Front. Agric. China 2007, 1(1): 37–42
DOI 10.1007/s11703-007-0006-y

RESEARCH ARTICLE

YANG Lanfang, CAI Zucong

Effects of nitrogen application and maize growth on N_2O emission from soil

Abstract Using the pot experiment and closed static chamber-gas chromatography (GC) technique, this paper studied the effects of nitrogen application (150 and 300 mg/kg soil) and maize growth on N_2O emission from soil. In maize-planted soil, the N_2O emission rate increased with increasing N application rate, its peak appeared at the seedling stage, and there was no significant correlation between N_2O emission rate and air temperature. Contrarily, in exposed soil, the peak of N_2O emission rate occurred at the later stages of the experiment, and there was a significant exponential correlation between soil N_2O emission rate and air temperature, in which Q_{10} (the value of soil N_2O emission rate responding to temperature) was 4.4 and 3.2 in high and low N applications. The total amount of N_2O emission increased remarkably with increased N application rate in both planted and un-planted soils. N_2O emission inventory from exposed and maize-planted soils in high N application was 2.5 and 1.6 times as high as that in low N application, respectively. In the same N application rate, N_2O emission inventory in high and low N application from exposed soil was 12 and 7.5 times as high as that from maize-planted soil, respectively. As compared with exposed soil, maize growth reduced N_2O emission by 92% and 87%, respectively, at high and low N application rates. In summary, maize growth and nitrogen application not only affected the seasonal variation and magnitude of N_2O emission from soil, but also altered the relationship between air temperature and soil N_2O emission.

Keywords maize growth, N_2O emission from soil, nitrogen application, temperature

Translated from *Chinese Journal of Applied Ecology*, 2005, 16(1): 100–104 [译自: 应用生态学报]

YANG Lanfang (✉)
School of Resource and Environmental Science, Hubei University, Wuhan 430062, China
E-mail: lfyang@hubu.edu.cn

CAI Zucong
State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China

1 Introduction

Nitrous oxide is an important green house gas and agricultural soils are its major source (Velthof et al., 2002). Direct emissions from agricultural soils totaled 2.1 Tg of N, direct emissions from animal production totaled 2.1 Tg of N and indirect emissions resulting from agricultural N input into the atmosphere and aquatic systems totaled 2.1 Tg of N_2O-N up to an annual total of 6.3 Tg N_2O-N (Mosier et al., 1998). Soil N_2O emission was affected by many factors, such as soil property, climate, practices of land use, and so on (Jiang and Huang, 2001; Xie and Li, 2002). Soil N_2O emission increased with N application (Feney, 1997; MacKenize, 1997), while the N_2O emission derived from N fertilizer accounted for 0.001%–6.8% of N application and 25%–82% of total soil N_2O emission (Eichner, 1990). Under a given soil water content, soil N_2O emission correlated exponentially to temperature (Zheng et al., 1997). In soil culture experiment, Dobbie and Smith (2001) found that soil N_2O emission increased with temperature, but the value of Q_{10} changed greatly, for example, when the temperature was between 5°C and 12°C, the value of Q_{10} was 50 in farm land and 8.9 in grass land; and when between 12°C and 18°C, it was 3.7 in farm land and 2.3 in grass land. Besides, plants could emit N_2O themselves (Chen et al., 1990; Li and Chen, 1993; Yang et al., 1995), and plant growth also influenced soil N_2O emission, so the pattern, amount and intensity were different in various plant-soil systems. For example, N_2O emission decreased in the order of growing wheat, rapeseed, and burley soils (Kaiser and Ruser, 2000). The effects of N application and plant growth on the relationship between soil N_2O emission and temperature has rarely been reported, but it was very important to control soil N_2O emission. In order to investigate the influence of N application and plant growth on the relationship between soil N_2O emission and temperature and to mitigate soil greenhouse gases emission in agricultural practice, this study determined the N_2O emission from exposed and maize-planted soils during the entire maize growing process in a pot experiment with two nitrogen application rates.

2 Materials and methods

2.1 Soil

The soil used in this experiment was Udic luvisols, which were derived from the matrix of quaternary loess. Soil organic carbon and nitrogen content was 4.8 and 0.6 g/kg and soil pH was 5.8 (H_2O, 2.5:1). The content of sand (20–200 μm), silt (2–20 μm) and clay (<2 μm) was 325, 462 and 213 g/kg, respectively and the texture was heavy loam.

2.2 Plant

Plant used in this experiment was maize (*Zea mays* L.) and the variety was Yedan 14.

2.3 Pot experiment

Twelve pots were used in the experiment and 4 kg of air-dried soil sieved through 5 mm was filled in each pot. Six pots applied 150 mg/kg of N, 75 mg/kg of P and 150 mg/kg of K as the treatment of low soil N-application, in three of which maize was planted and the other three were left un-cropped. The other six pots applied 300 mg/kg of N, 75 mg/kg of P and 150 mg/kg of K as the treatment of high soil N-application, and three of them were maize-planted and the rest un-cropped. N, P, and K were provided in the form of $(NH_4)_2SO_4$, KH_2PO_4, and K_2SO_4, respectively. Two maize seeds were sowed in each pot at 3-cm soil depth layer on April 30th, 2003. Seedlings emerged on May 5, 2003. One maize plantlet was carefully removed at its emergence stage. Sampling was started from the 4th day after emergence with a frequency of twice a week till the maize was thoroughly matured. The sampling time was fixed between 16:00 and 18:00 in a day in order to control the error derived from diurnal variation of soil N_2O emission. N_2O emission from soil had diurnal variation during plant growing (Zheng et al., 1997; Huang et al., 1995; Yu et al., 1995), so the error of diurnal variation of soil N_2O emission was stable with the fixation of sampling time. At the bottom of each pot there was a hole, through which a rubber tube was stretched into and connected with a vitrified-clay pipe, while the end of the rubber tube outside of the pot was joined to a trough in order for water to slowly travel into the pot, keeping a stable water content in each pot during maize growing.

2.4 Sampling

Sampling began on the 4th day after emergence by closed static chamber. For the convenience of sampling, a cylinder PVC pot of 20 cm in height and 15 cm in internal diameter was specially designed for maze culture. A trough was installed around the outside of the pot mouth to seal the chamber by water when sampling. A PVC tube (6 cm in length and 2.5 cm in diameter) was fixed in the center of the pot (2.5 cm above the pot mouth and 3.5 cm inserted into soil) for insulating plants from soil during sampling, in which maize seed was sowed in about 3 cm of soil in depth. Each pot has an open-bottom PVC chamber with a size of 20.5 cm $\times$ 20.5 cm $\times$ 6 cm, which was specially designed for gas sampling. At the center of the chamber cover is a hole, neatly fitting the PVC tube and a silicon septum was fixed on the cover of the chamber for sampling through the pinhead of a syringe. When sampling, the chamber was fitted outside the PVC tube and moved down into the trough filled with 200 mL water, preventing air exchange between the inside and outside of the chamber. Silicon gel was used to make the joint of the chamber with PVC tube airtight. To do so, the chamber only covered the soil surface and did not include the plant. Three gas samples were collected at 10-min intervals by a 20-mL syringe through a silicon septum fixed on the top of the chamber and immediately transferred to a pre-evacuated vial (18 mL) to await analysis of N_2O concentration. After sampling, the chamber was raised and crossed on trough so that gases could exchange freely between the soil and the atmosphere at the intervals between two samplings. Air temperature near the pot was recorded at the beginning of each sampling.

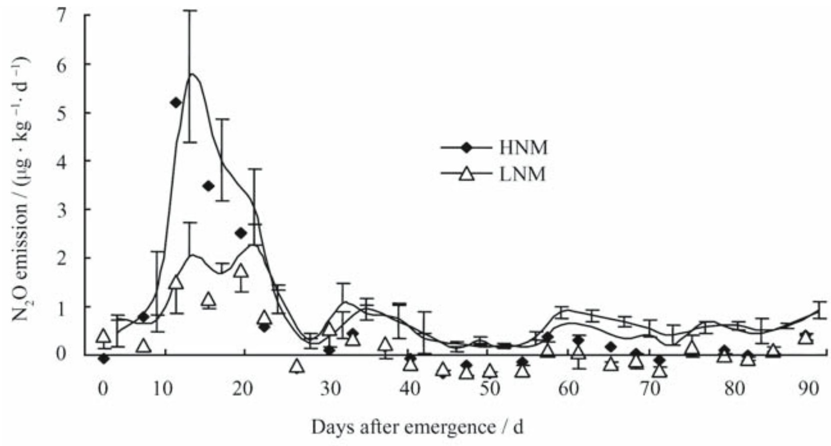
After sampling, the gas vial was brought to the laboratory to determine the N_2O concentration using a gas chromatograph (GC). The emission rate of N_2O was calculated based on the changes in N_2O concentration in the chamber with time (Huang et al., 1995).

3 Results

3.1 Seasonal variation of N_2O emission from soil

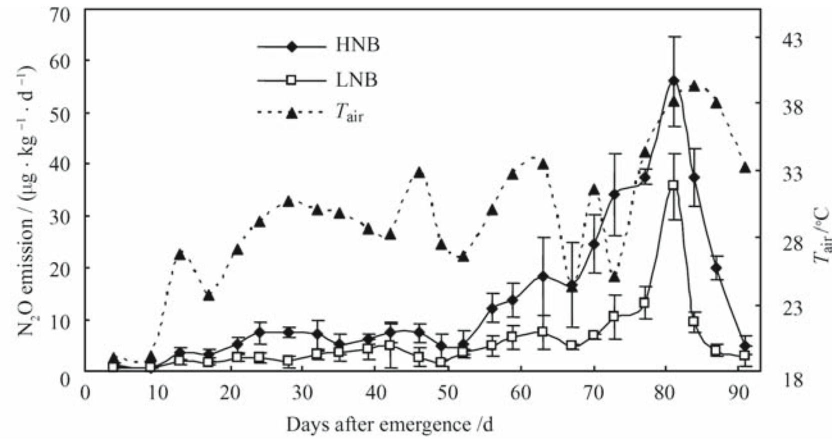
Figure 1 shows that during maize growing, N_2O emission rate from the planted soil increased with crop growing and reached the highest rate on the 13th day after emergence, then decreased with its growth to the lowest rate till the 28th day after emergence (stem elongation stage), thereafter, fluctuating at very low rate. During the entire growing period, the peak of soil N_2O emission was 5.66 and 2.02 μg /kg · h of N in high (300 mg/kg) and low (150 mg/kg) N applications, respectively. The difference of soil N_2O emission rate between high and low N applications only occurred before the stem elongation stage. In the period from the ninth day to the 21st day after emergence, soil N_2O emission rate was significantly higher in high N application than that in low N application, but it was not significant after the stem elongation stage.

Figure 2 shows the seasonal variation of N_2O emission rate from the exposed soil during the period of maize growth. It indicated that the variation of N_2O emission rate from exposed soil with time differed significantly from maize-planted soil. In exposed soil, N_2O emission rate increased slowly with time till the 52nd day after emergence, and thereafter, it increased obviously with time and reached the highest rate on the 81st day after emergence, then, decreased till the end of the experiment.



HNM: High N application; LNM: Low N application

Fig. 1 Seasonal variation of N_2O emission rate from maize-planted soil



HNB: High N application to exposed soil; LNB: Low N application to exposed soil; T_{air}: Air temperature

Fig. 2 Seasonal variation of N_2O emission from exposed soil and air temperature during maize growing period

3.2 Effects of N application and maize growth on N_2O emission from soil

The seasonal variation of N_2O emission from exposed soil was different from maize-planted soil. In maize-planted soil, the peak of soil N_2O emission rate appeared at the seedling stage (before stem elongation stage), but in the exposed soil, it occurred late (Fig. 1 and Fig. 2). The difference of soil N_2O emission rate between high and low N applications was significant only at the seedling stage in maize-planted soil, but its significances increased with the process of growth in the exposed soil on the whole, especially from the 52nd day after emergence.

Table 1 shows that in maize-planted soil, N_2O emission was high in the early stages and low in the late stages. But in the exposed soil, it was high in the late stages and low in the early stages. In maize-planted soil, the amount of soil N_2O emission during the seedling stage contributed 64% and 51%

Table 1 N_2O emission from soil at different growth stages and total emission during maize growth

Treatment	N_2O emission rate/ (μg·kg^{-1}·d^{-1})				Total /(μg·kg^{-1})
	BES	ES-TS	TS-FS	FS-RS	
HNM	2.54±0.36b	0.57±0.09c	0.32±0.02b	0.62±0.10c	95.8±4.0c
LNM	1.36±0.17c	0.64±0.13c	0.25±0.02b	0.51±0.07c	64.8±8.8d
HNB	3.86±0.77a	6.66±1.33a	5.73±4.51a	26.46±3.14a	1150±125a
LNB	1.71±0.46b	3.58±1.46b	3.69±0.79a	10.18±1.03b	485±50b

HNM: High N application to maize-planted soil; LNM: Low N application to maize-planted soil; HNB: High-N application to exposed soil; LNB: Low-N application to exposed soil; BES: Before elongation stage (Seedling stage); ES: Elongation stage (28 DAE), TS: Trumpet stage (46 DAE); FS: Flowering stage (59 DAE); RS: Ripening stage (91 DAE). The letters in a same column denote the significant level at 0.05.

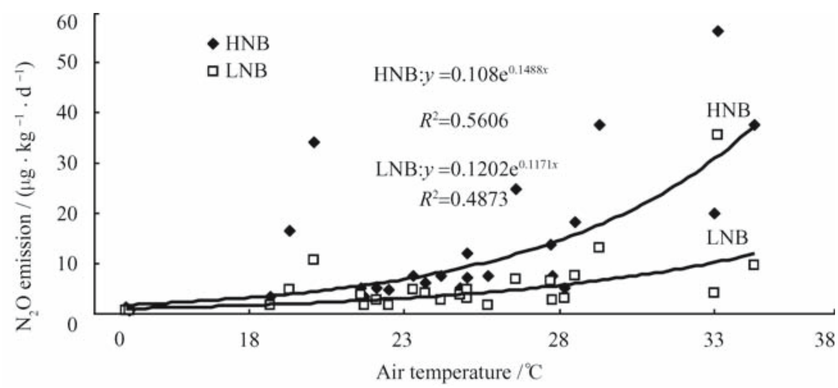
to the total emission during the entire growing stage in the treatment of high and low N applications, respectively, but this period was only about 29% of the total time. Moreover, the difference of soil N_2O emission quantity between high and low N applications was significant only in this period. Corresponding to the period of flowering to ripening stages of maize, the amount of N_2O emission from the exposed soil accounted for 75% and 68% of the total emission from exposed soil in the treatment of high and low N application, but this period was only 37% of total time.

The variation scope of soil N_2O emission rate was higher in high N application than that in low N application. The peak of soil N_2O emission rate in high N application was 2.5 times as high as that in low N application in maize-planted soil. For the exposed soil, the peak of soil N_2O emission rate in high N application was 1.6 times as high as that in low N application. The total soil N_2O emission during the entire growth period of maize in high N application was 1.5 times as high as that in low N application in the maize-planted soil and 2.5 times as high as that in low N application in the exposed soil (Table 1).

Under the same N application rate, N_2O emission from the exposed soil was significantly higher than that from maize-planted soil. N_2O emission from the exposed soil was 12 times as high as that from maize-planted soil in high N application and 7.5 times as high as that from maize-planted soil in low N application. The peak rate of N_2O emission from the exposed soil was about 10 and 16 times as high as that from maize-planted soil, respectively, in high and low N application treatments.

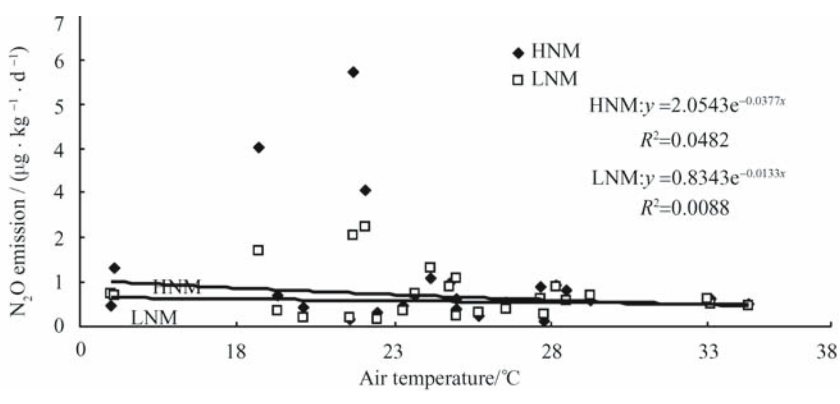
3.3 Effects of growing maize on the relationship between soil N_2O emission and temperature

Compared with the exposed soil, maize growth affected not only the seasonal variation and magnitude of soil N_2O emission, but also the relationship between soil N_2O emission and temperature. In the exposed soil with both high and low N applications, there was a significant exponential correlation between soil N_2O emission and air temperature (Fig. 3) and the $Q_{10,}$ which was the variation of soil N_2O emission rate caused by a temperature change of 10°C, was 4.4 and 3.2 in high and low N applications, respectively. But in maize-planted soil with both high and low N application treatments, the correlation of soil N_2O emission to air temperature was insignificant (Fig. 4).



HNB and LNB denote high and low N application to the exposed soil, respectively.

Fig. 3 Correlation of N_2O emission rate from the exposed soil with air temperature



HNM and LNM denote high and low N application to maize-planted soil.

Fig. 4 Correlation of N_2O emission rate from maize-planted soil with air temperature

4 Discussion

The significant difference of seasonal variation of N_2O emission rate between un-cropped and maize-planted soils showed the significant effects of plant growing on soil N_2O emission. That the total N_2O emission from the un-cropped soil was 7.5–12 times as high as that from the maize-planted soil implied that maize growth reduced N_2O emission from soil. The reason why maize growth could decrease soil N_2O emission was the demand of N for maize growth. After the utilization of soil N by maize, nitrification or denitrification would be impeded by the shortage of soil-available N, thus, the variation of N_2O production of soil-available N would be reduced. Surplus of soil-available N was one of the most important prerequisites to the production of N_2O (Maag and Vinther, 1999). Compared with the exposed soil, maize growth reduced about 92% and 87% of soil N_2O emission in high N application and low N application treatments, respectively, and this meant that the competition of soil-available N between plant and soil microorganisms decreased N_2O emission from soil. It was reported that N_2O emission from the exposed soil without fertilization was higher than that from forestry soil and lower than that from burley and grass planted soil (Maljanen et al., 2003). Duxbury et al. (1982) found that in organic soils, the annual N_2O emissions from fallow land were higher than those from Augustine-grass, sugarcane- and sweet corn-planted soils. These showed that soil N_2O emission could be decreased by the plant absorption of soil nitrogen.

In view of the undeveloped maize root system and its low absorption of soil N in the seedling stage, soil-available N became the source of N_2O production. That was why the peak of soil N_2O emission rate occurred at the seedling stage. No significant difference of soil N_2O emission during the seedling stage between the exposed soil and planted soil in the same N application treatment testified that maize growth had a little effect on soil N_2O emission at this stage. In the meantime, that N_2O emission from maize-planted soil during the seedling stage was significantly higher in high N application treatment than that in the low N application treatment implied that at this stage, soil-available N was the most important factor controlling soil N_2O emission. After the stem elongation stage, maize root system was well developed and its absorbing ability to soil N was greatly enhanced, thus, the nitrification or denitrification in soils was suppressed by the decrease of soil-available N, which led to a great decrease in soil N_2O emission and no difference of N_2O emission between high and low N applications in maize-planted soil (Table 1). In winter wheat-planted soil, soil N_2O emission was the lowest at the ripening stage (Wang et al., 1994). Zeng et al. (1994) reported that the peak of N_2O emission from the wheat planted soil occurred in the seedling stage. These results are consistent with ours and indicated that the weak ability of plants to absorb soil N at the seedling stage leading to the surplus of available N in soil was the main reason for high soil N_2O emission at the seedling stage in planted soil.

Because of plentiful available nitrogen in the un-cropped soil, soil N_2O production was no longer suppressed by soil-available N. This is why the total N_2O emission was significantly higher from the un-cropped soil than from the maize-planted soil. In the given soil, soil water content, temperature, and soil-available N were the main important factors controlling soil N_2O emission (Hou et al., 1998; Huang et al., 1999; Qi and Dong, 1999). In this experiment, soil water was controlled very well, especially in the un-cropped soil and soil water content was considerably stable. Therefore, soil-available N and temperature were the main factors controlling soil N_2O emission. Without stimulations from necessary temperature, N_2O emission was not increased by soil-available N (Zhou and Lin, 1994). During the seedling stage, soil nitrogen was rich, but the temperature was low, thus, soil N_2O emission rate was still low. With the process of crop growth, N_2O emission from the un-cropped soil increased with temperature and the difference of soil N_2O emission between un-cropped soil and maize-planted soil was gradually obvious. In brief, with certain N application treatment, N_2O emission from the un-cropped soil was controlled by temperature and highly correlated to air temperature.

The relationship of soil N_2O emission rate to air temperature showed that both plant growth and soil N application influenced the relationship of soil N_2O emission to temperature. The relative coefficient of soil N_2O emission rate to air temperature and the value of Q_{10} were higher in high N application treatment than that in low N application treatment, and this meant that the effect of temperature on soil N_2O emission was controlled by soil N level. When soil-available N was plentiful, soil N_2O emission was controlled by temperature. When soil lacked N, soil N_2O emission was controlled by soil-available N. Smith et al. (1998) found that in the mineral soil enriching N, there was an exponential correlation between soil N_2O emission and temperature, but the value of Q_{10} was 1.6 in sandy soil and 12 in clay soil with high water content. Maag and Vinther (1999) indicated that high temperature increased anaerobic respiration and denitrification, and the value of Q_{10} ranged from 3.4–5.4. Dobbie and Smith (2001) showed that soil N_2O emission increased with temperature. In this experiment, no significant correlativity of N_2O emission rate from maize-planted soil to air temperature suggested that in planted soil, the effect of temperature on soil N_2O emission was covered up by plant growth. This indicates that plant was a more important factor than temperature in controlling soil N_2O emission. Hou et al. (1997) reported that the influence of temperature on N_2O emission from paddy soil did not work when other factors worked on soil N_2O emission. It was the limitation of soil nitrogen deficiency resulting from the utilization of plant to the production and emission of soil N_2O that resulted in no significant correlativity of N_2O emission rate to temperature in this experiment.

N application accelerated N_2O emission from agricultural soil. The magnitude of soil N_2O emission derived from fertilizer N was about 1.5×10^6 t per year, which is 44% of anthropogenic N_2O emission into the atmosphere and 13% of total

N_2O emission into the atmosphere (Zhou and Huang, 2002). Ding et al. (2001) reported that soil N_2O emission in N application treatment was 2.4–4.2 times as high as in no N application treatment. Huang et al. (1995) found that N_2O emission from soybean- and maize-planted soils in northeast China was 2.64 and 7.10 $kg/hm^2 \cdot yr$, which was 4.3% and 1.3% of the applied N, respectively. Kaiser and Ruser (2000) showed that in the N application rate of 0, 82 and 156 kg/hm^2, soil N_2O emission was 2.08, 2.59 and 3.31 kg/hm^2, respectively. In this experiment, N_2O emission from exposed soil and maize-planted soil in high N application was 2.4 and 1.5 times as high as in low N application, respectively. All these indicated that soil N_2O emission increased with the increasing of N application rate. But our result confirmed that soil N_2O emission would be reduced by increasing the absorption efficiency of soil N and sustaining low level of soil-available N.

In conclusion, it was only in the soil with abundant available nitrogen that the effect of temperature on soil N_2O emission was significant, and maize growing altered not only the seasonal variation and magnitude of soil N_2O emission, but also the relationship of soil N_2O emission and air temperature.

References

Chen G X, Shang S H, Yu K W, Yu A D, Wu J, Wang Y J L (1990). Investigation on the emission of nitrous oxide by plant. Chin J Appl Ecol, 1(1): 94–96 (in Chinese)

Ding H, Cai G X, Wang Y S, Chen D L (2001). N_2O emission from different crop-fluvo-aquic soil system in the north China plain. Agro-environmental Protection, 20(1): 7–9, 30 (in Chinese)

Dobbie K E, Smith K A (2001). The effects of temperature, water-filled pore space and land use on N_2O emission from an imperfectly drained gleysol. Europ J Soil Sci, 52: 667–673

Duxbury J M, Bouldin D R, Terry R E, Tate R L (1982). Emission of nitrous oxide from soils. Nature, 298: 462–464

Eichner M J (1990). Nitrous oxide emissions from fertilized soils: Summary of available data. Journal of Environmental Quality, 19: 272–280

Feney J R (1997). Emission of nitrous oxide from soils used for agriculture. Nutrient Cycling in Agroecosystems, 49: 1–6

Hou A X, Chen G X, Cleemput O V, (1998). Effect of difference nitrogen fertilizers on N_2O smission from soil. Chin J Appl Ecol, 9(2): 176–180 (in Chinese)

Hou A X, Chen G X, Wu J, Wang Z P (1997). Relationship between CH_4 and N_2O emission from a rice field and its microbiological mechanism and impacting factors. Chin J Appl Ecol, 8(3): 270–274 (in Chinese)

Huang G H, Chen G X, Han B, Van Cleemput O (1999). Relationship between soil water and N_2O production. Chin J Appl Ecol, 10(1): 53–56 (in Chinese)

Huang G H, Chen G X, Wu J, Huang B, Yu K W (1995). N_2O and CH_4 fluxes from typical upland fields in northeast China. Chin J Appl Ecol, 6(4): 383–386 (in Chinese)

Jiang J Y, Huang Y (2001). Advance in research of N_2O emission from agricultural soils. Agro-environmental Protection, 20(1): 51–54 (in Chinese)

Kaiser E A, Ruser R (2000). Nitrous oxide emission from arable soils in Germany—an evaluation of six year long-term field experiments. J Plant Nutr Soil Sci, 163: 249–260

Li N, Chen G X (1993). N_2O emission by plants and influence of fertilization. Chin J Appl Ecol, 4(3): 295–298 (in Chinese)

Maag M, Vinther F P (1999). Effect of temperature and water on gaseous emission from soils treated with animal slurry. Soil Science Society of America Journal, 63(4): 858–865

MacKenize A F, Fan M X, Cadrin F (1997). Nitrous oxide emission as affected by tillage, corn-soybean-alfalfa rotations and nitrogen fertilization. Can J Soil Sci, 77: 145–152

Maljanen M, Liikanen A, Silvola J, Martikainen P J (2003). Nitrous oxide emission from boreal organic soil under different land-use. Soil Biology & Biochemistry, 35: 689–700

Mosier A, Kroeze C, Nevison C, Oenema O, Seitzinger S, Van Cleemput O (1998). Closing the global N_2O budget: Nitrous oxide emissions through the agricultural nitrogen cycle. Nutrient Cycling in Agroecosystems, 52: 225–248

Qi Y C, Dong Y S (1999). Nitrous oxide emission from soil and some influence factors. Acta Geographica Sinica, 54(6): 534–540 (in Chinese)

Smith K A, Thomson P E, Clayton H, McTaggart I P, Conen F (1998). Effects of temperature, water content and nitrogen fertilization on emission of nitrous oxide by soils. Atmospheric-Environment, 32(19): 3301–3309

Velthof G L, Kuikman P J, Oenema O (2002). Nitrous oxide emission from soils amended with residues. Nutrient Cycling in Agroecosystems, 62: 249–261

Wang S B, Song W Z, Su W H, Zeng J H, Zhang Y M, Wang Z P (1994). Nitrous oxide emission from winter wheat field. Agro-environmental Protection, 13(5): 210–212 (in Chinese)

Xie J F, Li Y E (2002). A review of studies on mechanism of greenhouse gas (GHG) emission and its affecting factors in arable soils. Journal of Chinese Agro-meteorology, 23(4): 47–52 (in Chinese)

Yang S H, Chen G X, Lin J H, Wu J, Ma Y Q (1995). N_2O emission from woody plants and its relation to their physiological activities. Chin J Appl Ecol, 6(4): 337–340 (in Chinese)

Yu K W, Chen G X, Yang S H, Wu J, Huang B, Huang G H, Xu H (1995). Role of several upland crops in N_2O emission from farmland and its response to environmental factors. Chin J Appl Ecol, 6(4): 387–391 (in Chinese)

Zeng J H, Wang Z P, Zhang Y M, Song W Z, Wang S B, Su W H (1994). Fluxes and estimation of nitrous oxide from the soil of wheat-maize rotation. Environmental Science, 16(1): 32–35, 67 (in Chinese)

Zheng X H, Wang M X, Wang Y S, Shen R X, Gong Y B, Zhang W, Luo D M, Jin J S, Li L T (1997). N_2O emission from rice-wheat ecosystem in southeast China. Chin J Appl Ecol, 8(5): 494–499 (in Chinese)

Zhou J W, Huang Y (2002). Effect of agricultural management practices on N_2O emission of farmlands. Rural Eco-environment, 18(1): 46–49 (in Chinese)

Zhou W N, Lin E D (1994). Study of properties of nitrous oxide emission from wheat field. Journal of Chinese Agro-meteorology, 15(2): 6–8 (in Chinese)