecting the production rate, the cause and effect relations of N_2O flux from the soil have not been completely resolved yet. Here we mainly discuss the effects of soil temperature, soil moisture and fertillization on N_2O fluxes.

(1). *Fertilization*

We have carried out experiments on flux measurements on unfertilized and fertilized fields, one for winterwheat and the other for alfalfa (Fig.4). Generally, N_2O flux on fertilized field is higher than that on unfertilized field, which means that fertilization increases the production rates of N_2O from the soil. So, it is no doubt that application of mineral nitrogen fertilizers accounts for a source of atmospheric N_2O. We can obtain the loss rate (L) of fertilizer nitrogen as N_2O through the following formula (Conrad et al., 1983)

$$L = \frac{P_1 - P_0}{M} , \qquad (1)$$

where P_1, P_0 represent the total amount of N_2O-N emitted from fertilized soil plot and unfertilized soil plot, respectively. M is the total amount of the applied fertilizer nitrogen. Values for P_1, P_0 are obtained by integrating the N_2O evolution rates observed during a period of 20 to 30 days after fertilization.

In North China, urea nitrogen are usually applied on farmlands with the average amounts of 12 g • N / m^2. By using N_2O evolution rates observed on winter wheat and alfalfa fields, we obtained the average loss rates of urea-nitrogen as N_2O-N of 0.10-0.16%. Eichner (1990) summarized the available data of N_2O emissions from fertilized soils and concluded that the emission coefficients of urea released as N_2O are at the range of 0.07-0.18%. Our results are close to that data.

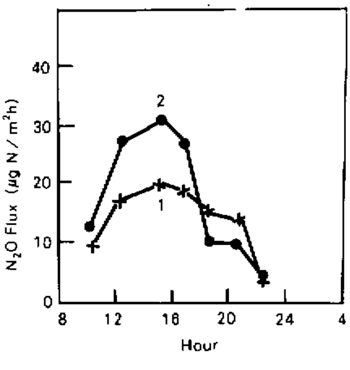

Fig.4. Diurnal variation of N_2O fluxes on fertilized and unfertilized fields.

(2). *Soil temperature*

The N_2O emission flux is dependent on soil temperature. The experimental data indicate that there exists a strong positive correlation between the soil temperature and the N_2O flux. During the daytime, the highest point of N_2O flux is at about 15:00 o'clock, that means, higher soil temperature leads to higher N_2O flux (Fig.2). The reason is that soil temperature influences the form of the products of denitrification and nitrification. The optimum temperature for the denitrification process is 25℃ and above, while the process is slow at 2℃ . Denitrification is still rapid at elevated temperature and will proceed to about 60 to 65℃. In nitrification the temperature optimum lies between 30 to 35℃, while below 5℃ and above 40℃ the activity is very low (Bouwman, 1990). In a day, the soil temperature firstly increases to the highest at 14:00–16:00, and then decreases gradually. So, the N_2O flux reaches the highest at 14:00–16:00.

Table 1. The Activation Energy of Arrhenius Equation between Soil Temperature and N_2O Flux

Soil Types	*Activation Energy (KJ / mol)*
Wheat field with urea	122
Wheat field unfertilized	83
Sward field with NH_4Cl*	61
Sward field with KNO_3*	70
Sward field unfertilized*	76

* Conrad et al., 1983

The effect of temperature on biochemical rate processes is well known to be exponential and adheres within limits to the classic Arrhenius equation. Focht (1974) proposed a Arrhenius equation for the simulation of denitrification and arrived at a good agreement between experiment and the model. Conrad et al. (1983) used their experimental data to obtain a modified Arrhenius equation in which the reaction rate is replaced by the N_2O evolution rate. The activation energies obtained on different soils are at the range of 61–76 KJ / mol (Table 1). These activation energies agree quite well and are similar to the values (76–83 KJ / mol) calculated from Q_{10} values reported by Denmead et al. (1979). Conrad et al. (1983) believed that the activation energies sometimes change from day to day, covering a

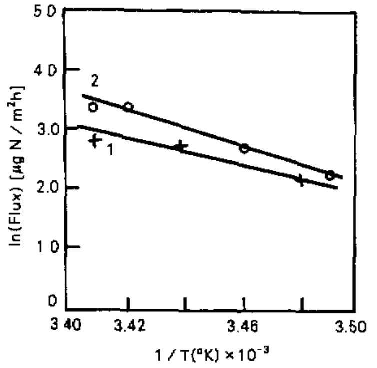

Fig.5. Relationship between N_2O flux and the soil temperature.

range between 20 and 150 KJ / mol. It is interesting that this range is similar to the range of activation energies (28 to 166 KJ / mol) reported for microbial denitrification and nitrification (Focht and Verstraete, 1977; Mckenney et al., 1980). This explains why the Arrhenius equation reflects well the effect of soil temperature on N_2O evolution rates. We make regression analyses of our results between the N_2O flux on fertilized and unfertilized plots and the temperature (Fig.5), and obtain the activation energies of 122 KJ / mol for fertilized plot and 83 KJ / mol for unfertilized plot, respectively (Table 1). These data are similar to the others.

(3). *Soil moisture*

Nitrous oxide emission is influenced by rainfall and irrigation. Rainfall and irrigation increase the soil moisture content, leading to the enhancement of nitrous oxide evolution. The effect of rainfall and irrigation on nitrous oxide evolution may be ascribed to several causes: (1) the moistening of soil may increase the activity of soil microorganisms and then consequently intensify the density of microorganisms. (2) The increased soil moisture content may also stimulate the availability of dissolved nutrients, such as organic matter, nitrate and ammonium, by their transport to other soil sites. (3) the increased soil moisture content hinders the diffusion of oxygen into the soil, so that soil microsite with a small supply of oxygen may develop (Conrad et al., 1983). Under these conditions, nitrous oxide production by denitrification as well as nitrification is stimulated.

Simulation of the effect of soil moisture on N_2O flux is difficult. Much work needs to be done further. Conrad et al. (1983) have got a typical correlation between the soil moisture and the N_2O evolution rates (Fig.6). The N_2O evolution rates are normalized to a constant average daily soil temperature of 20℃ by using the Arrhenius equation. At the range of 8–15% of

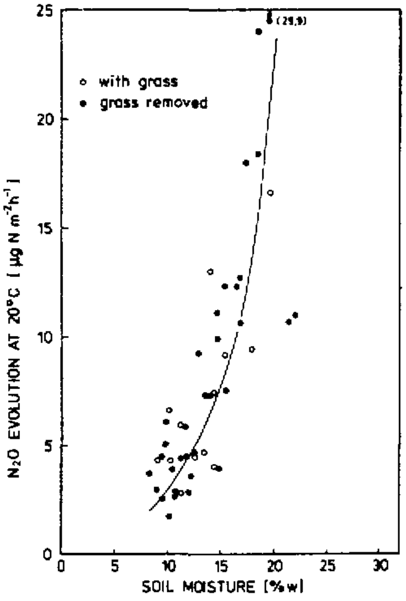

Fig.6. Influence of the soil moisture on the N_2O flux (taken from Conrad et al., 1983).

the soil moisture, the N_2O evolution rates increase gradually, while at the range of 15–20% of the soil moisture, they increase dramatically with increasing soil moisture. Grundman et al. (1987) obtained a similar correlation and they simulated the denitrification processes with the formulae well. We will not measure the soil moisture at this time and so can not quantify their correlations, but we are making arrangements on this research.

3. *Emissions of N_2O from Chinese Farmlands*

Agricultural lands in China include the dry and flooded lands. Most of N_2O productions occur in dry soil, while little amounts of N_2O are given off from flooded lands into the atmosphere (Bouwman, 1990). Khalil et al. (1990) made experiments on N_2O emission on rice fields in South China and concluded that the production of N_2O is nearly zero. Hence, the N_2O emission from flooded areas in China is ignored. The data of our flux measurements conducted on winter wheat, vegetation and alfalfa lands show that the production rates of N_2O from China farmlands vary from 2 μg • N / m^2 h to 60 μg • N / m^2 h with an average flux of 16 μg • N / m^2 h. With these results, we obtained the total average amount of N_2O emission from farmlands (7×10^{11}m^2) in China regions (CSY, 1992) as 9.8×10^7 Kg • N per year. Wang and Su (1992) have analyzed the N_2O emission from natural and anthropogenic sources and concluded that the total emission of N_2O in China area is 9.5×10^8 Kg • N per year (Table 2). So, the production of N_2O from agricultural lands is about 10% of total production in China.

Table 2. Estimation of N_2O Emissions from Natural and Anthropogenic Sources in China Region (Gg = 10^9 g)

Sources	Emissions (Gg • N / a)
Natural sources	
soils	388
freshwater areas	23
marine areas	265
Anthropogenic sources	
fossil fuel burning	118
fertilizers	48
biomass burning	18
others	92
Total	952

IV. CONCLUSION

Nitrous oxide emission from agricultural lands accounts for significant ratio of its total sources. Due to the conditions of the soil environment, nitrous oxide production rates on different farmlands vary in spatiality and temporality. The flux is at the range of 2–60 μg • N / m^2 h. Fertilization, high soil temperature and high soil moisture will increase the emission flux of nitrous oxide from the soil. Results indicate that the emission coefficient of urea-nitrogen that evolves as N_2O-N is 0.10–0.16%. Effect of soil temperature on N_2O flux can be expressed as Arrhenius equation. Relationship between soil moisture and N_2O flux is complicated, it is difficult to link their correlation with simple equation. Calculated results show that the amount of N_2O production from Chinese farmlands is about 9.8×10^7 Kg • N, which is 10% of the total sources in China regions.

REFERENCES

Bouwman A. F. (1990), Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere, In: Soil and the Greenhouse Effect, Bouwman A. F. (eds.), John Wiley & Sons, Chichester, pp 60–127.

Chinese Statistcal Yearbook (1991), Chinese Statistical Press, Beijing (in Chinese).

Conrad R., W. Seiler and G. Bunse (1983), Factor influencing the loss of fertilizer nitrogen into the atmosphere as N_2O. *J. Geophys. Res.*, **88(C11)**: 6709–6718.

Denmead O. T., J. R. Freney and J. R. Simpson (1979), Studies of nitrous oxide emission from a grass sward, *Soil Sci. Soc. Am. J.*, **43**: 626–628.

Eichner M. J. (1990), Nitrous oxide emissions from fertilized soils: summary of available data, *J. Environ. Qual.*, **19**: 272–280.

Firestone M. K. and E. A. Davidson (1990), Microbiological basis of NO and N_2O production and consumption, In: Exchange of Trace Gases between Terrestrial Ecosystem and the Atmosphere, Andreae M. O. and D. G. Schimel (eds.) John Wiley & Sons, New York, pp 7–22.

Focht D. D. (1974), The effect of temperature, pH, and aeration on the production of nitrous oxide and gases nitrogen–A zero order kinetic model, *Soil Sci.*, **118**: 173–179.

Focht D. D. and W. Verstraete (1977), Biochemical ecology of nitrification and denitrification, *Advan. Microbiol. Ecol.*, **1**: 135–214.

Grundmann G. I. and D. E. Rolston (1987), A water function approximation to degree of anaerobiosis associated with denitrification, *Soil Sci.*, **144**: 437–441.

Houghton J. T., G. J. Jenkins and J. J. Ephraums (1990), Climate Change: The IPCC Scientific Assessment, Cambridge University Press, London.

Khalil M. A. K., R. A. Rasmussen, M. X. Wang and L. Ren (1990), Emissions of trace gases from Chinese rice fields and biogas generators: CH_4, N_2O, CO, CO_2, *Chlorocarbons, and Hydrocarbons, Chemosphere*, **20**: 207–226.

Mckenney D. J., Shuttleworth K. F. and Findlay W. I. (1980), Temperature dependence of nitrous oxide production from Brookston clay, *Can. J. Soil Sci.*, **60**: 429–438.

Su W. H., Song W. Z., Zhang H. et al. (1992), Flux of nitrous oxide on typical winter wheat field in North China, Environ. Chem., **11(2)**: 26–32 (in Chinese).

Wang S. B. and Su W. H. (1992), Estimation of nitrous oxide emissions in China, Environ. Sci. (to be submitted) (in Chinese).