PERGAMON

Chemosphere – Global Change Science 2 (2000) 373–378

CHEMOSPHERE–
GLOBAL CHANGE
SCIENCE

Nitrous oxide emissions from terrestrial ecosystems in China

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Received 18 June 1999; accepted 4 May 2000

Impostance of this paper: Terrestrial ecosystem is one of major resources of atmospheric N_2O*. Currently, the sources and sinks of* N_2O *are not well characterized and unbalanced. One of the major reasons for this is that in situ measurement of* N_2O *emission is still limited. China is a big country. The* N_2O *emission in China is concerned widely. In this paper, we reported the* N_2O *fluxes and estimation of total annual emissions from terrestrial (agricultural, forest and grassland) ecosystems in China, and one technique mitigating* N_2O *emission from agricultural soil.*

Abstract

N_2O emissions from agricultural, forest and grassland ecosystems in China were in situ measured by closed chamber method, and estimation of total annual N_2O emissions from these ecosystems and a technique mitigating N_2O emission from agricultural soil were reported. The results showed: (1) the annual emissions of N_2O from rice, maize, soybean and wheat field, temperate forest and temperate grassland in China were 1.08–2.99, 0.47–4.51, 1.98, 1.02–2.93, 0.28–1.28 and 0.27–0.61 kg N_2O–N ha^{-1}, respectively. The total annual N_2O emissions from agricultural, forest and temperate grassland ecosystems in China were estimated as 152.49, 94.10 and 112.13 Gg N, respectively. Industrially co-crystallized ammonium bicarbonate (AB) with dicyandiamide, substituting for ammonium bicarbonate in China, decreased N_2O emission significantly from a meadow brown soil in laboratory (80.2% at soil moisture 12% and 40.0% at soil moisture 22%, respectively) and upland field condition (74.0%).

Keywords: Nitrous oxide; Terrestrial; Ecosystem; Mitigation; China

1. Introduction

N_2O is a greenhouse gas much more radiactive than CO_2 and CH_4 (mass basis) at absorbing infrared radiation (Rodhe, 1990). It contributes greatly to global warming and to stratospheric O_3 depletion (Cruzten, 1981). Therefore, more and more attention was paid to N_2O. Currently, the sources and sinks of N_2O are not well characterized, and unbalanced. In situ measurement of N_2O emission is needed to further investigate potential and known sources and sinks of atmospheric N_2O. It was suggested that the terrestrial sources of N_2O had probably been underestimated. Meanwhile, studies on techniques mitigating N_2O emission are also concerned. More attention is given to nitrogen fertilizer induced N_2O emission, which contributes significantly to the increase of atmospheric N_2O.

China is a big country. The N_2O emission in China is concerned widely. In this paper, we reported the N_2O fluxes and estimation of total annual emissions from terrestrial (agricultural, forest and grassland) ecosystems in China, and one technique mitigating N_2O emission from agricultural soil.

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2. Materials and methods

2.1. N_2O emissions from agricultural ecosystems

Field experiments were carried out at Shenyang Experimental Station of Ecology, Chinese Academy of Sciences (CAS) (41°32′N, 123°23′E). The characteristics of the experimental site were shown in Table 1. Rice field was fertilized with urea (172 kg N ha^{-1}) 3 times at the rates of 61.6 (late May, just before transplanting), 61.6 (late June) and 48.8 kg N ha^{-1} (mid August), respectively. Rice field was flooded by 5–10 cm water layer during the entire growing season (late May–middle September). Maize field was fertilized with urea at sowing (138 mg N ha^{-1}) and stamening (207 kg N ha^{-1}) times. A small amount of urea (35.4 kg N ha^{-1}) as starting N was applied to the soybean field at sowing time (early May). The closed chamber ($80 \times 80 \times 100$ cm^3) technique was used for flux measurements. Gas samples were taken after 40 min incubation from the chambers by syringes and analyzed by an electron capture detector of GC14A (SHIMADZU). The temperature of the detector, column and injection was 300°C, 60°C and 100°C, respectively. The carrier gas was N_2 at a flow rate of 1 ml s^{-1}. The N_2O concentration of sample gas was calculated by comparing the peaks of sample gas and standard gas.

2.2. N_2O emissions from forest ecosystem

In situ measurements of N_2O emissions from four typical temperate forest ecosystems were carried out at Changbai Mountain Forest Research Station, CAS in Northeast China (41°23′N, 126°55′E). The characteristics of the four experimental sites were shown in Table 2. The measurements of N_2O emission were conducted from June 1994 to October 1995 once a month, except those days when it heavily snowed or the soils were deeply frozen. Closed chamber (diameter 10 cm, height 24 cm) ($n = 5$) method was used for N_2O measurement. Gas sampled after 1 h incubation by syringe and stored in air bag. The method for analysis of N_2O concentration of gas sample, was the same as in Section 2.1.

2.3. N_2O emissions from grassland ecosystem

In situ measurements of N_2O emissions from two typical temperate native steppes and a degraded grassland with different stocking rates were carried out at Grassland Ecosystem Research Station of Inner Mongolia, CAS (43°26′N, 116°04′E) from May to October 1995. The characteristics of these two native grasslands were shown in Table 3. Eremophytes were dominant in the degraded grassland and the soil was chestnut soil. Fencing plots (1 ha) were built in the degraded grassland. Rotation grazing was adopted with a stocking rate 0, 1, 4 or 7 sheep per ha in 138 days in a cycle of 15 days grazing and 30 days rest. Gas samples ($n = 3$) were taken after 1 h incubation from the chambers ($60 \times 60 \times 40$ cm^3) by syringes and stored in air bag. The method for the analysis of N_2O concentration of gas sample was the same as in Section 2.1. The water content and mineral N content of 0–15 cm soil layer were also measured.

Table 1
Characteristics of Shenyang experimental station of ecology, CAS (41°32′N, 120°32′ E)

Annual temperature	Annual precipitation	Cropping system	Soil type	Organic matter (g kg^{-1})	Total N (g kg^{-1})	pH
7.0–8.0°C	630 mm	Single harvest	Meadow brown	16.17	0.76	6.4

Table 2
Characteristics of four types of typical forest in Changbai mountain in Northeast China (41°23′N, 126°55′E)

Sampling site	Altitude (m)	Vegetation	Soil	Annual average Temperature (°C)	Annual precipitation (mm)	pH
Mixed broad-leaved Korean pine forest	740	*Pinus koraiensis*, *Tilia amurrensis*, *Fraxinus mandshunica*	Dark brown forest soil	3.3	700–800	5.67
Coniferous forest	1280	*Picea jezoensis*, *P. koyamai var koraiensis*	Brown coniferous forest soil	−0.7	1000–1100	5.55
Erman’s birch forest	1850	*Betula ermanni*	Soddy forest soil	−3.1	1000–1100	4.97
Alpine tundra	2200	*Rhododendron aureum*	Tundra soil	−7.3	1110–1300	5.54

Table 3
Characteristics of two temperate native steppes in Inner Mongolia (43°26′N, 116°04′E), China

Grassland type	Soil type	Soil depth (cm)	Organic matter ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Annual average temperature (°C)	Annual precipitation (mm)	pH
Aneurolepidium Chinense	Dark brown soil	0–10	33.60	2.06	−0.4	350–450	6.6
		10–20	17.90	1.01			6.7
Stipa grandis	Brown soil	0–10	19.66	1.30	−0.4	350–450	7.8
		10–20	4.69	0.30			8.0

2.4. Mitigation of N_2O emission from agricultural soil

The meadow brown soil used in the experiments was the same as in Table 1. In the laboratory experiment, the soil was partly air dried and sieved (< 2 mm). 40 g soil (d.w.) was put into the flask (250 ml) ($n = 3$) and treated with water containing no fertilizer (CK), 20 mg N (equivalent to 500 ug N g^{-1}) as ammonium bicarbonate (AB), or modified AB (MAB), or urea (U). Then the soil was incubated at 25°C under soil moisture 12%, 22% or 32%. The soil moisture was maintained gravimetrically every other day. Field experiments were carried out at Shenyang Experimental Station of Ecology, CAS. The maize plot ($2 \times 4\ m^2$) ($n = 3$) was treated with no fertilizer (CK), 180 kg N N ha^{-1} as AB, MAB or urea (U) at sowing time only once. For measurement of N_2O emission from the incubated soil, the flask was flushed with ambient air and sealed by septum for 12 h. The 10 ml gas was sampled by syringe from the headspace of the flask for N_2O analysis. The measurement of N_2O emission from the maize field, was the same as in Section 2.1.

3. Results and Discussion

3.1. N_2O emission from agricultural ecosystems

Comparison of our results on N_2O emissions from agricultural fields in Northeast China with others' data in other regions of China (Zeng et al., 1994; Lu et al., 1997; Zheng et al., 1997) showed that N_2O emissions from different agricultural fields had high spacial and temporal variabilities (Table 4). Crop type, cropping system and fertilizer application were the major factors affecting the N_2O fluxes from agricultural ecosystems. In rice field, N_2O emission mainly occurred during non-flooding/fallow period (Fig. 1). This was also found in rice–wheat rotation field (Zheng et al., 1997). Therefore, monitoring N_2O emission during non-flooding/fallow period was much more important for estimating annual N_2O emission from rice or rice-upland crop rotation field.

For building empirical formula for estimation of N_2O emission from agricultural soil, some environmental factors need to be adopted. Climate, such as precipitation and temperature determine cropping system. Soil properties, such as total N, C/N influence the intensities of nitrogen immobilization/mineralization, hence the N_2O emission from background soil. Soil pH affects composition of nitrogenous substances in nitrogen cycling. Besides, the data on these factors was obtainable. Thus, for estimation of total annual N_2O emissions from agricultural fields in China, climate (precipitation, temperature), soil properties (pH, total N and C/N) and application of chemical nitrogen fertilizer, were considered as independent factors. Based on the data in Table 4 and of other studies (Xu et al., 1999), two empirical equations were built: formula 1 (for rice field), N_2O flux ($kg\ N\ ha^{-1}\ yr^{-1}$) $=$ $a*$ total $N * \log c_t * N/C + b *$ N application; formula 2 (for upland field), N_2O flux ($kg\ N\ ha^{-1}\ yr^{-1}$) $=$ $\text{background flux} + c * (\text{precipitation}/\text{pH} * 100)^2 * t^{1/2} * \text{N}$ application, where c_t was cumulative temperature, t was temperature, a, b and c were the coefficients. For single cropping system, c_t when $t > 0°C$ was adopted; for multiple cropping system, half of c_t when $t > 10°C$ was adopted (The period when $t > 10°C$ in China in a year was about 250 days, about two-fold the rice growth period in multiple cropping system). In 1992, rice cultivation area was 3.21×10^7 ha (5452 Gg N applied) and upland crop cultivation area was 1.49×10^8 ha (12109 Gg N applied). Adopting these two formulae, the annual total N_2O emission from rice and upland fields in China was estimated as 37.45 and 115.04 Gg N, respectively. Correspondingly, chemical N fertilizer induced N_2O emission accounted for 45.6% and 37.2%, respectively.

3.2. N_2O emission from forest ecosystems

Until now, few researches have been carried out on N_2O emission from forest ecosystems in China. The result from our research showed that all the four soils were the sources of atmospheric N_2O, but their source strengths were different (Table 5). The results also

Table 4
N_2O emission from agroecosystems in China

Region	Location	Cropping system	Crop	Water management	Fertiliser type	Fertiliser rate (kg N ha^{-1})	Period (m/d)	Range of flux (μg N m^{-2} h^{-1})	Total emission (kg ha^{-1})	Reference
Northeast China	Shenyang	Single	Rice	Flooding	Urea	172	03/07–12/06	−39.3– 164.2	1.08[a]	
		Single	Maize	No irrigation	Urea	345	03/07–12/06	−11.9– 557.2	4.52	
		Single	Soybean	No irrigation	Urea	35	03/07–12/06	−20.3–217.6	1.99	
North China	Shijiazhuang	Wheat–maize	Wheat	Irrigation	Urea	150	09/25– 05/24	11.2–31.2	1.02	Zeng et al.
		Wheat–maize	Maize	Irrigation	Urea	150	06/01–09/21	16.3– 21.2	0.67	
East China	Wuxian	Wheat–rice	Wheat	No irrigation	Urea	191	07/05/–11/05	−9.8– 1194.6	2.93	Zheng et al.
		Wheat–rice	Rice	A[b]	Urea	160	11/05–07/05	−11.2–751.5	2.99	
South China	Guangzhou	Double	Late rice	Flooding	Urea	150	08/04–11/11	−22.0–53.8	0.18	Lu et al.
		Double	Late rice	A	Urea	150	08/04–11/11	0–74.0	0.31	

[a] Only the data from the fields fertilized and managed normally were given here.
[b] A – Continuously flooded + soil drying + alternately flooded and drained.

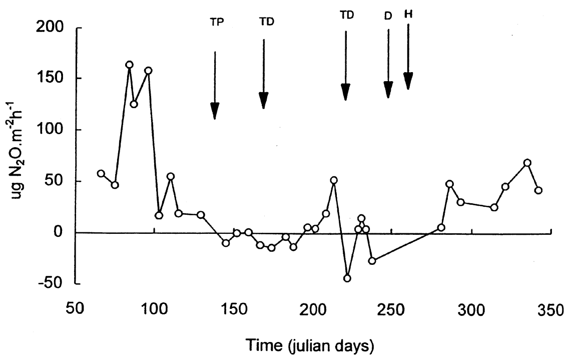

Fig. 1. Seasonal variation of N_2O emission from the rice field in Northeast China. TP – Transplanting; TD – Top dressing; D – Drainage; H – Harvest. Legend for *X*-axis – Time (julian days); Legend for *Y*-axis – ug N_2O m^{-2} h^{-1}.

showed that temperature and water content were the important environmental factors influencing N_2O flux from the forest soils (data not shown).

At present, the area of forest in China is 1.34×10^8 ha with a coverage ratio of 13.9%, and temperate forest is not the main part of forest in China (Ministry of Forestry, 1994). No data on N_2O emission from other types of forest in China is available. For building the empirical equation for N_2O emission from forest ecosystem in China, besides the data we obtained, the data on similar types of forest of other countries were adopted (Duxbury et al., 1982; Keller et al., 1986; Matson and Vitousek, 1987; Matson and Vitousek, 1990). Annual average temperature and annual precipitation were adopted as independent factors for multiple regression analysis. An experimental formula was established between annual average N_2O flux (F_a) and annual average temperature (T_a): log F_a (ug N m^{-2} h^{-1} $= 0.00290 \times T_a + 0.0479$. Adopting this formula, the total annual emission of N_2O from forest ecosystem in China was estimated as 94.10 Gg N.

3.3. N_2O emission from grassland ecosystems

Aneurolepidium chinense steppe and Stipa grandis steppe are the typical temperate semi-arid nature steppes. Results from in situ measurements of N_2O fluxes from sample area of these two native grassland ecosystems showed that they both were the sources of N_2O, but their strengths were different due to the different types of soil and vegetation (Table 6). Grazing did not change the role of grassland as the source of N_2O. However, stocking rates positively related with the N_2O emission from the degraded grassland. In situ and laboratory experiments also showed that temperature, NO_3^-–N and water content in soil (data not shown) were the important positive environmental factors influencing N_2O flux from the grasslands.

Temperate grassland ecosystems are the main part of grassland ecosystems in China. The total area of grassland was 3.53×10^8 ha China, among which, the area of northern temperate grassland was 2.87×10^8 ha (Zhao et al., 1992). Based on the data obtained from the grazed and native grasslands, the total annual N_2O emission from temperate grassland in China was estimated as 112.13 Gg N.

Table 5
N_2O emissions from four soils under four vegetations in Changbai mountain, China

Sampling point	Flux (μg N m^{-2} h^{-1})		Annual flux (kg N ha^{-1})
	Range	Average	
Dark brown forest soil/Mixed broad-leaved Korean pine forest	1.41–98.78	35.89	1.28
Brown coniferous forest soil/Coniferous forest	5.80–11.24	7.80	0.37
Soddy forest soil/Erman's birch forest	0.99–15.40	7.04	0.30
Tundra soil/Alpine tundra	0.70–13.99	6.63	0.28

Table 6
N_2O emissions from grassland ecosystems in Inner Mongolia, China

Sampling point	Description	Flux (μg N m^{-2} h^{-1})		Annual flux (kg N ha^{-1})
		Range	Average	
Native grassland	Dark brown soil/Aneurolepidium chinense	0.72–9.69	7.09	0.61
	Brown soil/Stipa grandis	−0.54–6.37	3.07	0.27
Degraded grassland	No sheep	0.42–10.47	3.52	0.31
	1 sheep per ha[a]	1.64–9.69	3.55	0.31
	3 sheep per ha	0.07–18.05	5.18	0.45
	7 sheep per ha	1.22–11.17	4.76	0.42

[a] Rotation grazing adopted in 138 days in a cycle of 15 days grazing and 30 days rest.

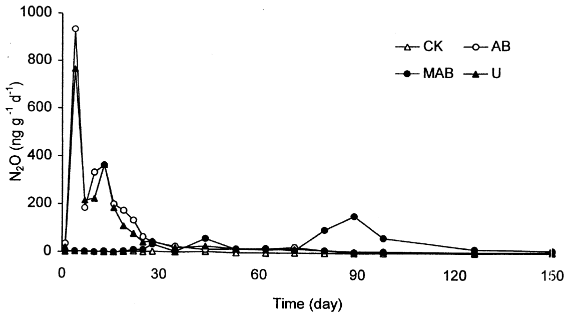

Fig. 2. N_2O emission from the differently fertilized soil in incubation (soil moisture, 22%). Legend for *X*-axis – Time (days); Legend for *Y*-axis – ng N_2O g^{-1} d^{-1}.

3.4. Mitigation of N_2O emission from agricultural soil

Application of nitrogen fertilizer modified with inhibitors of nitrogen transformation may decrease nitrogen fertilizer induced N_2O emission from agricultural soil. However, few modified fertilizers have been applied on large scale to confirm their positive effect on crop yield. Now, in China, industrially co-crystallized ammonium bicarbonate (AB) with dicyandiamide, namely modified ammonium bicarbonate (MAB), is popularized substituting for AB (popular as urea in China, 8.5×10^6 t AB–N applied in 1997). In the laboratory, in comparison with AB and urea, MAB application decreased the N_2O emission from the meadow brown soil by 80.2% and 88.4% at moisture 12%, by 40.0% and 27.6% at moisture 22% (Fig. 2), and little reduction and 45.9% at moisture 32%, respectively. In the maize field, the N_2O emission with MAB application decreased by 74% and 78%, respectively. At the same time, the maize yield was increased by 13.6% and 8.0%, respectively. The large-scale demonstration of MAB application (1.33×10^6 ha) in different regions of China also showed that crop yield averagely increased about 10% and nitrogen utilization efficiency enhanced about 11% (Zhang et al., 1997). These results suggested the possibility of cost effectively decreasing N_2O emission from agricultural soil through changing fertilizer formula.

Acknowledgements

Financial supports by National Natural Science Foundation of China (NSFC), Chinese Academy of Sciences and ABOS, Ministry of Foreign Affair, Belgium are highly appreciated.

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Chen G.X., Professor of microbiology, has been engaged in research on C, N, S, P biogeochemical cycling.