Short communication

NO_x fluxes from several typical agricultural fields during summer-autumn in the Yangtze Delta, ChinaShuangxi Fang^a, Mu Yujing^{b,*}^a Chinese Academy of Meteorological Sciences, China Meteorological Administration, Beijing 100081, China^b Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

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ABSTRACT

NO_x fluxes from three kinds of vegetable lands and a rice field were measured during summer–autumn in the Yangtze Delta, China. The average NO fluxes from the rice fields (RF), celery field (CE), maize field (MA) and cowpea field (CP) were 4.1, 30.8, 54 and 32.2 ng N m^{−2} s^{−1}, respectively; and the average NO₂ fluxes were −2.12, 0.68, 1.33 and 0.5 ng N m^{−2} s^{−1}, respectively. The liquid N fertilizer (the mixture of swine excrement and urine) which is widely applied to vegetable lands by Chinese farmers was found to quickly stimulate NO emission, and have significant contribution to NO emission from the investigated vegetable lands. Apparent linearity correlations were found between NO₂ fluxes and the ambient concentrations of the rice fields, with a compensation point of about 2.84 μg m^{−3}. Total emissions of NO during summer–autumn time from this area were roughly estimated to be 4.1 and 8.4 Gg N for rice field and vegetable lands, respectively.

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1. Introduction

The oxides of nitrogen (NO_x = NO + NO₂) play a critical role in regulating the oxidant balance of the troposphere (Crutzen, 1983). Agricultural land has been identified as an important source for nitric oxide (Yienger and Levy, 1995). The formation of NO in soils is primarily through the processes of nitrification and denitrification (Bremner, 1997; McKenney and Drury, 1997), and the microbial processes are affected by many factors such as N availability, soil water content, soil pH, temperature and enzyme status (Ludwig et al., 2001). Accordingly, the reported fertilizer-induced NO emission ratios varied from 0.003% to 11% (Yan et al., 2003). Although many studies have investigated the exchange of NO_x between various agricultural fields and the atmosphere (Akiyama and Tsuruta, 2002; Stohl et al., 1996; Veldkamp and Keller, 1997; Zheng et al., 2003a,b; Fang and Mu, 2006, 2007; Scheer et al., 2009; Yu et al., 2008), the available data are still limited to accurately estimate NO emissions from agricultural fields. In the empirical model of Yienger and Levy (1995), 2.5% of the fertilizer N applied to soil was assumed to be emitted as NO (based on the arithmetic mean of eight reports). Veldkamp and Keller (1997) arrived at a value of 0.5% by regressing six field-scale studies with duration of at least one complete growing season and with a non-legume as the

principle crop. Yan et al. (2003) recently estimated the fertilizer-induced NO emission ratio from soils by using a statistical distribution model, a value of 0.71% was derived from a Weibull distribution based on 48 data points from 14 studies, and pointed out that more measurements, especially on paddy fields, were needed.

The Yangtze Delta is the most developed economic region in China, and environmental pollutions in this area have been aroused great attentions in recent years, especially for eutrophication, soil acidification and photochemical smog etc. which are closely relating to local agriculture activities. The production of grain from the Yangtze Delta accounts for large proportion to the total production in China, for example, winter wheat production represented 20% of Chinese total wheat harvest and 5% of Chinese entire grain production in 1990 (Colby et al., 1992). As the important precursors of acid rain and ozone, NO_x emissions from agricultural fields in this region have been investigated in recent years by several investigators (Fang and Mu, 2006, 2007; Fang et al., 2006; Zheng et al., 2003a,b). There are also two reports about NO emission from croplands in North China Plain and in the Pearl River Delta (Li and Wang, 2007; Walsh, 2001). But these measurements were only investigated during one complete growing season (the non-waterlogged period, November–June). To our knowledge, there are still no data available for paddy fields in China.

The results of our previous investigations indicated that NO emission rates from the vegetable fields were comparable to that of cereal fields in this region and strongly depended on cultivation

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manners and vegetable species. To better understand the role of NO_x emitted from the agricultural fields in this region on local environment, NO_x emissions from various kinds of fields during different growing seasons are still needed.

In this study, we report our field measurements of NO_x fluxes from a typical Chinese rice–wheat rotation field during a complete rice growing season and from three kinds of vegetable lands (celery, cowpea and maize) during the summer time. The total emissions of NO_x in this region during the investigating period were also estimated based on the measured data.

2. Experimental

2.1. Sampling site

The location of the sampling site was in Shuangqiao farm ($30^\circ 50' \text{N}$, $120^\circ 42' \text{E}$), Zhejiang province, China. The investigated crop lands in this study were identical to our previous studies, and the characters and textures of the soil were described in our previous work (Fang and Mu, 2006, 2007; Fang et al., 2006). The rice field was divided into two plots, one was conventionally fertilized (RF), and the other had no fertilizer input (RN). The vegetable field was divided into four plots, and was cultivated as follows:

1. Unfertilized plot (conventionally tilled but didn't cultivate any seeds, VN plot).
2. Celery (CE)
3. Maize (MA)
4. Cowpea (CP)

The areas for the rice field and the vegetable field were 667 m^2 , respectively. These fields have been conventionally cultivated with corn or vegetables for more than 10 years. Each plot was separated from others by four layers of plastic film which were inserted into the soil about 1 m depth to prevent transfers among the plots. The rice was transplanted on July 6, 2004. Compound fertilizer (300 kg ha^{-1} , N: P_2O_5 : K_2O 20:10:10%) was applied as basal fertilizer to the RF plot. On July 15, 2004 and August 30, urea (69 and $51.7 \text{ kg N ha}^{-1}$, respectively) was side-dressed to the RF plot. The rice was harvested on October 30. The measuring days for vegetable lands were conducted from June 6 to August 22, 2006. The celery and cowpea were seeded on May 10, 2006, and the fertilizer (compound fertilizer, 600 kg ha^{-1} , N: P_2O_5 : K_2O 15:15:15%) and seeds were broadcasted for celery and planted in rows for cowpea. The maize was cultivated on June 10, 2006. Compound fertilizer (225 kg ha^{-1} , N: P_2O_5 : K_2O 15:15:15%) was used as the basal fertilizer. When cultivating, the maize seeds and the compound fertilizer were covered by soil to form ridges distributed in rows with a distance of about 20 cm. According to the cultivation habit of local farmer, the mixture of swine excrement and urine was side-dressed to the CE plot on June 10 (67 t ha^{-1} , ca. 5.6 kg N ha^{-1}), June 21 (134 t ha^{-1} , ca. $11.2 \text{ kg N ha}^{-1}$) and July 4 (67 t ha^{-1} , ca. 5.6 kg N ha^{-1}), respectively. The same mixture was applied to the CP plot on June 10 (67 t ha^{-1} , ca. 5.6 kg N ha^{-1}) and to MA plot on July 4 (134 t ha^{-1} , ca. $11.2 \text{ kg N ha}^{-1}$). Celery and cowpea were harvested on July 25, and the maize was harvested on August 12, 2006. To prepare for the next cultivation, the VN and MA plots were tilled on August 12. All of the practices to the fields were strictly according to the local cultivation habits.

2.2. Method and analysis

NO_x fluxes from the rice field were measured with dynamic chamber method (Fang et al., 2006). Four identical dynamic

chambers (Diameter: 200 mm, Height: 850 mm) were simultaneously applied to cover a piece of Teflon film (reference), RN and RF plots, respectively. The NO_x fluxes were calculated from the concentrations difference in the outlets between the sample chambers and the reference chamber. The RF plot had a duplicate.

The NO_x fluxes from vegetable lands were measured by static chamber method. The Plexiglas chambers (diameter 30 cm, height 20 cm) were applied to cover the pedestals (diameter 30 cm, height 30 cm) which were inserted into soil with a depth of 5 cm during all the experimental days. Each chamber and pedestal was sealed by a silicon plastic ring. A plastic fan fixed on the top of the chamber was used to mix the air in it. NO_x concentrations were analyzed by a chemiluminescent NO – NO_2 – NO_x analyzer (Thermo Electron, model 42i). The detail method was described in Fang and Mu (2007). The NO_x fluxes from vegetable fields were calculated from the linearity slope of NO_x concentration versus time (in 14 min) after chamber covering. Typical linearity correlations coefficients (r) of NO concentration versus time exceeded 0.99. There were three replications in each plot.

Soil temperature was measured by a mercury thermometer inserted 2 cm into the soil. Soil samples were taken from the upper 10-cm layer and the mineral N was extracted with 100 mL of 2 M KCL solution. Water samples were collected from the surface water of the rice field. Concentrations of NO_3^- and NH_4^+ were determined by colorimetric analysis (APHA, 1976).

The average sampling frequency for the rice plots was about once a day between 9:00 and 14:00, and about twice a day (8:00–9:00; 14:00–15:00) for vegetable plots except for the period of July 26 to August 10, 2006 due to the malfunction of the instrument. NO_x fluxes from the duplicates in each plot had similar trend during the whole measuring days. The relative standard deviations (RSD) for the plots were generally more than 50%. Considering the differences from the duplicates in each plot, the average fluxes were used in the following discussions.

3. Results and discussions

3.1. NO fluxes

NO fluxes from the paddy field during the whole growing season were shown in Fig. 1a. The average NO fluxes ($n = 122$) from the RF and RN were 0.8 (Range from -2.8 to 5.9) and 4.1 (Range from -4 to 15.7) $\text{ng N m}^{-2} \text{ s}^{-1}$, respectively. With the exception of two estimations (Wang et al., 2005; Davidson and Kingerlee, 1997), to our knowledge, there is still no data available for direct field measurement of NO flux from Chinese paddy field. The value of RF plot was lower than the estimated value ($6.57 \text{ ng N m}^{-2} \text{ s}^{-1}$) for Chinese rice field in July of 1999 (Wang et al., 2005), and was much larger than the value ($0.04 \text{ ng N m}^{-2} \text{ s}^{-1}$) estimated by Davidson and Kingerlee (1997). As shown in Fig. 1a, NO fluxes from RF plot were much larger at late growing period (especially after 15 September when the rice field was drained) than at early stage, although fertilizers were mainly applied to the field at the early stage of the rice growing period.

It was commonly realized that NO and N_2O emission from agricultural lands were mainly from the process of nitrification and denitrification (Bremner, 1997; Johansson and Gallbally, 1984). As the rice field was waterlogged during the main early growing period, the process of nitrification might be greatly hindered for the revolution of NO in the soil or water, for example, no obvious linearity correlations were found between the fluxes and mineral N contents in the soil or water of the rice field (Fig. 2). The pathways of NO emission from the rice field might through the rice plants or the soil/water interface. If NO emission came from the soil/water surface, there would be negative correlations between

Fig. 1. The long term variations of NO fluxes from rice plots and vegetable plots. Arrow 1 indicates the basal compound fertilizer to RF. Arrow 2, 3 indicated the side-dress of urea on July 15 and August 30, 2004. Arrow 4 indicates the application of the liquid mixture of swine excrement and urine to CE and CP on June 10, 2006. Arrow 5 indicates the liquid mixture applied to CE on June 21, 2006, and arrow 6 indicates the liquid mixture applied to CE and MA on July 4, 2006.

NO fluxes and the ambient concentrations. However, their correlation coefficient was less than 0.32 ($P < 0.02$, $n = 53$). Yu et al. (1997) found that more than 80% of the N₂O emission from paddy soil was through the rice plants when the paddy soils were flooded. So we proposed that the main pathway of NO emission during waterlogged period might be also through the rice plants rather than soil/water surface. Nitrification might be the dominant pathway for NO revolution in the soil during the late growing stages when the rice field was non-waterlogged. NO produced by

nitrification at surface of the soil under this condition could easily escape from the soil to the atmosphere, and resulted in higher NO emission rates.

NO fluxes from the vegetable lands in 2006 (Fig. 1b) ranged from -2.0 to $267 \text{ ng N m}^{-2} \text{ s}^{-1}$. On the contrary to the rice field, larger NO emission mainly focused on the early growing stage of the vegetables, especially after fertilizer application. The average NO fluxes during the measuring time were 11 (VN), 30.8 (CE), 54 (MA) and $32.2 \text{ ng N m}^{-2} \text{ s}^{-1}$ (CP, $n = 43$), respectively. It's evident that NO

Fig. 2. Mineral N contents (NH₄⁺, NO₃⁻) variations in the soil and water of the rice field.

emission intensity from these vegetable fields was much larger than that from rice field. Considering the large cultivated area of vegetable (one fifth of the total crop land area) in the Yangtze Delta, the vegetable fields during the summer–autumn time might act as more important sources of atmospheric NO than the rice field.

The values of NO flux from CE and CP plots during the summer time were very close to that from the potato lands, but significant higher than those from cabbage and soybean fields investigated during the spring–summer time in 2005 and 2006 by our previous studies (Fang and Mu, 2006, 2007). The flux from maize field was much higher than other croplands we investigated previously as well as in this study, but still within the range of the reported values from various temperate and tropical fertilized upland arable fields in China (Table 1).

It should be noted that the liquid mixture of swine excrement and urine application could immediately stimulate NO emission. The contributions of the liquid mixture application to the total NO emission flux for each vegetable lands during the whole investigation period were about 21.8%, 9.2% and 31.5%, respectively for the CP, MA and CE plots. As the liquid mixture of animal or human excrement and urine was widely used as vegetable fertilizer by Chinese farmers, and the contribution of the liquid mixture on NO emissions should be considered.

3.2. Factors affecting NO flux

It was widely realized that nitrogen fertilizer application can greatly stimulate soil biogenic emission of NO (Veldkamp and Keller, 1997; Liu et al., 2005; Li and Wang, 2007; Fang and Mu, 2006, 2007). Further evidence for the influence of fertilizer on NO emission can be found in this study as shown in Fig. 1a (after the fertilizer application to the rice field on August 30, 2004) and Fig. 1b. It should be mentioned that NO emission characters were strongly depended on the fertilizer type (McTaggart et al., 2002), for example, NO fluxes increased greatly and lasted for more than 20 days after the basal fertilizer was applied to the maize field, while the increase of NO fluxes just lasted for about one day after the liquid mixture of swine excrement and urine application to the CE and MA plots (Fig. 1 b) on June 21 and July 4, 2006. Our previous study also found that it took about 26 days for NO flux increasing from 20.8 to 127.3 ng N m⁻² s⁻¹ (108 kg N ha⁻¹) after the compound fertilizer application to the same region (Fang and Mu, 2007). In addition to the minor N input by the liquid mixture, the increase of soil moisture by the liquid mixture might also contribute to NO emission, because the soil moisture of the vegetable lands was relatively low (less than 30%) at that time. Akiyama et al. (2004)

pointed out that the optimal water content for NO evolution in the soil was 42–58% (WFPS).

Without considering the influence of the basal fertilizer (compound fertilizer, 600 kg ha⁻¹, N:P₂O₅:K₂O 15:15:15%, was applied to CE and CP plots about one month before flux measurements) on NO flux measurements for CE and CP plots, the fertilizer rates for CE, CP and MA plots were 28, 5.6 and 45 kg N ha⁻¹, respectively. The extremely high NO flux from the MA plot compared with the other plots might be partially due to the high fertilizer rate. Compared with the CE plot, although the fertilizer rate for CP plot was much less than the CE plot, NO flux from CP plot was close to that from CE plot, further indicating NO flux from vegetable lands strongly depended on species, especially for leguminous crops which can transfer N from the atmosphere to the soil.

Several studies reported that the soil emitted NO was strongly depended on the soil surface temperature (Williams et al., 1992; Zheng et al., 2003b; Wang et al., 2005; Fang and Mu, 2006). However, in this study, neither NO fluxes from the rice field nor from the vegetable fields exhibited exponential dependence on the soil temperature ($R = 0.04$ for rice field, and $R < 0.3$ for vegetable plots), although the soil temperature varied in a large range (from 17 to 34 °C) during the investigation period. No apparent correlation was also found between NO fluxes and soil temperature by Li and Wang (2007) who conducted measurements from a typical vegetable field in the Pearl River Delta. This was possibly because that the soil temperature was generally above the optimum level for nitrification and denitrification (25 °C) during the most investigation time, which inhibited the microbial activities.

Tillage has been recognized as an important factor affecting NO fluxes (Civerolo and Dickerson, 1998; Yamulki and Jarvis, 2002; Liu et al., 2005; Fang and Mu, 2006; Li and Wang, 2007). Our previous study (Fang and Mu, 2006) found that tillage caused four times immediately increase of NO emission relative to that before tillage. In this study, the impact of tillage on NO emission was also observed, for example, about five times increase of NO emission (from 2.9 to 15.2 ng N m⁻² s⁻¹) was found for the CE plot after the celery harvest with tillage on July 25, 2006. Although the cowpea was harvested at same time as the celery, no such significant variation of NO emission was observed because the cowpea was just cut down the stem without tillage. The increase of NO fluxes from the VN and MA plots was also observed after the crops in these plots were harvested with tillage on August 12.

The difference of NO fluxes among the three investigated vegetable lands (as shown in Fig. 1b), to large extent, might be due to the soil coverage rates by the canopies of different vegetables. The soil of the CE plot had been fully covered by the celery leaves during most of the investigation time, while for CP and MA plots,

Table 1
Reported values of NO emissions from various temperate and tropical fertilized upland arable fields in China.

Location	Crop/treatment	Sample period	Fertilizer type	N rates	Flux ng N m ⁻² s ⁻¹	NO–N lost rate %	Reference
Guangzhou, China	Flowering Chinese cabbage	3rd Sep.–Oct.	Urea + human excreta		47.5	2.4	Li and Wang (2007)
Jiangsu, China	Winter-wheat	Nov.–Dec., 1996 Jan.–Feb. 1997 Mar.–Jun., 1997	Organic manure + synthetic fertilizer	191 kg N ha ⁻¹	9.9 ± 3.4 –1.6 ± 1.6 38.6 ± 12.6	1.75	Zheng et al. (2003a)
Jiaxing, China	Cabbage Potato	Mar.–Jun., 2005	Compound fertilizer Compound fertilizer + dunghill	45 kg N ha ⁻¹ 45 kg N ha ⁻¹	11.5 34.2	0.6 3.6	Fang and Mu (2006)
Jiaxing, China	Paddy rice	4th Jul.–2nd Nov., 2004	Compound fertilizer + urea	180.7 kg N ha ⁻¹	4.1	0.2	This study
	Celery	6th Jun.–22nd Aug., 2006	Compound fertilizer + swine excrement + urine	106.8 kg N ha ⁻¹ 106.8 kg N ha ⁻¹ 44.95 kg N ha ⁻¹	30.8 54 32.2	2.6 3.5 14.2	
	Maze						
	Cowpea

Fig. 3. The long term variations of NO_2 fluxes from the rice field in 2004 and vegetable lands in 2006.

the soil coverage rates by the two crops were much less. The extremely low value of NO flux (especially during the earlier investigation period) from the CE plot compared with the other plots might be ascribed to its canopy impact. To separate the influence of fertilizer, the canopy influence could be better illustrated by comparing the NO fluxes between CE and CP plots, because the same amount of fertilizers were simultaneously applied to the two plots before June 21, 2006. It should be also mentioned that the flux measurements for CP and MA plots were only conducted on the soils, because the two crops were too high to be contained in the flux chambers.

3.3. NO_2 fluxes

The long term variations of NO_2 fluxes from the rice field and vegetable lands were illustrated in Fig. 3. The average values during the two measurement periods were listed in Table 2. In general, the rice field acted as a small sink for atmospheric NO_2 , while the vegetable lands acted as weak sources. For vegetable lands, the upward NO_2 fluxes might be ascribed to the chemical reaction (via the $\text{NO} + \text{O}_3$ reaction) in the static chamber, because O_3 concentration was extremely high during the summer daytime (generally above 100 ppbv) in this area. The linearity correlation between the average NO fluxes and the average NO_2 fluxes from the four vegetable lands (Fig. 4) might be a circumstantial evidence. Walton et al. (1997) observed a similar upward flux of NO_2 above a canopy of orchard at low ambient NO_2 concentrations. They thought that the

upward flux of NO_2 was due to the below canopy chemical production of NO_2 rather than plant physiological effect.

There were significant linearity correlations between NO_2 fluxes and the atmospheric concentrations for the rice plots. The correlation coefficients (R) were -0.65 ($P < 0.001$, $n = 122$) and -0.9 ($P < 0.001$, $n = 122$, Fig. 5) for RN and RF plots, respectively, indicating that the air concentration was the key factor affecting NO_2 flux from the rice field. The compensation point for RF plot could be calculated from the linearity regression to be about $2.84 \mu\text{g m}^{-3}$ (1.38 ppbv), which was lower than that (4 ppbv) for a canopy of orchard reported by Walton et al. (1997). The average NO_2 deposition velocities during the measuring days were 0.17 and 0.67 mm s^{-1} for RN and RF, respectively. The significant difference for the deposition velocities between the two plots indicated that the rice growing status might play important role on absorbing atmospheric NO_2 . For the fertilizer plot (RF), the plants flourished with larger biomass (dominated by the leaves) than those in the unfertilized plot (RN) during the main rice-growing period, and hence induced greater deposition velocities. The deposition

Table 2
The range and the average value of NO_2 fluxes.

Sample	Range ($\text{ng N m}^{-2} \text{ s}^{-1}$)	Average ($\text{ng N m}^{-2} \text{ s}^{-1}$)	Days
RN	-8.5–7	-0.78	122
RF	-10.1–9.9	-2.12	122
VN	-3.4–8.5	0.06	43
CE	-2–7.7	0.68	43
MA	-3.1–5.6	1.33	43
CP	-2.3–13.5	0.5	43

Fig. 4. The relationship between average NO fluxes and NO_2 fluxes from vegetable lands.

Fig. 5. The linearity correlations between NO_2 fluxes of rice plots and ambient concentrations.

velocity of the rice field (RF) was three times greater than the value (0.2 mm s^{-1}) for the winter wheat field in our previous study (Fang et al., 2006). Hereid and Monson (2001) found that NO_2 deposition velocity was dependent on incident photosynthetic photon flux density (PPFD; 400–700 nm), that is, plant physiological factors play important roles for assimilating NO_2 . Therefore, different plants may assimilate NO_2 at different rates due to their different physiological characters, for example, Hereid and Monson (2001) found a deposition velocity of $1.2 \pm 0.1 \text{ mm s}^{-1}$ for corn leaves while Walton et al. (1997) got a much greater value of $2\text{--}6 \text{ mm s}^{-1}$ for a fruit orchard field.

For the vegetable fields, no obvious correlations between NO_2 fluxes and the ambient concentration were found in this study. NO_2 flux from the vegetable lands might be result from the assimilation by the vegetables and the chemical conversion (via the $\text{NO} + \text{O}_3$ reaction) in the static chamber, the former case was governed by the ambient NO_2 concentration and the later case is dominated by the concentrations of NO and O_3 in the chamber. As the later case dominated in the chamber, especially during summer when high concentration of O_3 existed in the ambient air, the correlation between NO_2 fluxes and the ambient concentration must be masked.

3.4. Fertilizer lost rates

The fertilizer-induced emission ratio of NO , which was defined as the ratio of the difference between NO emissions from fertilized and unfertilized plots to the amount of fertilizer N applied, was calculated and listed in Table 3. The $\text{NO}\text{--N}$ lost rate (0.2%) from the RF plot was lower than the value (0.69%) reported by Tsuruta (1995). It was possibly because that the N fertilizer application rate (180 kg N ha^{-1}) in this study was lower than the study (400 kg N ha^{-1}) of Tsuruta. The fertilizer lost rates for the celery and

maize lands investigated by this study were in the range of 0.003–11% for different uplands reviewed by Yan et al. (2003). The high $\text{NO}\text{--N}$ lost rate for cowpea field was close to the value (11%) conducted by Shepherd et al. (1991) on a bean field in Canada. Since the cowpea and bean were all leguminous crops which can transfer N from the atmosphere to the soil, NO emission might partly be from the fixed N and accordingly the fertilization loss rates be exaggerated. In addition, there was no observation data during the period from the celery and cowpea cultivation on May 10–June 6, 2006, and the basal fertilizer applied to the fields was simply assumed to be consumed entirely during this period for calculating the fertilizer-induced emission ratio of NO . Thus, the fertilization rates for these two fields were only considered as the upper limits.

3.5. Total emission of NO from agricultural lands

Generally, total emission of NO from a district was estimated from the fertilizer lost rate multiplying by the total amount of N fertilizer applied (Yan et al., 2003). However, it seemed to be hard to do so because there were few reports of accurate total amount of N fertilizer applied to the vegetable lands and the rice field in the Yangtze China. Therefore, the total NO emission from the investigated fields in the Yangtze Delta was calculated from the average NO emission rate multiplying by the total cultivated area. It has been reported that the rice field area was $95,217 \text{ km}^2$ and the vegetable lands area was $58,136 \text{ km}^2$ (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong provinces, from China year book, 2005). Considering the large proportions of cultivated area for the three kinds of vegetables, the average values of NO fluxes from CE, MA and PO plots were adopted as the average emission intensity from the vegetable lands. The total emissions from this place were calculated to be about 4.1 Gg N for rice fields and 8.4 Gg N for vegetable lands during the measuring time. The NO emission from rice fields in this area accounts for more than 50% of the total emission from the whole Chinese rice field in July (7.8 Gg N) estimated by Wang et al. (2005). The total emission of NO from vegetable field was similar to that (9.1 Gg N) during the March–June time in our previous study (Fang and Mu, 2006) in 2005.

4. Conclusions

The present study first presented NO_x flux from a paddy field in the Yangtze Delta. The average NO flux from the paddy field was $4.1 \text{ ng N m}^{-2} \text{ s}^{-1}$, which was about 37.8% lower than the estimated

Table 3
Total emissions of NO and the fertilizer-induced lost rates.

Sample	Average flux ($\text{ng N m}^{-2} \text{ s}^{-1}$)	Days	Total emissions Kg N ha^{-1}	Fertilizer-induced NO loss
RN	0.8	122	0.084	–
RF	4.1	122	0.43	0.2%
VN	11	43	0.41	–
CE	30.8	43	1.14	2.6%
MA	54	43	2.0	3.5%
CP	32.2	43	1.2	14.2%

value by Wang et al. (2005). NO fluxes from the investigated vegetable lands were about a factor of 7.8–13 higher than that from the paddy field. The total emissions of NO from paddy field and vegetable lands in the Yangtze Delta during summer–autumn were calculated as about 4.1 Gg N and 8.4 Gg N, respectively. It's evident that the vegetable land acts as a more important source than the paddy field in this area. Several influencing factors for NO emission from the investigated fields were further recognized and discussed in this study. In addition to fertilizer application, tillage and the canopy of vegetables also played important roles on NO emission. Vegetables with high density have much less NO emission potential than those with low density, and should be advocated for reducing NO emission from agricultural activities. The liquid mixture of animal or human excrement and urine was widely used as vegetable fertilizer by Chinese farmers, and the contribution of the liquid mixture on NO emissions accounted for more than 9% of the total NO emission from the three vegetable lands.

In general, the rice field acted as a sink while the vegetable lands acted as a small source for atmospheric NO₂. Compared with NO emission from the rice field, the sink strength of NO₂ were significant, and should be considered for NO_x budget from the paddy field. As for the vegetable lands, NO₂ emission strength only accounts for less than 2.5% of the NO emission rates, and hence can be neglected for NO_x budget.

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