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Nitrous oxide emissions from cultivated soils in the North China Plain

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ABSTRACT

Using an enclosed chamber technique, N_2O emissions from intensively cultivated soils in the North China Plain were measured during periods from October 1995 to September 1996 and June 1997 to June 1998, to reflect distinct contributions of the winter wheat and summer maize growing seasons. The results show that the measured annual mean emission of N_2O from soils treated with chemical N fertilizer and from soils treated with chemical N fertilizer combined with organic manure were 52.8 and 61.4 μg N_2O m^{-2} h^{-1}, respectively. These emissions from fertilized soils were significantly higher right after the chemical fertilizer was applied. A relatively low annual mean emission of 2.2 μg N_2O m^{-2} h^{-1} was measured in soils that had not been fertilized for 12 years. Maximal annual emissions of N_2O from the studied agroecosystem were 3.9 kg N_2O–N ha^{-1} y^{-1}. The results indicate that the application of organic manure also had a significant effect on N_2O emissions, which combined with the use of chemical N fertilizer increased about 20% over the whole year. A weak correlation was found between N_2O emissions and soil available NH_4^+–N content. Average annual N_2O emission from fertilized soils was estimated to be 57.1 μg N_2O m^{-2} h^{-1}, which is in good agreement with the average emission of 52.7 μg N_2O m^{-2} h^{-1} reported in other fertilized soil flux studies at different locations in China.

1. Introduction

The atmospheric concentration of nitrous oxide is currently increasing at a rate of about 0.25% per year (Houghton et al., 1992). The seemingly small growth rate, about 0.8 parts per billion (ppb, 10^{-9} moles per mole), is the result of a large imbalance between the sources and sinks (Khalil and Rasmussen, 1992). Interest in the increase in atmospheric N_2O has recently been stimulated by the recognition that this trace gas plays an important role in the chemistry and the ozone layer destruction in the stratosphere. The radiative forcing of N_2O has, on a molar basis, about 220–290 times greater global warming potential than that of CO_2 (Lloyd, 1995). The principal mechanism of N_2O destruction is photolysis in the stratosphere, followed by reaction with exited singlet oxygen atoms. This is the major natural source of stratospheric nitrogen oxides which has a significant effect on the chemistry of the stratosphere and the ozone layer (Crutzen, 1971).

While estimates of the magnitude and global distribution of nitrous oxide emissions from natural soils and from agricultural soils have been made, fluxes from Chinese agricultural soils are still poorly defined, and the budget of global atmospheric N_2O remains, therefore, uncertain (Bouwman et al., 1995; Dong, et al., 1998).

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Numerous studies of soils have illustrated that most atmospheric N_2O is being emitted from soils by the microbial processes of nitrification, denitrification, and dissimilatory reduction of nitrate to ammonium. These microbial processes are strongly influenced by fertilizer application (Bremner et al., 1980; Seiler and Conrad, 1981; Duxbury, 1994). More than 7% of the total Chinese land surface area are soils of intensive agricultural use with considerable amounts of nitrogen fertilizer applied annually. More than 30% of the world's total chemical N was added to Chinese soils in 1990, which should, therefore, count as an important regional N_2O source. A better understanding of this source is needed to more accurately estimate and control regional and global climate changes caused by increasing N_2O concentrations in the atmosphere.

The objective of this study was to determine the N_2O emissions from intensively cultivated soils in traditional land management systems. We compared, in parallel, N_2O emissions from differently treated soils: soils not fertilized for 12 years, soils treated with chemical N fertilizer, and soils treated with chemical N fertilizer in combination with organic manure. In a separate experiment the relationship between soil N_2O emission and soil available nitrogen content in soils treated with chemical N fertilizer during the warm period was also explored.

2. Materials and methods

2.1. Experimental site and soils

The soil flux measurements were carried out at the Yucheng Integrated Experimental Station (36°57′N, 116°38′E, 23 m above sea level) of the Chinese Academy of Sciences, which is located on the alluvial flat of the North China Plain. It is representative and typical of the natural conditions and the average level of agricultural productivity. The area has a semi-arid and sub-humid monsoon climate with a mean annual precipitation of 608 mm and average air temperature of 13.1°C (30 years). The soil in the study area is classified as aquatic series with a sandy loam texture containing organic matter (0.78%), total nitrogen (0.049%), and available nitrogen (58 ppm) in the top 20 cm layer. The soil of this top layer has a pH of 7.9 (in a 1 : 5 soil-to-water ratio) with a bulk density 1.45 g cm^{-3}.

2.2. Soil treatments

We examined three treatments in this study, which included soils treated with chemical N fertilizer, soils treated with chemical N fertilizer combined with organic manure, and soils not fertilized for 12 years (since 1985) to served as a control. The organic manure was animal excreta composted with straw organic matter used at a rate of 10 t ha^{-1}. The effect of the application of organic manure prior to the summer maize and winter wheat sowing time on soil N_2O emissions was also investigated. Chemical N fertilizer was applied at a rate of 210 kg N ha^{-1} in the form of urea for each crop, split into two applications for maize and two or three applications for wheat in each season. The experimental area of fertilized soil was larger than 1 ha, while a smaller area of 1200 m^2 was used for the unfertilized soil flux measurements. Summer maize was planted in late June and harvested in mid-October, and winter wheat was planted in late October and harvested in mid-June.

2.3. Flux measurements and techniques

Measurements of vertical N_2O fluxes were conducted weekly using an enclosed chamber technique. During the wintertime measurements were done biweekly. The enclosed chamber was made from 8 mm-thick acrylic material with a 0.23 m^2 surface area. An acrylic lid with a rubber seal was placed on top of the chamber and removed between measurements. The chamber was fitted with an air mixing fan, temperature sensor, and 3-way sampling stopcock. The chamber (30 cm in height) was directly inserted into the soil at a depth of 8 cm and used for most of the measurements. A chamber 70 cm in height was used during the later growing times of winter wheat, to cover higher plants. During each of the flux measurements (generally between 09:00 to 12:00 h), 0.5 L of headspace gas was extracted using a Teflon-covered membrane pump at 0, 10, 20, and 30-min following placement of the chamber lid and collected in polyethylene-coated aluminum bags.

From 6 August 1997 to 3 December 1997, in a separate experiment, soil flux measurements and

soil samples taken from soils treated with chemical N fertilizer were analyzed to determine the effect of available nitrogen (NH_4^+, NO_3^-) content on N_2O fluxes. Three 2 cm diameter soil sampling cores from around the flux chamber were extracted to a depth of 20 cm. NH_4^+ and NO_3^- was analyzed following extraction with 2.0 M KCl, using a colorimetric continuous flow analyzer.

Air samples were analyzed within two weeks by gas chromatography (Hewlett-Packard 5890II) with an electron capture detector (ECD). The detector temperature was maintained at 330°C. The GC had a backflush system with a stainless steel precolumn (1.84 m, 3.2 mm o.d.) and an analytical column (3.68 m, 3.2 mm o.d.) packed with porapak Q, both 80–100 mesh, and held at 90°C oven temperature. The carrier gas (5% CH_4 in Ar) flow was adjusted to 26 ml min^{-1} through the analytical column, and the backflush gas to a flow rate of 40 ml min^{-1} through the precolumn. Analytical variability was less than 0.8% for repeated analysis of ambient air compared to an N_2O standard of 315 ppbv in compressed air (Deuste Steininger) during 8 h.

2.4. Statistical analyses

Comparisons of different treatments were made using one-way analysis of variance on the annual mean with the Origin version 4.1 for Windows. Two-population t-tests were used for pair-wise comparisons. Results were considered statistically significantly different when the significance level was greater than 5% ($p < 0.05$).

The dependence of N_2O emissions on environmental parameter variables was evaluated by linear regression using the Lotus-123R3 software.

3. Results and discussion

3.1. N_2O emission from unfertilized soil

The unfertilized soil that was used for this study had not been fertilized since 1985. It had been continuously planted, using a rotation system, with winter wheat and summer maize year by year for a long-term fertilization experiment. Monthly means of measured N_2O emissions from unfertilized soils (CK) show a large scatter and extremely low flux rates (Table 1). The annual mean emission rate was 2.2 ± 0.6 μg N_2O m^{-2} h^{-1} ($n = 86$, ±SE), with a relatively small annual emission of 0.1 kg N_2O–N ha^{-1} y^{-1}, which is in great contrast to the fertilized soils (Table 2). The N_2O fluxes from unfertilized soils were significantly less than those of soils treated with chemical N fertilizer and soils treated with chemical N fertilizer combined with organic manure (*t*-test, $p = 0.002$ and $p = 0.001$, respectively). They were also nearly three times lower than fluxes from natural unfertilized temperate forest soils (Dong et al., 1998) and five times lower than those from an unfertilized temperate grassland soil (Dong et al., 2000). These lower emissions may, therefore, be due to the continuous non-fertilization.

3.2. N_2O emission from fertilized soils

3.2.1. Variability of N_2O emissions. The annual cycle of N_2O fluxes from fertilized soils indicate similar seasonal patterns of higher emissions in the spring and fall months (Figs. 1, 2). This seasonality is mainly caused by a combination of two critical factors: (1) concentrated fertilizer applications which enhance N_2O emissions (the total annual amount of chemical N fertilizer was split into four or five applications in March, June, July, and October and a single application of organic manure used prior to the wheat sowing time in October) and (2) irrigation and rainfall after fertilization, which made the soil water content more adequate for N_2O production by denitrification and nitrification (Schuster and Conrad, 1992). In general, the agricultural soils of this area are managed with a moisture content satisfactory for crop growth. The soil water content varies between 40 and 70% of field water capacity.

It can be seen in Figs. 1, 2 and Table 1 that the majority of N_2O emissions from soils occur during the late spring to autumn months. About 84% of all emissions occurred between April and October, while the rest (16%) was contributed during winter and early spring. It can also be calculated that about 55% of the total yearly emission was contributed from July to October during the maize growing period.

The daily continuous measurements of N_2O emissions taken at the study site show strong diurnal variation with higher fluxes during the daytime and maximal flux between 14:00 and 16:00 in the afternoon (Fig. 3). The greatest difference in emissions within one day was calculated to be about 40%. The average N_2O flux rate

Table 1. *Monthly mean N_2O fluxes from unfertilized soil (CK), soils treated with chemical N fertilizer (CNT), and soils treated with chemical N fertilizer combined with organic manure (CNOT, CNOT*)*

N_2O fluxes (μg N_2O m^{-2} h^{-1}), 1995 and 1996			
Month	CK	CNT	CNOT
October 95	0(1)	37.3 ± 16.1(2)	77.5 ± 21.4(2)
November 95	−1.0 ± 4.3(5)	9.8 ± 2.8(5)	39.0 ± 15.7(5)
December 95	−1.5 ± 1.5(4)	2.1 ± 1.2(4)	5.0 ± 1.2(3)
January 96	0(2)	6.0 ± 1.4(2)	7.2 ± 2.3(2)
February 96	0(3)	7.8 ± 1.3(3)	11.2 ± 0.3(3)
March 96	0(2)	10.6 ± 7.9(2)	8.3 ± 3.9(2)
April 96	0.7 ± 0.7(4)	144.6 ± 24.3(4)	82.9 ± 19.0(4)
May 96	0.5 ± 0.5(5)	92.7 ± 35.0(5)	65.9 ± 35.8(5)
June 96	4.2 ± 4.2(2)	61.6 ± 13.5(4)	107.4 ± 92.6(2)
July 96	7.9 ± 5.3(3)	65.4 ± 28.0(3)	185.5 ± 169.4(3)
August 96	8.3 ± 8.7(4)	91.5 ± 66.7(4)	161.5 ± 147.1(4)
September 96	3.3 ± 1.2(2)	34.4 ± 5.1(2)	24.4 ± 0.4(2)
N_2O fluxes (μg N_2O m^{-2} h^{-1}), 1997 and 1998			
Month	CK	CNOT	CNOT*
July 97	3.2 ± 2.5(4)	56.0 ± 42.2(4)	166.2 ± 83.0(4)
August 97	2.4 ± 1.0(5)	126.9 ± 76.8(5)	208.7 ± 112.5(5)
September 97	4.2 ± 2.8(4)	7.1 ± 2.4(4)	18.0 ± 5.8(4)
October 97	1.6 ± 1.6(5)	78.6 ± 49.5(5)	91.2 ± 43.2(5)
November 97	1.8 ± 1.9(6)	128.3 ± 29.0(6)	20.0 ± 9.0(6)
December 97	3.4 ± 1.7(3)	42.4 ± 23.4(3)	1.5 ± 1.5(3)
January 98	0(2)	3.9 ± 0.9(2)	1.4 ± 1.4(2)
February 98	0(2)	9.9 ± 7.8(2)	1.7 ± 0.6(2)
March 98	2.8 ± 1.9(4)	23.3 ± 11.7(4)	68.0 ± 52.5(4)
April 98	1.4 ± 0.9(4)	80.3 ± 42.3(4)	57.6 ± 35.8(4)
May 98	0.2 ± 3.0(5)	18.1 ± 4.0(5)	17.7 ± 3.8(5)
June 98	6.6 ± 2.5(5)	12.5 ± 5.3(5)	1.4 ± 1.4(5)

The estimates (average values for each treatment ± standard error) are based on individual measurements in the indicated month with the number of measurements in parenthesis.
CNOT = organic manure is used prior to winter wheat sowing time (October). CNOT = organic manure is used prior to summer maize sowing time (June).

Table 2. *Average emission rates (μg N_2O m^{-2} h^{-1}) and yearly emission (kg N_2O–N ha^{-1} y^{-1}) for each of the experiments*

Soil treatment	Average emission (1995–1996)	Average emission (1997–1998)	Average emission (1995–1998)	Yearly emission
CK	1.8 ± 1.2(37)	2.5 ± 0.6(49)	2.2 ± 0.6 ($n = 86$)	0.1 ± 0.001
CNT	52.8 ± 0.6(40)		52.8 ± 10.6 ($n = 40$)	2.9 ± 0.067
CNOT	69.1 ± 21.4(37)	56.6 ± 12.1(49)	61.4 ± 9.4 ($n = 135$)	3.4 ± 0.060
CNOT*		60.5 ± 16.7(49)		

The estimates (average value for each treatment ± standard error) are based on individual measurements in the year with number of measurements in parenthesis.

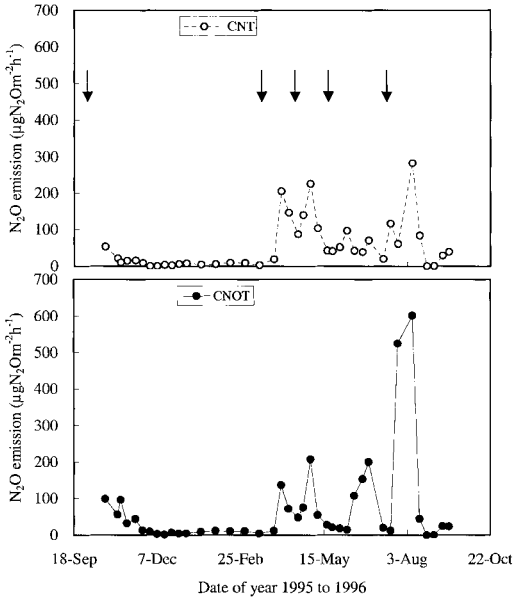

Fig. 1. Variations in N_2O emission from soils treated with chemical N fertilizer (CNT) and chemical N fertilizer combined with organic manure (CNOT), 1995 and 1996. Organic manure was applied prior to the winter wheat sowing time (9 October 1995) in the CNOT experiment. Arrows (↓) indicate the days of chemical N fertilizer application.

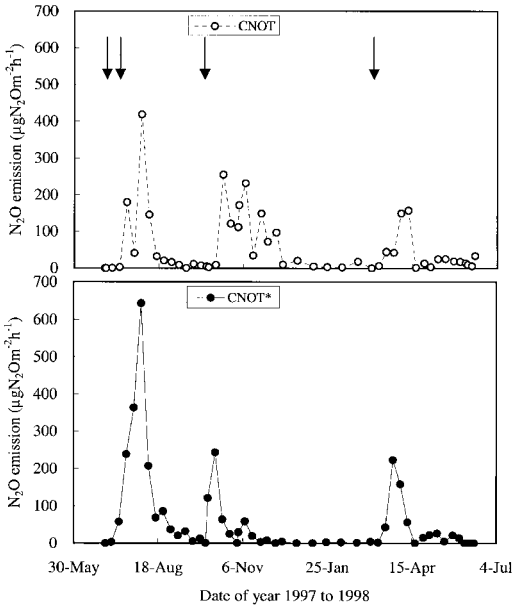

Fig. 2. Variations in N_2O emission from soils treated with chemical N fertilizer combined with organic manure, 1997 and 1998. In the CNOT experiment, organic manure was applied prior to the winter wheat sowing time (10 October 1995), and in the CNOT* experiment organic manure was applied prior to the summer maize sowing time (25 June 1997). Arrows (↓) indicate the days of chemical N fertilizer application.

during the day was found to be very close to the values obtained between 08:00 and 12:00; therefore, we generally made the flux measurements between 09:00 and 12:00 in the day. As expected based on the observed diurnal variation in emissions, there was a good linear correlation ($R^2 = 0.43$, $n = 15$, $\alpha < 0.01$) between N_2O soil fluxes and environmental air temperature. This is in agreement with reports of daily trace gas fluxes from soils under conditions which were more controlled with regard to temperature variation (Wang and Song, 1995).

3.2.2. Soil available nitrogen content and N_2O emission. From August to December 1997, the soil flux measurements and soil samples from soils treated with chemical N fertilizer were analyzed in a separate experiment to determine the effect of available nitrogen (NH_4^+, NO_3^-) content on N_2O fluxes. No significant changes in N_2O emissions were observed to correlate with changes of soil available NO_3^-–N content in this study ($R^2 =$

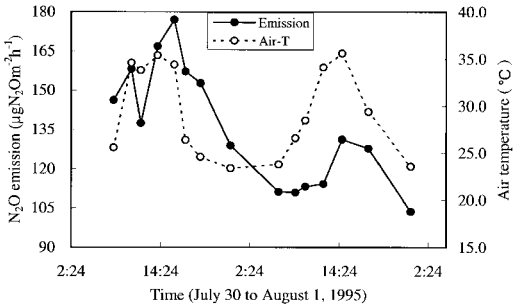

Fig. 3. Diurnal variation in N_2O emission from the summer maize field.

0.13, $n = 12$, $\alpha < 0.05$), however, a weak linear correlation ($R^2 = 0.28$, $n = 12$, $\alpha < 0.01$) was found between N_2O fluxes and soil available NH_4^+–N content (Fig. 4). This may be because soil water is conducive to the creation of oxidizing conditions in the soil, and this suggests that the nitrification process ($NH_4^+ \rightarrow NH_2OH \rightarrow N_2O \rightarrow NO_2^- \rightarrow NO_3^-$)

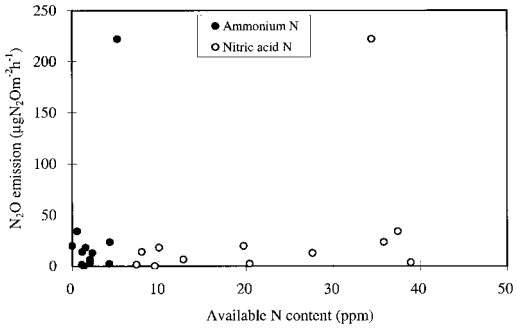

Fig. 4. Relation between N_2O emission and soil available nitrogen content in soils treated with chemical N fertilizer.

may be the main source of N_2O emissions from cultivated soils in the North China Plain. Nitrification is generally the main N_2O source in agricultural soils under oxic conditions (Davidson, 1992; Skiba et al., 1993).

3.2.3. The influence of fertilizer on N_2O emissions. Figs. 1, 2 and Table 1 show that N_2O emissions were significantly influenced by both chemical N and organic manure applications. N_2O emissions from fertilized soil were significantly higher than from unfertilized soils (t-test, $p < 0.002$). Furthermore, the N_2O emission rates in the CNOT experiment were generally higher than in the CNT experiment, except for April and May 1996, which is due to a little more chemical N fertilizer having been applied in the CNT experiment to supplement the lesser chemical N fertilizer applied at sowing time. Although the annual mean emission rate and most of the individual flux measurements in the CNOT experiment were higher than in the CNT experiment, these differences were not significant (t-test, $p = 0.5$). We calculated that the annual mean emission rates from soils treated with chemical N fertilizer and soils treated with chemical N fertilizer combined with organic manure were 52.8 ± 10.6 and 61.4 ± 9.4 μg N_2O $m^{-2}\,h^{-1}$, respectively. The annual mean N_2O emission rate from fertilized soils was estimated to be 57.1 μg N_2O $m^{-2}\,h^{-1}$. The maximal mean emission rate in this agricultural system was found to be 69.1 μg N_2O $m^{-2}\,h^{-1}$. Applications of chemical N fertilizer was almost always followed by peak emission; the duration of the emission peak was usually three weeks, with a rise in N_2O emission seen 3 days after fertilizer application (Figs. 1, 2). This is comparable to other reports with a similar situation of chemical N fertilizer application (Bremner and Blackmer, 1978; Mosier et al., 1982).

The annual total fluxes measured over the whole observation period are compiled in Table 2. Overall the results indicate that each soil treatment resulted in a significantly different amount of N_2O emission. The greater quantity of N_2O emission was obtained in the experiment in which chemical N fertilizer was combined with organic manure, with a mean annual emission of 3.4 ± 0.060 kg N_2O–N $ha^{-1}\,y^{-1}$. The annual maximum emission from this agricultural system was 3.9 kg N_2O–N $ha^{-1}\,y^{-1}$.

The calculated chemical N fertilizer transformed into N_2O emission over the whole of the winter wheat and summer maize growing time was 0.67% or 6.7 g N_2O–N kg $N^{-1}\,y^{-1}$, with a total input of 420 kg-N $ha^{-1}\,y^{-1}$ as urea. This result is comparable to a recent report by Yamulki et al. (1995). They found that 0.93% of fertilizer N was transformed to N_2O in a wheat field. Eichner (1990) summarized available global data for fertilizer-derived N_2O emissions from arable land, and he came up with a range of 0.04 to 1.7% of applied fertilizer N. In comparison with the soil unfertilized for a 12 year period, our results also show that application of chemical N together with organic manure increased N_2O fluxes by a factor of 24.1–28.1 (Table 2). This value is higher than the value obtained for N_2O emission from grass land, which increased by a factor of 2–3 following N-fertilizer application of 22 kg-N $ha^{-1}\,y^{-1}$ over a 13 year period (Mosier et al., 1991), and it was also higher than the numbers of Sitaula et al., 1995, who found that application of N-fertilizer increased N_2O fluxes of forest soil by a factor of 1.2–7 with application of N-fertilizer in the range of 30–90 kg-N $ha^{-1}\,y^{-1}$. Together the data suggest that the amount of fertilizer and the history of fertilizer application are factors that influence N_2O release from soils.

Fig. 2 shows a significant influence of the time of organic manure application on N_2O emission (t-test, $p < 0.05$). When organic manure was applied prior to the summer maize sowing time on June 25, the emissions in the CNOT* experiment were always higher than emissions in the CNOT experiment between June and September,

but this critically changed to emissions of CNOT being higher than in the CNOT* experiment between October and December, when organic manure was applied prior to the wheat sowing time on October 10. Both Figs. 1, 2 illustrate that the organic manure has a long-term influence on soil N_2O emissions, but it was not always obvious, since the effect of chemical N fertilizer is often seen within a short period of time (about 3 weeks). Table 1, Figs. 1, 2 also show a significant influence of organic manure application on N_2O fluxes, which is estimated to increase the N_2O emission by about 20% in a year. If we estimate 4.5% as the mean nitrogen content in organic manure, 0.11% of the nitrogen in organic manure was transformed into N_2O–N, which is a lower rate of N loss reported as loss of N_2O–N from soils after excreta application which ranged between 0.1 and 2.4% (Yamulki et al., 1998; Vermoesen et al., 1997). This may be explained by the lower carbon and nitrogen content of organic manure available for microbial processing and N_2O production, in particular a lower extractable nitrogen content.

3.4. Comparison with regional studies

Table 3 summarizes present reports of field N_2O emissions observed at different locations in China, which indicates that the mean N_2O emissions varied between 9.4 and 168.1 μg N_2O $m^{-2}\,h^{-1}$. For comparison, the average emission rate of N_2O for all of these studies is 52.7 μg N_2O $m^{-2}\,h^{-1}$, which is in close agreement with the average N_2O emission rate of 57.1 μg N_2O $m^{-2}\,h^{-1}$ of the fertilized soils in our study. This agreement is excellent considering that these independent studies were carried out at different cultivated locations in China, with different crops, different fertilizer treatments, and over different time periods. It supports the conclusion that our value is indeed the mean N_2O flux rate from fertilized soils at the present time in China and, therefore, useable as

Table 3. *Summary of N_2O emissions (μg N_2O $m^{-2}\,h^{-1}$) from cultivated soils in China as reported for different fertilizer treatments, locations, and crops*

Fertilizer treatment	Crop type	Meas. period (days)	Mean N_2O emission	Location	Investigators
chemical N[a)]	wheat	180	41.3	Hebei	Wang and Song (1995)
	wheat	90	9.4	Hebei	Su et al. (1992)
	wheat	40	22.0	Shengyang	Chen et al. (1997)
	maize	273	122.6	Shengyang	Chen et al. (1997)
	soybean	273	67.6	Shengyang	Chen et al. (1997)
	wheat–rice	180	72.3	Suzhou	Xing and Zhu (1997)
	wheat–rice	180	11.0	Jurong	Xing and Zhu (1997)
	wheat–rice	180	9.4	Suzhou	Xing and Zhu (1997)
	rice	94	141.4	Guangzhou	Song et al. (1996)
	rice	110	40.9	Guangzhou	Xing and Zhu (1997)
	rice	120	67.6	Yujiang	Xing and Zhu (1997)
	rice	120	23.6	Nanjing	Xing and Zhu (1997)
	rice	120	83.3	Suzhou	Xing and Zhu (1997)
	rice	120	80.1	Suzhou	Xing and Zhu (1997)
	rice	120	77.0	Fengqiu	Xing and Zhu (1997)
chemical N plus organic manure	wheat–maize	365	38.0	Hebei	Zeng et al. (1995)
	rice	94	9.4	Guangzhou	Song et al. (1996)
	rice	94	12.6	Guangzhou	Song et al. (1996)
	rice	260	26.7	Shengyang	Xing and Zhu (1997)
	rice	120	168.1	Nanjing	Xing and Zhu (1997)
non-fertilizer[b)]	wheat–maize	365	16.7	Hebei	Zeng et al. (1995)
	wheat	150	19.5	Hebei	Wang and Song(1995)

[a)] The chemical N application rate of the reference was in the range of 150–300 kg N ha^{-1} for each crop.
[b)] The fertilizer was not used during the flux measurement period.

basic emission rate in calculations to estimate N_2O emission from fertilizer applications and cultivated soils for the whole of the country.

4. Conclusions

Nitrous oxide emissions from agricultural soils in the North China Plain showed strong yearly temporal variability, which was mainly due to the human activities of fertilization. Compared to an unfertilized soil, which emitted 0.1 kg N_2O–N ha^{-1} y^{-1}, continuous chemical N application is a critical factor in raising N_2O emission from cultivated soils. The organic manure applications increase N_2O emissions by about 20% when combined with chemical N fertilizer, and this appears to be another important source of N_2O from agricultural soils. Sustainable and continued agricultural development in China, including continued large scale use of intensive management of agricultural soils with increases in both chemical N fertilizer and organic manure inputs, will ensure that N_2O emissions from agricultural soils continue to increase in China, affecting stratospheric chemistry and increasing global warming potential.

Assuming that the total area of cultivated soils in China is 9.5×10^7 ha (including 2.5×10^7 ha of rice-based agroecosystems) with nearly all of the cultivated soils receiving chemical N fertilizer and half of the area being treated with organic manure, we estimate that the regional N_2O emission from cultivated soils in China is about 302.1 Gg N_2O–N y^{-1} (1 Gg = 10^9 g) at the present time.

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