Emissions of nitrous oxide, nitrogen oxides and ammonia from a maize field in the North China Plain

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ABSTRACT

The exchange fluxes of nitrous oxide (N₂O), nitrogen oxides (NO_x) and ammonia (NH₃) from a maize field with three different treatments were simultaneously measured using static and dynamic chambers in the North China Plain (NCP) from June 28 to October 11, 2009. The three treatments included control plot (CK, without crop, fertilization and irrigation), fertilizer N plot (NP) and wheat straw returning plus fertilizer N plot (SN). N-fertilizer application greatly stimulated the emissions of N₂O, NO_x and NH₃, with durations of about 10 days for N₂O and NO, and about 7 days for NH₃. Fertilizer loss rates were 1.08% (NP plot) and 1.20% (SN plot) as N₂O–N, were 1.93% (NP plot) and 0.76% (SN plot) as NO–N, and were 5.24% (NP plot) and 3.03% (SN plot) as NH₃–N. In comparison with the NP plot, the significant low fertilizer loss rates as NO–N and NH₃–N from the SN plot indicated that the wheat straw returning to the field could reduce NO_x and NH₃ emissions. The molar ratio of NO/N₂O was greater than unity for most data during the pulse emission periods induced by fertilization, and thus, nitrification was the dominant process for N₂O and NO emissions during these periods. Considering the significant amount (>80%) of N₂O and NO_x emissions occurred during the pulse emission periods, the emissions of NO_x and N₂O from the investigated field were mainly ascribed to nitrification process.

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1. Introduction

Nitrous oxide (N₂O), nitrogen oxides (NO_x) and ammonia (NH₃) in the atmosphere play important roles in regional and global environment. N₂O is one of the important greenhouse gases and participates in the depletion of stratospheric ozone (Crutzen, 1970; Cicerone, 1987; IPCC, 2001). NO_x is a major precursor of atmospheric photo-oxidants and has important contribution to acid deposition and tropospheric ozone (Crutzen, 1979). NH₃, the most abundant alkaline constituent in the atmosphere, regulates the atmospheric acidity (Brasseur et al., 1999) and soil acidification (Roclofs et al., 1987). Agricultural field has become one of the major anthropogenic sources for atmospheric N₂O, NO_x and NH₃ (Khalil et al., 2006) and they are mainly from fertilization (Jambert et al., 1997; Bouwman et al., 2002a; Sehy et al., 2003; Khalil et al., 2006; Li and Wang, 2007, 2008). The current estimation of N₂O emission from agriculture soil to the global budget ranges from 0.11 to 6.3 Tg N yr^{−1} (Mosier et al., 1998; Bouwman et al., 2002b), of NO

emission from soil varies from 4 to 21 Tg N yr^{−1} (Yienger and Levy, 1995; Davidson and Kingerlee, 1997; Lee et al., 1997; Yan et al., 2005), and of NH₃ emission from agricultural field accounts for ~23% of global NH₃ emission (Bouwman et al., 2002a). The large uncertainties of the estimations were mainly due to the spatial-temporal variations of their emissions from agricultural field.

The North China Plain (NCP) occupies an agricultural area of about 300,000 km², accounting for 23% of Chinese cropland area (Ding et al., 2007). About 30% of the national fertilizer is being applied in this region for maintaining the high crop yield (Zhang et al., 2004). The amount of chemical N fertilizer applied to the region also greatly stimulates N₂O, NO_x and NH₃ emissions (Walsh, 2001; Dong et al., 2001, 2007; Cai et al., 2002; Zhang et al., 2004; Wang et al., 2004; Meng et al., 2005; Ding et al., 2007). To our knowledge, most of the studies in this region mainly focused on N₂O emission, and only one and three studies investigated NO exchange (Walsh, 2001) and NH₃ volatilization (Cai et al., 2002; Zhang et al., 2004; Wang et al., 2004), respectively. Because the emissions of the three nitrogen compounds from agricultural field are closely interrelated (Cabrera et al., 1991; Khalil et al., 2006; Firestone and Davidson, 1989), simultaneous measurements of the three nitrogen compounds can provide valuable information

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about their formation processes. As for the data of N_2O , the large differences of fertilizer loss rates (ranging from 0.006% to 1.94%) and average fluxes (ranging from 4.21 to 74.6 $\text{ng N m}^{-2} \text{s}^{-1}$) from the agricultural field of the NCP indicate that further field measurements are still needed.

In this study, N_2O , NO_x and NH_3 exchange fluxes from a maize field in the NCP during the whole growing period were simultaneously investigated in 2009, and the originations and environmental implications of the three nitrogen compounds from the field were also discussed.

2. Materials and methods

2.1. Experimental site and field treatments

The field experiments were carried out in an agricultural field ($38^\circ 71' \text{N}$, $115^\circ 15' \text{E}$) in Wangdu County, Hebei Province, China. Winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) have been cultivated for several decades in the field. The soil is classified as aquic inceptisol with a sandy loam texture. The soil pH (in a 1:2.5 soil to water), organic C and total N were 8.1, 8.34–9.43 g kg^{-1} and 1.02–1.09 g kg^{-1} , respectively. This field is located in the northern part of the NCP with annual mean rainfall of about 555 mm and annual mean temperature of about 12.3°C . The highest and lowest monthly mean air temperatures are 26.5°C in July and -4.1°C in January, respectively.

The investigated field with total area of 68 m^2 was divided into three $6.5 \times 3.5 \text{ m}^2$ plots, including control (CK, without crop, fertilization and irrigation), fertilizer N (NP) and wheat straw returning plus fertilizer N (SN) treatments. Each plot was separated by plastic boards which were inserted into the soil about 0.5 meter depth. Maize was sown on June 29, 2009. Compound fertilizer (412 kg ha^{-1} , N: P_2O_5 : K_2O = 24%: 12%: 6%) was broadcast to the NP and SN plots as basal fertilizer and air-dried wheat straw (4.3 t ha^{-1} , N = 0.48%, C: N ratio = 96.9: 1) was also applied as basal fertilizer to the SN treatment. Urea (150 kg ha^{-1} , N = 46.2%) was broadcast to NP and SN plots as supplementary fertilizer on 1 August in 2009. Flooding irrigation was carried out immediately after the basal fertilizers application, while the field was not irrigated after the supplementary fertilization because of strong rain events with cumulative rainfall of ~25 mm both before and after the fertilizer application. Maize was harvested on 7 October. All above field management was strictly according to the cultivating manner of local farmers.

2.2. Measurements and analysis of N_2O , NO_x and NH_3

N_2O flux was measured by static chambers. Seven identical static chambers made of Plexiglas ($60 \times 60 \times 90 \text{ cm}^3$) were applied to cover corresponding pedestals which were inserted into the soils of the three plots at a depth of 10 cm during the whole maize growing season. The pedestal made of stainless steel had a gutter around its upper rim to permit water to seal with the chamber during flux measurements. Two fans were fixed at opposite position in the middle of each chamber for mixing the air in the chamber evenly. In order to reduce solar heating and greenhouse effect in the chamber, three sides (the top side and the sides towards south and east) of the chambers were covered by aluminum foils. The daily fluxes were measured from 9:30 a.m. to 10:30 a.m. (Beijing time). Five campaigns were designed for field flux measurements: 12 days from June 28 to July 9, 8 days from July 30 to August 6, 9 days from August 25 to September 2, 12 days from September 10 to 21, and 1 day on October 11. Four air samples were collected into polyethylene-coated aluminum bags (Delin, Dalian, China) by a mini-pump (NMP 830 KNDC, Germany) at 10-min intervals after the chambers being enclosed (0, 10, 20 and 30 min). N_2O concentrations were analyzed

by a gas chromatography (Model SP3410, Beijing Analytical Instrument Factory) with an electron capture detector (ECD). Gas samples were loaded into a 2 mL loop connected to a 10-port valve that is used for injecting sample to GC and back flushing a pre-column. The pre-column and an analytical column were made of stainless steel with the same size ($2 \text{ m} \times 4 \text{ mm}$) and packed with Porapak Q (80–100 mesh). High purity of N_2 (99.999%) was used as carrier gas for both the columns with flow rates of 30 mL min^{-1} . In order to improve the instrument sensitivity, a makeup gas (979 ppmv CO_2 in N_2) was introduced into the downstream of the analytical column with a flow rate of 8 mL min^{-1} , and the N_2O signal increased at least 4 times after the introduction of CO_2 . Zheng et al. (2008) pointed out that the use of N_2 as the carrier gas led to significant overestimate of N_2O emissions due to influence of CO_2 accumulation in static chamber enclosures. However, no influence of CO_2 concentration (200–2000 ppmv) in the air samples on N_2O quantification was found by our improved method. The variation coefficient of our method for analyzing N_2O was less than 0.31% based on the reproducibility of a N_2O standard gas (358 ppbv, Center of Standard Reference Materials, Beijing, China) within 9 h. The N_2O fluxes were calculated based on the change rate of N_2O concentrations with time in the chambers, and the correlation coefficients were always greater than 0.95.

NO_x and NH_3 fluxes were measured by dynamic chamber technique. Each dynamic chamber (32 cm diameter, 80 cm height) consisted of a chamber cap and a pedestal. The chamber caps were made of stainless steel bracket which was wrapped with Teflon film. Seven inlets (10 mm, I.D.) are evenly distributed on the top of each chamber cap and six outlets (3 mm, I.D.) are evenly connected with the chamber cap at about 10-cm above its bottom. The pedestals made of stainless steel were always inserted into the soils about 10-cm depth of the three treatments during the whole maize growing period. Water was added to the channel along the pedestals' upper rim to make airtight seal with the chamber cap during flux measurements. Six mini-pump (NMP 830 KNDC, Germany) simultaneously pumped air from the outlets to flush the chambers with total flow rate of about 15 L min^{-1} during sampling. To eliminate the possible loss of NO_x and NH_3 on the wall of the chamber, a chamber with bottom covered with Teflon film was used as reference chamber. NO_x and NH_3 fluxes were derived from the concentrations' differences of NO_x and NH_3 at the outlets between the sampling chamber and reference chamber. Two air samples from each chamber were collected into Teflon bags (2 L in volume each) when the concentrations of NO_x and NH_3 reached steady state (at 15 min, more than 2 flushing cycles), and analyzed immediately in the field laboratory. The daily sampling time was from 15:00 p.m. to 17:00 p.m. (Beijing time). NO_x and NH_3 concentrations were analyzed by a chemiluminescent NH_3 analyzer (Thermo Electron model 17i, USA). The instrument was calibrated by BML-Dynamic Dilution Calibrator System before transported to the field, and further calibrated in the field before every campaign according to following procedure: purified air (through a trap filled silica gel and active carbon) with NO_x and NH_3 concentrations around their detection limits was continually passing through the instrument as background, and seven concentrations respectively for NH_3 and NO in 2 L Teflon bags prepared by dilution standard gases (Center of Standard Reference Materials, Beijing, China) were injected into the instrument by switching a 3-way valve between the trap and the inlet of the instrument. Good linear correlations ($R^2 \geq 0.998$) between the actual values and the measured values were observed in every calibration for NO and NH_3 , respectively.

The maize distances between rows and between hills were 50 cm and 30 cm, respectively. The pedestals of the static chambers and dynamic chambers covered four maize crops and one crop, respectively. The top parts of the maize in the pedestals were cut off

on 24 August 2009 for fitting the size of the chamber. The flux measurements had three duplicates for each plot with the relative standard deviations (RSD) generally less than 60%, and only the average fluxes were presented in this study. During sampling period, soil temperature at 10-cm depth and air temperature inside the chambers were simultaneously recorded.

2.3. Soil sampling and analysis

Soil samples were collected 1–2 times during each sampling campaign. Two soil samples randomly removed by a ring sampler (5 cm I.D. $\times$ 5 cm Height) from 0–5 cm topsoil of each plot were used for the water-filled pore space (WFPS) analysis and four soil samples from the 0–10 cm layer gathered by a trowel were used for analyzing soil $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$. Soil moisture was determined by drying the soil at 105 °C for 12 h. WFPS was calculated by dividing the volumetric water content by total soil porosity. Total soil porosity was calculated according to the relationship: soil porosity = $(1 - \text{soil bulk density}/2.65)$, assuming a particle density of 2.65 g cm^{-3} . $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ contents were measured by a colorimetric continuous flow analyzer (SANT++, Skalar Company, the Netherlands).

2.4. Data analysis

The data analysis was performed using SPSS 13.0 software (SPSS Inc., Chicago, USA) and Origin 7.5 (Origin Lab Corporation, USA). Cumulative N_2O , NO, NO_2 and NH_3 emissions from each plot were integrated based on sampling date. It is assumed that the emissions were followed a constant flux rate (the average rate between two sampling date) during the periods when no samples were taken.

3. Results and discussions

3.1. N_2O exchange fluxes

N_2O emissions increased quickly after one day of fertilizer applications, and the highest emission rate was about $140 \text{ ng N m}^{-2} \text{ s}^{-1}$ after 6 days of the basal fertilizer application and 4 days of the supplementary fertilization in the NP and SN plots (Fig. 1a). The duration of N_2O emission induced by fertilization was about 10 days. The average N_2O emission fluxes (mean $\pm$ SE) from NP and SN plots were $30.0 \pm 3.1 \text{ ng N m}^{-2} \text{ s}^{-1}$ and $35.0 \pm 3.4 \text{ ng N m}^{-2} \text{ s}^{-1}$ (mean $\pm$ SE, $n = 106$), respectively. Fertilizer loss rates as $\text{N}_2\text{O-N}$ were 1.08% and 1.20%, respectively.

An extremely high N_2O emission ($312 \text{ ng N m}^{-2} \text{ s}^{-1}$) occurred in the CK plot after a rain event with rainfall of about 12 mm on 8 July. Because of consecutive sunny days lasted for more than 15 days before the rain event, the soil in the CK plot became extremely dry (WFPS < 20%) due to no shield of plant canopy. The extremely high N_2O emission from the CK plot on the day was ascribed to the rewetting of the extremely dry soil (Jørgensen et al., 1998). Each N_2O pulse from CK plot during later cases was also corresponding to a rain event, but N_2O emission strength was much lower than that of the first case, which was probably due to the higher soil water content (WFPS > 40%) during the later rain events. Compared with CK plot, the shield of the maize canopy on the two fertilization plots would largely reduce the influence of the small rain events on wetting the soil, and hence, only two pulse emissions corresponded to the two rain events on 8 July and 5–6 August were observed. These pulse emissions were probably due to effects of fertilization, because these dates were just after several days of fertilizer application.

Fig. 1. Variations of N_2O (a), NO (b), NO_2 (c) and NH_3 (d) fluxes from the three treatments during the maize growing period. Arrows show fertilizer applications.

3.2. NO_x exchange fluxes

NO_x emissions from the NP and SN plots also increased quickly just after N-fertilizer application, and the duration of the pulse emission induced by basal fertilization was also about 10 days (Fig. 1b, c). However, NO_x emission peaks after the two fertilizations were about two days earlier than those of N_2O emission. The highest NO emission rate ($\sim 1100 \text{ ng N m}^{-2} \text{ s}^{-1}$) from the NP plot was about 3 times higher than that ($340 \text{ ng N m}^{-2} \text{ s}^{-1}$) from SN plot after the basal fertilization, whereas, there was no significant difference between the two plots after the supplementary fertilizer application ($\sim 350 \text{ ng N m}^{-2} \text{ s}^{-1}$). The possible reason was that the fresh wheat straw in the SN plot could consume oxygen in the soil, and NO formed in the soil was easily consumed by denitrifiers (Conrad, 1996). The wheat straw had become rotten when the

supplementary fertilizer application and its influence on soil oxygen became less accordingly. Several investigators found the burst of NO emission when dry soil becomes wet (Scholes et al., 1997; Martin et al., 1998), and this effect of soil moisture change on NO emission has been incorporated into the statistical and empirical models for estimating NO emission from soils (Yienger and Levy, 1995; Yan et al., 2005). However, contrasting with N₂O emission, only a small pulse emission (from -7.85 to $34.6 \text{ ng N m}^{-2} \text{ s}^{-1}$) of NO from the CK plot was observed after the rain event on 8 July. The possible reason for this phenomenon was that denitrification was probably the dominant process during re-wetting of the dry soil and contributed the extremely high N₂O emission, while NO emission is mainly from the nitrification (Davidson, 1992).

The average NO fluxes were 1.08 ± 0.46 , 36.5 ± 13.2 and $16.7 \pm 5.67 \text{ ng N m}^{-2} \text{ s}^{-1}$ for CK, NP and SN plots, respectively. Fertilizer loss rates as NO–N were 1.93% and 0.76% for the NP and SN plots, respectively. It is evident that straw returning to the field could greatly reduce NO emission ($\sim 54\%$). The NO loss rates obtained by this study were in the range of different types of soils with different plants (0.003%–11%, Yan et al., 2003).

Evident NO₂ emissions were only observed from the NP and SN plots after fertilizations. Significant correlation between NO and NO₂ fluxes ($R = 0.67$ – 0.81 , $N = 38$, $P < 0.01$) were found for the three plots, which indicated that NO₂ emissions were mainly ascribed to photochemical conversion of NO to NO₂ in the dynamic chamber. The average NO₂ fluxes during the maize growing period (late June–October) were 0.81 ± 0.52 , 4.13 ± 2.84 and $0.22 \pm 2.13 \text{ ng N m}^{-2} \text{ s}^{-1}$ for CK, NP and SN plots, respectively.

3.3. NH₃ exchange fluxes

Two evident emission peaks of NH₃ were observed on 2 July from the NP and SN plots and on 2 August from NP plot (Fig. 1d). Differing from NO, the first NH₃ emission peaks from the two plots were almost identical and the second NH₃ emission peak with one-day duration was only observed from the NP plot. The relatively low NH₃ emission after the supplementary fertilization from the SN plot was coincident with the relatively low NH₄⁺ concentration in the soil (data not shown). In addition, the duration of the NH₃ pulse emissions induced by basal fertilization was about three days later than those of N₂O and NO. The average NH₃ fluxes were -23.8 ± 4.56 , 94.0 ± 45.3 and $15.2 \pm 44.1 \text{ ng N m}^{-2} \text{ s}^{-1}$ for CK, NP and SN plots, respectively. It is evident that straw returning to the field could also greatly reduce NH₃ emission ($\sim 84\%$).

With exception of the pulse emissions induced by fertilization, the investigated field always acted as a small sink for atmospheric NH₃. The fertilizer loss rates as NH₃–N, therefore, were calculated only based on the data during the two emission periods (30 June–7 July for basal fertilizer application and 2–5 August for supplementary fertilizer application) as 5.24% and 3.03% for the NP and SN plots, respectively. Compared with the basal fertilizer application, the significantly low NH₃ emission after the supplementary fertilizer application indicated that the maize crop could absorb large proportion of NH₃ emitted from the soil.

3.4. Origins of N₂O, NO_x and NH₃ emissions

The formation processes for N₂O, NO_x and NH₃ in agricultural soils have been recognized to be nitrification, denitrification, and ammonification. However, the detail information (especially for N₂O and NO_x) about the dominant process in most agricultural fields is still unclear. The ratio of NO/N₂O is being used as a potential methodology for distinguishing soil nitrification and denitrification (Anderson and Levine, 1986; Williams et al., 1998; Meijide et al., 2007). Anderson and Levine (1986) found the molar ratio of NO/

N₂O was usually greater than unity for nitrifiers and much less than unity for denitrifiers. From field measurements, however, Meijide et al. (2007) found the predominance of nitrification occurred when NO/N₂O > 0.11. As for our data, the ratios of NO/N₂O from NP and SN treatments less than unity were both 68%, and less than 0.11 accounted for 53% and 59%, respectively. As for the CK plot, 79% of NO/N₂O ratios were less than 0.11. The higher percentage of NO/N₂O < 0.11 in the SN plot than that in the NP plot was ascribed to the wheat straw consuming oxygen in the SN plot, which was in favor of denitrification. The significantly less percentage of NO/N₂O < 0.11 in the NP and SN plots than that in the CK plot was mainly due to fertilizations. Therefore, N₂O emissions during most of the maize growing period might be dominated by denitrification. Because the largest proportions of N₂O (>80%) and NO (>95%) emitted from the NP and SN plots during the periods after fertilization when the ratios of NO/N₂O were more than unity (Fig. 2), nitrification greatly contributed to NO and N₂O emissions from the investigated maize field.

Anderson and Levine (1986) found N₂O emissions depend upon the competition between nitrite and oxygen for electrons removing from ammonium during nitrification, with more N₂O production via nitrite reduction. The extremely high NH₃ emissions just after fertilization indicated that large amounts of ammonium were formed in the soil. The formed ammonium might greatly consume oxygen absorbed in the soil, and nitrite consumption dominated for N₂O formation, which might be the reason why N₂O emission peaks appeared two days later than those of NH₃ and NO.

3.5. Comparison with previous studies in the NCP

3.5.1. N₂O emission

Among the investigations of N₂O emission from maize field in the NCP, the large difference was N₂O emission strength (especially for the peak emissions), e.g. the peak value obtained in this study was about a factor of 2–3 higher than those reported by Zhang et al. (2004) and Dong et al. (2001), but it was about 40% lower than the data recently reported by Ding et al. (2007) with similar fertilization level as ours. This difference was mainly ascribed to the large spatial-temporal variation. In addition, the sampling frequency also affected the observed peak values due to significant daily variation of N₂O emission after fertilization. The sampling frequencies for most studies in the NCP were only once or twice per week, which would result in large uncertainty for estimating N₂O emission from the maize field, e.g. the cumulative N₂O emission (SN plot, $3.21 \text{ kg N ha}^{-1}$) investigated in this study was similar to the value

Fig. 2. Molar NO/N₂O ratios from NP and SN plots during the maize growing period. The intercept of the dash line on the Y-axis represents the molar ratio of NO/N₂O equated to unity.

($3.78 \text{ kg N ha}^{-1}$) reported by Ding et al. (2007), though our peak values were about 40–80% lower than theirs.

3.5.2. NO exchange fluxes

To our knowledge, only Walsh (2001) studied NO exchange fluxes at China agricultural University (Beijing) for seven weeks from May to June. The mean NO fluxes from the two fertilization plots (NP: $36.5 \pm 13.2 \text{ ng N m}^{-2} \text{ s}^{-1}$, SN: $16.7 \pm 5.67 \text{ ng N m}^{-2} \text{ s}^{-1}$) in this study were lower than that ($77.5 \pm 65 \text{ ng N m}^{-2} \text{ s}^{-1}$) reported by Walsh (2001), but fertilizer loss rates as NO–N (0.76–1.93%) were closed to his (0.75–1.6%). In the study of Walsh (2001), several NO emission peaks were observed after fertilization with the maximal peak about 10 days after fertilizations. In this study, however, the only one obvious NO emission peak after each fertilization case from the two treatments occurred about two days after fertilizations.

3.5.3. NH₃ volatilization

Only three reports about NH₃ volatilization in the NCP are available in the literature. The three reports and ours revealed that NH₃ volatilization from maize field increased quickly after fertilizations with peak emissions around 1–4 days after fertilizations and the duration of the pulse emission induced by fertilization was usually less than 7 days. However, the emission strengths investigated by different groups were largely variable. The peak value (e.g. $3744 \text{ ng N m}^{-2} \text{ s}^{-1}$ for NP plot) after basal fertilizer application in this study was about a factor of 1.5 less than that reported by Cai et al. (2002) with fertilizer rate of 75 kg N ha^{-1} , and 3.2-fold less than that reported by Zhang et al. (2004) with fertilizer rate of 157 kg N ha^{-1} , and 1.0–1.8 times higher than those reported by Wang et al. (2004) with fertilization rates of 60–120 kg N ha^{-1} . The extremely high NH₃ emission from the maize field studied by Zhang et al. (2004) was mainly due to high fertilization rate that was about 1.6 times higher than ours. As for the supplementary fertilization, only Wang et al. (2004) conducted similar experiment as ours. The peak of NH₃ emission ($1961 \text{ ng N m}^{-2} \text{ s}^{-1}$, NP plot) in this study was about 1.5 times less than that reported by Wang et al. (2004) with the same fertilization rate. It should be mentioned the vented-chamber without crop used by Wang et al. (2004) would greatly overestimated NH₃ emission during this period, because a large proportion of NH₃ emitted from soil could be re-absorbed by crop via stomata (Jones et al., 2007). The fertilizer loss rates as NH₃–N of 3.03%–5.24% from the two treatments after basal and supplementary fertilization in this study were much less than 22.6% reported by Zhang et al. (2004) and 18% reported by Cai et al. (2002), and closed to the values (3.2–6.3%) reported by Wang et al. (2004).

3.6. Environmental implications

Maize is cultivated in this region during June–September when the photochemical reactions are the most active. Because the formation of photochemical oxidants (such as O₃) in rural areas is usually limited by NO_x (Aneja et al., 1996), the strong NO pulse emissions induced by fertilizations would greatly elevate atmospheric O₃ level over a large region, which can impact on the air quality of the metropolis (such as Beijing and Tianjin) in this region because of the elevation of background concentration by long distance transportation. To effectively mitigate O₃, in the viewpoint of the authors, reduction of NO_x emission from the agricultural field in the NCP should be considered.

A large fraction of the emitted NH₃ from the maize field in this region can be quickly converted to ammonium as fine particles via heterogeneous reactions on acid particles or photochemical reactions. The fine particle of ammonium is readily soluble, and can

greatly reduce atmospheric visibility via absorption of atmospheric water vapor. Although the duration of the pulse NH₃ emission induced by fertilizer only lasted for several days, the long lifetime of atmospheric ammonium in the fine particles can maintain the influence on environment for much longer time and over larger region. The high frequency of haze day in the NCP in recent years is closely relating to the high concentration of fine particles in which ammonium accounted for the largest proportion of the total cations (Sun et al., 2006). Zhang et al. (2010) recently calculated agricultural ammonia emissions inventory in the NCP, and found that 54% of the total emission ($3071 \text{ kt NH}_3\text{–N yr}^{-1}$) was from mineral fertilizer application. Therefore, to improve the air quality in the NCP, mitigating NH₃ emission from the agricultural field in this region is urgently needed.

4. Conclusion

The current N-fertilizers (compound fertilizer and urea) used in the NCP could greatly stimulate N₂O, NO_x and NH₃ emissions from the maize field. The molar ratio of NO/N₂O indicated that N₂O and NO emissions from the field was mainly dominated by denitrification during the most maize growing period, while nitrification during the pulse emission periods made the largest contribution for their total emissions. The strong pulse NO_x and NH₃ emissions from the field had important influence on the regional air quality. To improve the air quality in the big cities such as Beijing and Tianjin, the agricultural sources of NO_x and NH₃ should be considered. Straw returning to the field should be further advocated for mitigating NO_x and NH₃ emissions from this region.

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