

## Atmospheric Terrestrial Exchange of Nitrous Oxide in the Mid-latitude Region of China

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### ABSTRACT

The significance of Northern China in the budget of atmospheric trace gases is discussed briefly. Sites for the research work of the IGBP/IGAC Activity 7.2 and some results of preliminary measurements on N<sub>2</sub>O flux are also introduced.

In China, 6 sites along 40°N have been identified as contributors to research efforts described by IGBP/IGAC Activity 7.2. These sites are located in forest, grassland, agriculture, arid and semi-arid and desert regions. On one of these sites, the Luancheng Comprehensive Experimental Station of Agricultural Ecology, the flux of N<sub>2</sub>O on a typical, winterwheat field was measured. Measurements were taken during the growing season of winterwheat in both fertilized and unfertilized fields. Measurements were also taken in an alfalfa fields. It was shown that fertilization, irrigation and soil temperature were positively related to the emission of N<sub>2</sub>O. The diurnal variability of fluxes was measured. The fluxes in different treatments varied from 2-46  $\mu\text{g N m}^{-2}\text{h}^{-1}$ .

(Key words: Temperate region, China, Trace gases)

### 1. INTRODUCTION

Nitrous oxide is one of the most important long-living greenhouse gases, and, in addition, is the primary source of oxides of nitrogen in the stratosphere, which, along with chlorofluorocarbons, play a critical role in controlling the abundance and distribution of stratospheric ozone. The atmospheric concentration of nitrous oxide is about 310 ppbv with

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a rate of increase of 0.2-0.3% per year (WMO, 1992). This represents an annual atmospheric growth rate of about 3 to 4.5 TgN. Since the total annual emission rate of nitrous oxide appears to be in the range of 10-17.5 TgN, as deduced from the magnitude of its sinks, and its rate of accumulation in the atmosphere and the estimated annual sources are between 5.2 and 16.1 TgN (Houghton *et al.*, 1992), it seems that the emission rates of some of the identified sources have been underestimated or that there are some unidentified sources. It has been suggested that land-use change and agricultural development may stimulate N<sub>2</sub>O production in soils and account for some of the principal missing emissions (Bouwman, 1990). Additionally, the agricultural areas of the mid-latitudes may be making significant contributions to the observed increases, or even to the unestimated part of the sources.

## 2. EXPERIMENTAL SITES FOR TRACE GAS EXCHANGE STUDY IN NORTHERN CHINA

Northern China, located around 40°N and between 75° and 135°E, includes a variety of temperate ecosystems. Having a long history of development lasting thousands of year, this region has undergone extensive land-use change and agricultural practices. However, extensive changes during the last century are evident. In the past fifty years, agricultural changes related to fertilization, irrigation and new crop varieties have contributed to marked increases in grain production. All of these play an important role in the changes of sources and sinks of trace gases, especially CH<sub>4</sub>, N<sub>2</sub>O and CO<sub>2</sub>. There is a need for basic emission data of trace gases, for studies on trace gas exchange in this region and for global budget and environmental impact research. However, in the vast area of Northern China, there have been very few research studies on N<sub>2</sub>O emission and very limited data are available (Su *et al.*, 1989, 1990, 1992).

The Chinese Academy of Sciences runs the Chinese Ecological Research Network consisting of more than fifty ecological stations covering important natural, semi-natural and ecotone ecosystems all over the country. In this Network, six sites along 40°N have been identified as contributors to research efforts described by IGBP/IGAC Activity 7.2: Trace Gas Exchange: Mid-Latitude Terrestrial Ecosystems and Atmosphere. These sites are located in forest, grassland, agriculture, arid and semiarid, and desert regions as shown in Figure 1 and Table 1.

## 3. MEASUREMENT OF N<sub>2</sub>O FLUX ON A WINTERWHEAT FIELD-A PRIMARY FLUX STUDY AT MID-LATITUDE OF CHINA

This work took a site on a winterwheat field as an experimental site for N<sub>2</sub>O flux measurement since winterwheat is a main crop in Northern China. This site is located at the Luancheng Comprehensive Station of Agricultural Ecology, Institute of Agriculture Modernization, the Chinese Academy of Sciences (Shijiazhuang, Province Hebei, 37°54'N, 114°42'E).

Measurements were made on two kinds of winterwheat fields: unfertilized and fertilized with 120 kg N ha<sup>-1</sup> year<sup>-1</sup>, and also on two kinds of alfalfa fields: unfertilized and fertilized with 120 kg N ha<sup>-1</sup> year<sup>-1</sup>. In spring after winterwheat turned green, flux measurements were performed on the fields after being fertilized and irrigated, during the earing and mature stages of winterwheat, and they were compared with those in the alfalfa fields.

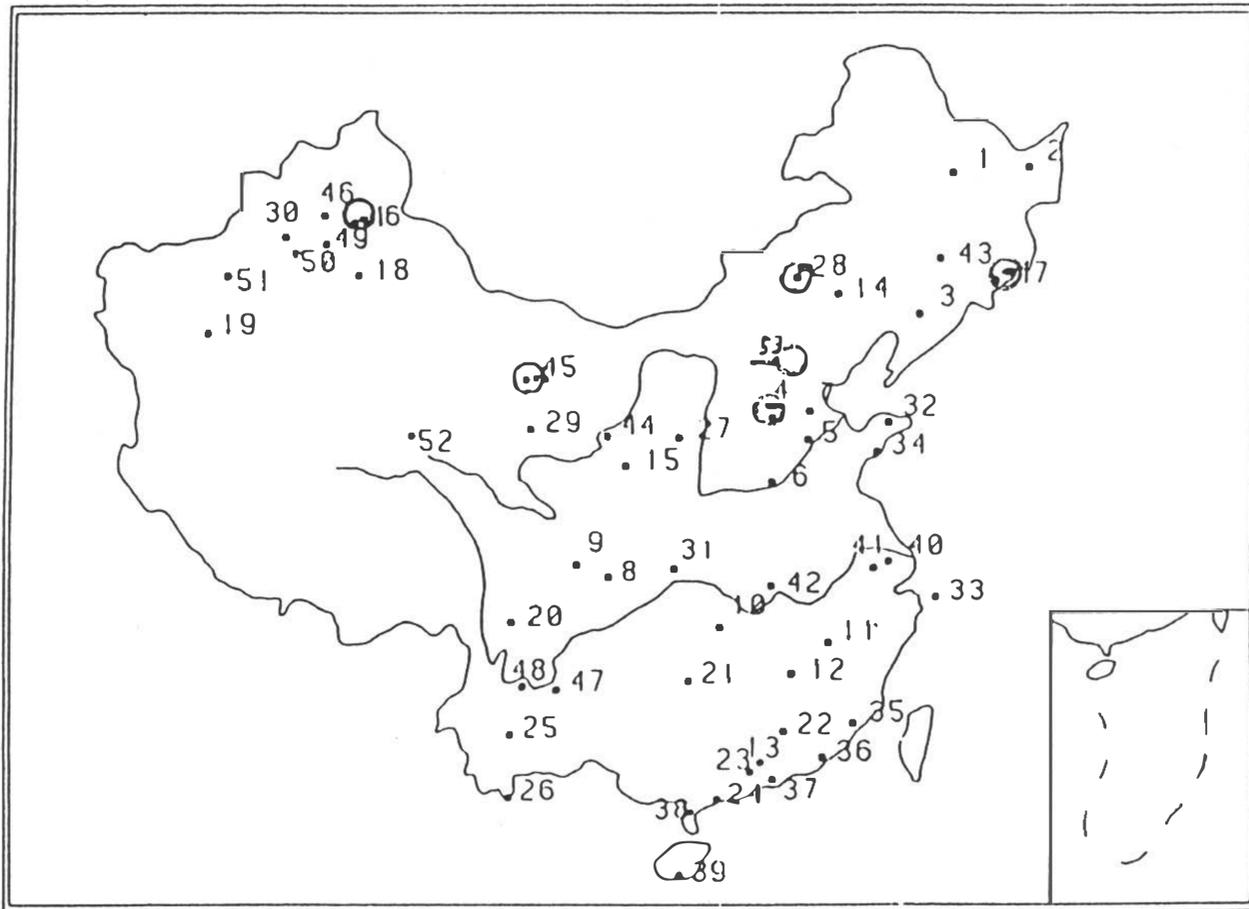


Fig. 1. Distribution of ecological research stations under Chinese Academy of Science.

Table 1. Experimental sites for the trace gas exchange study in the mid-latitude region of China.

No.	Name	Location	
		N	E
4	Luancheng Comprehensive Station of Agricultural Ecology	37°54'	114°42'
16	Fukang Experimental Station of Desert Ecology	44°10'	87°55'
17	Changbaishan Experimental Station of Forest Ecosystem	42°24'	128°06'
28	Inner Mongolia Experimental Station of Grassland Ecosystem	43°36'	116°04'
45	Linze Experimental Station of Desert	39°20'	100°09'
53	Beijing Forest Ecosystem Experimental Station	40°01'	115°28'

The sampling instrumentation consisted of a sealed box (1 m × 1 m × 1 m) placed on the fields. The walls and the top of the box were made of teflon film produced by the Du Pont Company. There was a sampling vent on the side of box. The gas sample was drawn into a sampling bag from a sampling box by a miniature air pump. The sampling bags were made of aluminium-plated film with a 1-litre volume. Meteorological and soil temperature data were recorded. In this paper, soil temperatures always refer to those at 10 cm below surface. The gas samples were analysed on an SP-3410 gas chromatography apparatus with on Ni<sup>63</sup> electron capture detector.

$N_2O$  flux ( $F$ ) -  $N_2O$  mass released from land into the atmosphere per unit area per unit time - is a synthetically macroscopical value consisting of many factors. It can be expressed by:

$$F = (m_2 - m_1)/A(t_2 - t_1)(\mu g m^{-2} hr^{-1}) \quad (1)$$

where  $m_1$  and  $m_2$  are  $N_2O$  mass ( $\mu g$ ) inside the box volume  $V$  ( $m^3$ ) at time  $t_1$  and  $t_2$  respectively;  $A$  is the bottom area of the sampling box ( $m^2$ );

$$m_1 = Vc_1d, \quad m_2 = Vc_2d(\mu g) \quad (2)$$

where  $d$  is the mass density of  $N_2O$  ( $\mu g/m^3$ );  $c_1$  and  $c_2$  are the volume mixing ratios of  $N_2O$  at time  $t_1$  and  $t_2$  (ppb), respectively, thus:

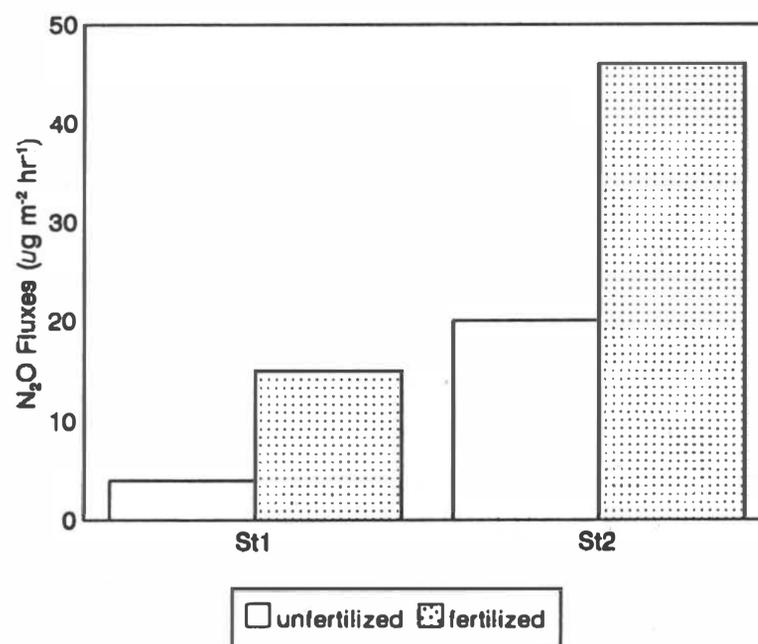
$$F = Hd(c_2 - c_1)/(t_2 - t_1)(\mu g/m^3 hr), \quad (3)$$

where  $H(=V/A)$  is the height of the sampling box.

After the winterwheat turned green, measurements were performed on different farming practices (fertilization, irrigation) and at different growth stages (earring, mature, harvest). The results of these investigations follow.

In the unfertilization stage, the  $N_2O$  fluxes of the winterwheat and alfalfa fields were 2 and 3  $\mu g N m^{-2} hr^{-1}$  respectively, but those of fertilized fields were above 20 (winterwheat) and 22 (alfalfa)  $\mu g N m^{-2} hr^{-1}$ , respectively. This means with more nitrogen sources in the soil, the  $N_2O$  flux became higher, and on neighbouring fields with the same soil nature and under similar farming practices, the  $N_2O$  fluxes of the winterwheat and alfalfa fields were close. This shows that biological-chemical processes play a dominant role in the production process of  $N_2O$ .

Soil moisture has a certain influence upon  $N_2O$  releases. Three days after the winterwheat field was irrigated, flux became relatively high as shown in Figure 2, reaching a maximum of 46  $\mu g N m^{-2} hr^{-1}$ .



St1-Before irrigation, St2-After irrigation

Fig. 2.  $N_2O$  fluxes before and after the irrigation of the winterwheat field.

The Diurnal variations in the N<sub>2</sub>O fluxes of the fertilized and unfertilized winterwheat fields were observed. The diurnal variation in the N<sub>2</sub>O flux on the fertilized winterwheat field shows that during the earing stage, it was high in the daytime but low at night. Flux varies with soil temperature (see Figure 3), with its maximum (30 μg N m<sup>-2</sup>hr<sup>-1</sup>) occurring after midday when the soil temperature was the highest (17°C). However, its minimum (5 μg N m<sup>-2</sup>hr<sup>-1</sup>) occurred after midnight when the soil temperature was low (12°C). As to the unfertilized winterwheat field, there were similar circumstances, the maximum of flux (18 μg N m<sup>-2</sup>hr<sup>-1</sup>) occurring in the daytime, and its minimum at night (see Figure 4).

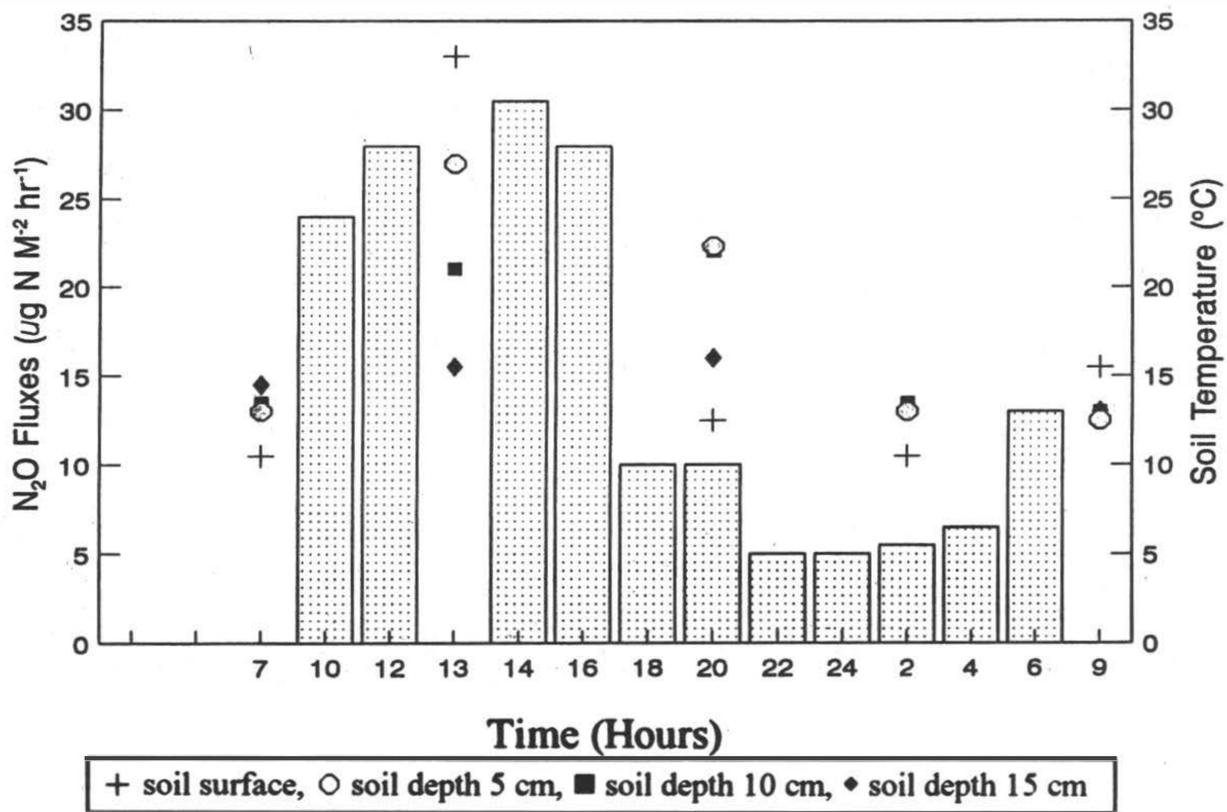


Fig. 3. The diurnal variability of N<sub>2</sub>O fluxes (▨) and soil temperature on the fertilized farmland in the earing stage of winterwheat (1990.6.4-6).

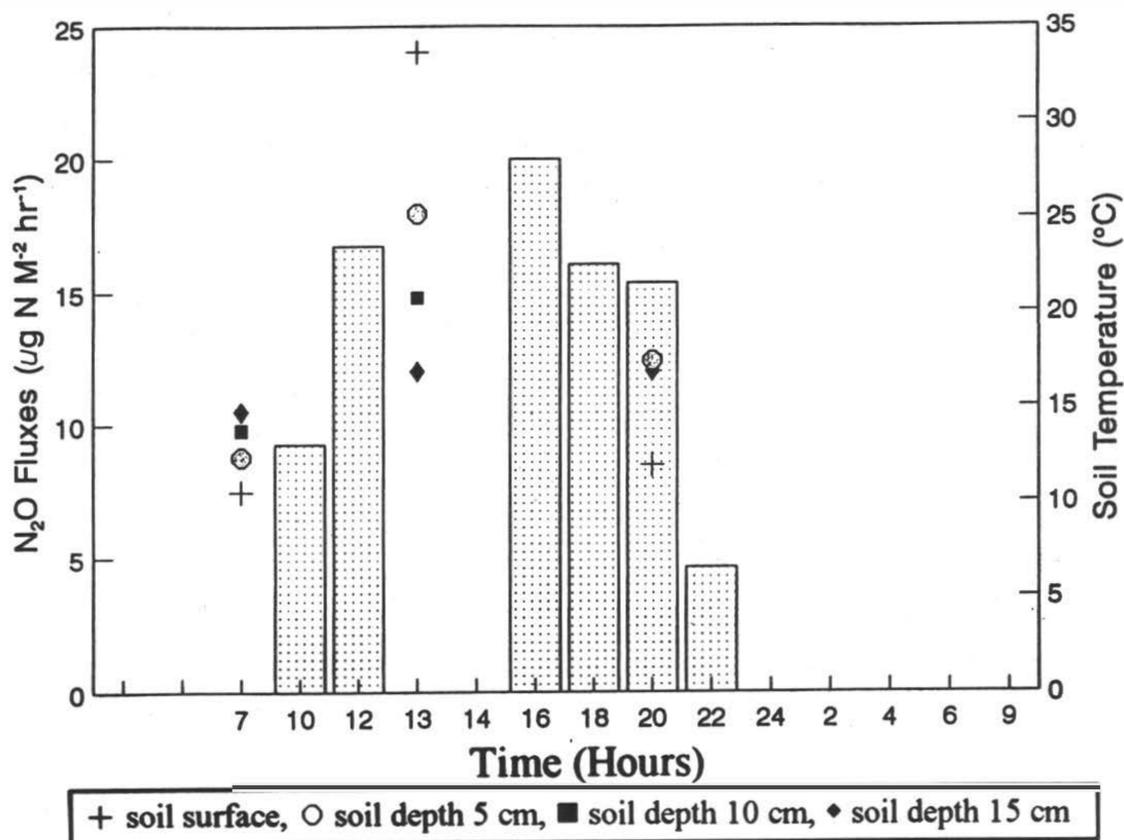


Fig. 4. The diurnal variability of N<sub>2</sub>O fluxes (▨) and soil temperature on the fertilized farmland in the earing stage of winterwheat (1990.5.4-5).

The Diurnal variations in flux of the winterwheat fertilized field during the mature stage are shown in Figure 5. The pattern here is similar to that during the earing stage. All of the flux values were below  $14 \mu\text{g N m}^{-2}\text{hr}^{-1}$  ( $27^\circ\text{C}$ ), which were lower than those of the earing stage. After harvest, the variation in flux was basically irregular. Fluxes were lower than or close to the values before harvest, though soil temperature after harvest was apparently higher than those temperatures during other growth stages of winterwheat.

All of the above mentioned indicates that the  $\text{N}_2\text{O}$  fluxes of the fields during different growth periods were different. According to Figure 6, beginning when the winterwheat turned green, the flux on the third day after fertilization was about  $20 \mu\text{g N m}^{-2}\text{hr}^{-1}$ , with an average soil temperature of  $9.2^\circ\text{C}$ ; flux on the third day after irrigation reached the maximum of about  $46 \mu\text{g N m}^{-2}\text{hr}^{-1}$ ; flux of the unfertilized field reached  $15 \mu\text{g N m}^{-2}\text{hr}^{-1}$  too. This indicates an increase in soil moisture is advantageous to  $\text{N}_2\text{O}$  release in biological-chemical processes. If there are sufficient nitrogen sources and suitable soil moisture, the rise in temperature is also advantageous to the increase in flux. During the earing stage of winterwheat, the mean fluxes of fertilized and unfertilized fields were 17 and  $12 \mu\text{g N m}^{-2}\text{hr}^{-1}$  respectively, with a mean soil temperature of  $16^\circ\text{C}$ . During the mature stage, the averaged value of fluxes in the fertilized field was  $8 \mu\text{g N m}^{-2}\text{hr}^{-1}$ , though the mean soil temperature was  $23.3^\circ\text{C}$ . After harvest, although the mean soil temperature reached the high value of  $24.3^\circ\text{C}$ , the averaged flux value was only  $6 \mu\text{g N m}^{-2}\text{hr}^{-1}$ .

All of these results show that the application of nitrogen fertilizer may be a primary factor in the increase in  $\text{N}_2\text{O}$  flux on the basis of  $\text{N}_2\text{O}$  release from bio-chemical processes. If soil moisture increases and soil temperature rises too, more  $\text{N}_2\text{O}$  fluxes from soil moisture. During the growth processes of winterwheat, the  $\text{N}_2\text{O}$  flux fell as the nitrogen content in the soil was consumed by plant growth. Fluxes during the earing and mature stages tended to decrease though the soil temperature was considerably high. The reason that flux after harvest was very small may be that the nitrogen content in the soil was exhausted and then the  $\text{N}_2\text{O}$  emission was basically a result of its natural releases from the soil.

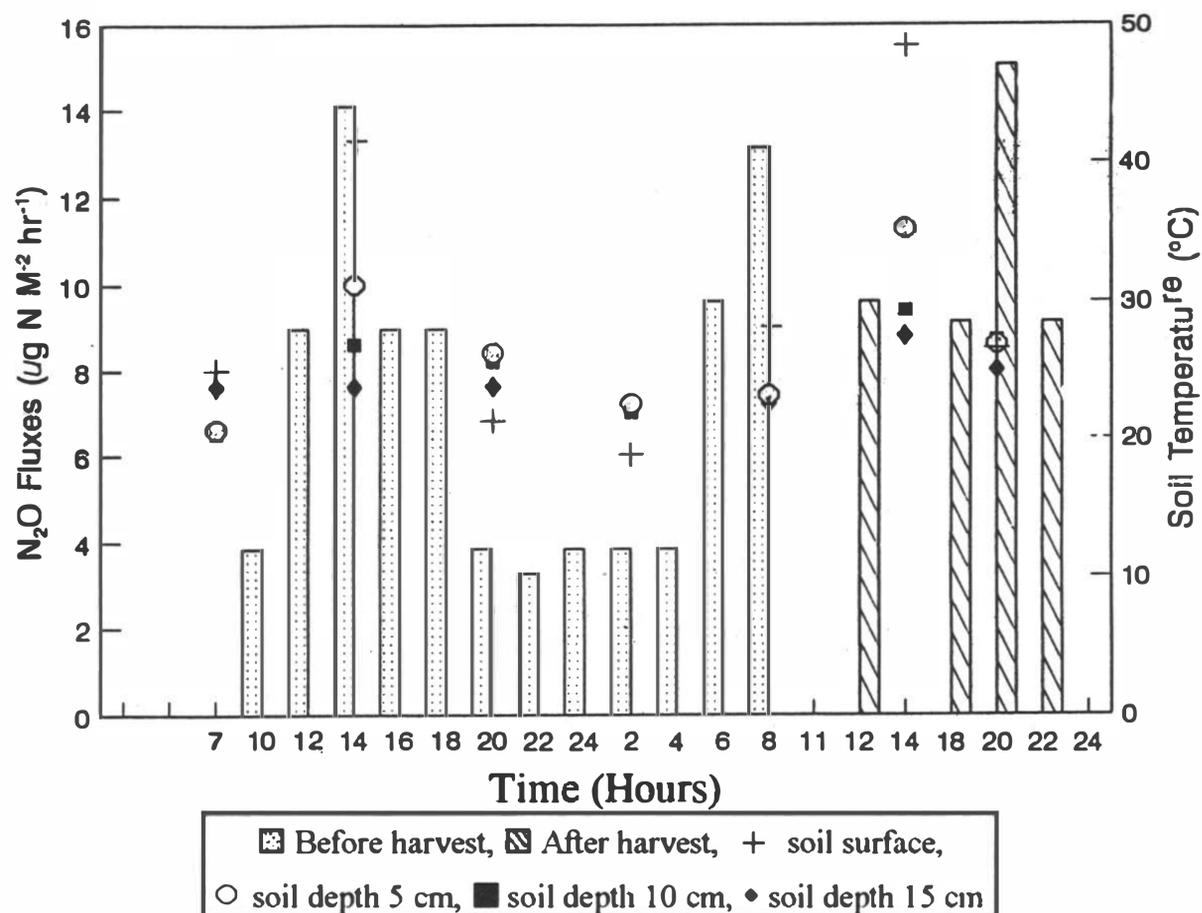


Fig. 5. The diurnal variability of  $\text{N}_2\text{O}$  fluxes on the fertilized farmland in the ripening stage and after harvest of winterwheat.



Table 2. N<sub>2</sub>O emission rates from some croplands.

Crop	Fertilizer	Fertilizer Application (Kg N ha)	Mean Flux Range ( $\mu\text{g N m}^{-2}\text{h}^{-1}$ )		Annual Emission Range (Kg N ha <sup>-1</sup> y <sup>-1</sup> )			
Winterwheat	NH <sub>4</sub> NO <sub>3</sub>	210	19	23	1.7	-	2.0	Colburn, <i>et al.</i> , 1984
Corn	NH <sub>4</sub> NO <sub>3</sub>	132	25	33	2.2	-	2.9	Duxbury, <i>et al.</i> , 1982
Corn	Organic	130	27	43	2.4	-	3.8	
Barley	NH <sub>4</sub> NO <sub>3</sub>	56		25			2.2	Mosier
Barley	Organic	71		29			2.5	<i>et al.</i> , 1982
Barley		0		14			1.2	
Barley	NH <sub>4</sub> NO <sub>3</sub>	70/140	10	64	0.9	-	5.6	Burford <i>et al.</i> , 1981
Alfalfa		0	26	48	2.3	-	4.2	Duxbury, <i>et al.</i> , 1982
Winterwheat	(NH <sub>2</sub> ) <sub>2</sub> CO	120	6	45	0.5	-	3.6	Su <i>et al.</i> , 1990

published data on N<sub>2</sub>O fluxes on different croplands. Apparently, soils nurturing these crops as well as farming practices, such as fertilization and irrigation, differ from each other very much, and consequently, it is not easy to get a reliable and reasonable mean value of N<sub>2</sub>O flux for climate and environment research.

Therefore, it is necessary to deliberate thoroughly and to perform research work carefully on such problems as: the methods and reasonableness of mean value calculations for N<sub>2</sub>O fluxes during different stages in the growth process of a crop; the synthetic comparability of various data obtained from different crops, lands and farming practices; etc. It is suggested that future studies include the study of flux problems on typical land and crops; the accumulation of data; processing data by reliable mathematical statistical methods. It is also necessary to measure fluxes of other gaseous nitrogen compounds and to probe their production mechanisms so as to provide more thorough scientific basis for environment and climate research.

#### 4. CONCLUSION

- (1) For the contribution to research efforts described by the IGBP/IGAC Activity 7.2, six sites in the Mid-Latitude Region (along 40°N, between 75°-135°E) of Northern China were identified. These sites are located in forest, grassland, agriculture, arid and semiarid, and desert regions and are used for comprehensive research in the atmospheric terrestrial exchange of trace gases, eco-environmental change and impact.
- (2) N<sub>2</sub>O fluxes between soil and atmosphere on winterwheat and alfalfa farmland were measured at the Luancheng Comprehensive Station of Agricultural Ecology, located in a typical production region of winterwheat in Northern China. When winterwheat and alfalfa are grown in the same field, their fluxes are close to each other.
- (3) Fluxes in different growth stages of winterwheat are different from each other. fertilization, irrigation, soil temperature, etc. may be important control factors in the N<sub>2</sub>O

production in soil. Fluxes exist in the range of 2-46  $\mu\text{g N m}^{-2}\text{hr}^{-1}$  for the whole growth process of winterwheat.

### REFERENCES

- Bouwman, A. F., 1989: The role of soils and land use in the greenhouse effect. published by ISRIC, Wageningen, The Netherlands.
- Burford, J. R. et al., 1981: Emission of nitrous oxide to the atmosphere from direct drilled and ploughed clay soils. *J. Sci. Food Agriculture*, **32**, P.219.
- Colbournm, P. et al., 1984: Estimation of the total gaseous nitrogen losses from clay soils under laboratory and field conditions. *J. Soil Sci.*, **35**, 11-22.
- Duxbury, S. M. et al., 1983: Emission of nitrous oxide from soils, *Nature*, **298**, 462-464.
- Houghton, J. T., B. A. Callander, and S. K. Varney, 1992: Climate change 1992. Cambridge University press.
- Mosier, A. R., 1982: Nitrous oxide emission from barley plots treated with ammonium nitrate or sewage. *J. Environ. Quality*, **11**, P.78.
- Su, W. H., 1989: Measurement of CH<sub>4</sub> and N<sub>2</sub>O emission and experement network in China, on Int'l Conference on Soil and the Greenhouse Effect, 14-18 August 1989, Wageningen, The Netherlands.
- Su, W. H., et al., 1990: A primary study of nitrous oxide emission in agriculture region of northern China. *J. Environ. Sci.*, **2**, p.86.
- Su, W. H., J. H. Zeng, W. Z. Song, H. Zhang, Y. M. Zhang, M. Q. Cao, H. R. Lu, and Q. Zhou, 1992: Flux of nitrous oxide on a typical winterwheat field in northern China. *Environ. Chem.*, **11**, 26-32.
- WMO, 1992: Scientific Assessment of Ozone Depletion: 1991, WMO/UNEP, WMO Global Research and Monitoring Project, Report No. 25, Geneva.

