NO and N₂O emissions from agricultural fields in the North China Plain: Origination and mitigation

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HIGHLIGHTS

- Nitrification mainly contributes to the NO and N₂O emissions from soils in the NCP.
- Contribution of denitrification to N₂O emission from the field depends on time.
- Propose the effective control measures for mitigating NO and N₂O emissions.

GRAPHICAL ABSTRACT

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ABSTRACT

Agricultural soil has been recognized as a major source of atmospheric NO and N₂O emissions which have important impacts on regional and global environments. Here we comparably investigated the effects of ammonium, nitrate fertilizers and nitrification inhibitor dicyandiamide (DCD) addition on NO and N₂O emissions from the agricultural soil in the North China Plain (NCP). Compared with the ammonium fertilizer application, the reductions of NO emissions caused by nitrate fertilizer and DCD addition were 100% and 93%, and of N₂O emissions were 54% and 74%, respectively. Remarkable reductions of NO and N₂O emissions were also observed from five different agricultural soils in the NCP by replacing ammonium with nitrate fertilizer, indicating that nitrification is the predominant process for the emissions of NO and N₂O from the soils in the vast area of NCP. NO emission peaks were found to be several days later than N₂O peaks after the application of ammonium fertilizer and flooding irrigation, implying that most of NO initially produced via nitrification process might be fast reduced to N₂O under the high soil moisture condition. Interestingly, the relative contribution of denitrification to N₂O emission showed obviously time-dependent, e.g., evident N₂O emission caused by the application of nitrate was only observed after the basal fertilization for the maize and the topdressing for the wheat. Replacing ammonium with nitrate fertilizer and mixing with the nitrification inhibitor are verified to be effective measures for mitigating NO and N₂O emissions from arable soils in the NCP.

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1. Introduction

NO is a relevant precursor of atmospheric photo-oxidants and notably contributes to troposphere ozone and acid deposition (Crutzen, 1979). N₂O, one of the important greenhouse gases, participates in the depletion of stratospheric ozone (Crutzen, 1970; Cicerone, 1987). Agricultural soil has been considered as the single largest source of anthropogenic N₂O emission (Del Grosso et al., 2006), contributing 0.11–6.3 Tg N year⁻¹ (Mosier et al., 1998; Bouwman et al., 2002) to the global atmospheric N₂O budget. Meanwhile, the NO emission was estimated in the range of 8.9–20 Tg N year⁻¹ from global soil (Davidson and Kinglerlee, 1997; Denman et al., 2007).

The microbial nitrification and denitrification are two key processes in regulating NO and N₂O emissions from agricultural soils (Davidson, 1991; Firestone and Davidson, 1989). Simply, nitrification is the oxidation of NH₄⁺ to NO₃⁻ by nitrifiers while denitrification is the reduction of NO₃⁻ to NO₂⁻ and further to NO, N₂O and N₂ by denitrifiers (Williams et al., 1998). It is widely recognized that denitrification of NO₃⁻ is the main process for N₂O emission when the soil water-filled pore space (WFPS) is beyond 60% (anaerobic soil) (Firestone and Davidson, 1989; Davidson, 1991; Bateman and Baggs, 2005; Liu et al., 2007). Although NO is an obligatory intermediate of denitrification, NO emission from anaerobic soil can't be observed due to its fast reduction or slow diffusion under the anaerobic condition (Russow et al., 2008). Both NO and N₂O can be produced as by-products in nitrification process (Remde and Conrad, 1990). Many lab and field experiments suggest that NO released from soils is mainly produced through the nitrification of NH₄⁺ while denitrification is the major source of N₂O under most situations (Davidson et al., 1993; Hutchinson et al., 1993; Parsons and Keller, 1995; Skiba et al., 1997; Gödde and Conrad, 2000; Dobbie and Smith, 2001; Azam et al., 2002; Russow et al., 2008; Vilain et al., 2014). Nevertheless, few studies also reported that N₂O emission was mainly ascribed to nitrification process from the agricultural soil in the North China Plain (NCP) (Ju et al., 2011; Cui et al., 2012). Based on the molar ratio of NO to N₂O, our previous study also revealed that

nitrification was probably the dominant process for both NO and N₂O emissions from a maize field in the NCP (Zhang et al., 2011). Because nitrification and denitrification can occur simultaneously in the same soil aggregates, it is still a great challenge to distinguish their relative contributions of the both microbial processes to N₂O emission (Arah, 1997; Butterbach-Bahl et al., 2013).

Nitrogen fertilizer application has been recognized as the key factor for increasing NO and N₂O emissions from agricultural field, because it provides substrates for driving soil nitrification and denitrification processes. Reducing total N input has been verified to be an effective measure for mitigating N₂O emission from the agricultural field in the NCP (Ding et al., 2007; Ju et al., 2011; Shi et al., 2013; Yan et al., 2013). However, this strategy is not practical, because farmers usually prefer to use high fertilization rate for increasing crop yield. Other optional measures for mitigating N₂O emission were also investigated in the NCP, such as applying manure (Meng et al., 2005; Cai et al., 2013; Ding et al., 2013; Hu et al., 2013) and straw (Zhang et al., 2011; Hu et al., 2013), adding nitrification inhibitors and slow release fertilizer (Ding et al., 2010, 2015; Ju et al., 2011; Shi et al., 2013) and applying different kinds of nitrogen fertilizers (NH₄⁺-N and NO₃⁻-N fertilizers) (Ju et al., 2011; Ding et al., 2015). Among these control measures, only the application of nitrification inhibitors and nitrate fertilizer are found to be effective (Ding et al., 2010, 2015; Ju et al., 2011). However, the few studies on the reduction of N₂O emission only conducted in maize or wheat growing season of one agricultural field, and more investigations in the vast area of NCP are still necessary to verify the effect of the aforementioned control measures. To date, little information is available about the mitigation of NO emission from the agricultural field in the NCP.

In this study, field comparison experiments were conducted to measure NO and N₂O emissions from a maize–wheat rotation field in the NCP with the applications of ammonium, nitrate fertilizers and DCD addition. To verify if the behavior of NO and N₂O emissions from the vast area of NCP is similar, the NO and N₂O emissions were comparably investigated from five different agricultural soils in the NCP with application of ammonium and nitrate fertilizers after incubation in the

Fig. 1. Location of the North China Plain (NCP) in China's territory and the five different sampling locations in the NCP (marked with five-pointed stars). Red line is the boundary of the NCP.

Table 1
Soil properties from five agriculture fields in the NCP.

Location	pH H ₂ O	Bulk density Mg m ⁻³	Organic C g kg ⁻¹	Total N g kg ⁻¹	NH ₄ ⁺ -N mg kg ⁻¹	NO ₃ ⁻ -N mg kg ⁻¹	Sand %	Silt %	Clay %
Fengqiu	8.39	1.23	8.06	0.969	4.17	13.6	45	33	22
Yucheng	7.83	1.13	9.16	1.37	3.68	99.2	13	63	24
Luancheng	7.75	1.03	12.3	1.54	4.50	46.8	19	57	24
Beijing	7.86	1.01	9.34	1.25	13.2	64.9	33	41	26
Wangdu	8.01	1.26	8.18	1.14	5.74	37.5	25	50	25

investigation field. We hypothesized that the majority of NO and N₂O released from ammonium fertilizer application by the nitrification pathway in the NCP soils. The overall objectives of this study were to reveal the origination of NO and N₂O and propose the strategies to mitigate NO and N₂O emissions from the agricultural soils in the NCP.

2. Materials and methods

2.1. Field experiment

2.1.1. N₂O and NO emissions from agricultural field in Wangdu County

The experiment was conducted in a winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) rotation field in Wangdu County, Hebei Province, China (38°71'N, 115°15'E). The detailed description of the experiment field had been described in our previous researches (Zhang et al., 2011, 2014).

Three different treatments were designed in completely randomized block: CK (no fertilization, but with the same irrigation as the other treatments), NP-NH₄⁺ (traditional fertilization,

fertilized with ammonium fertilizer), and NP-NO₃⁻ (fertilized with calcium nitrate). Each treatment had three replicates plots (6.5 × 4.5 m² each). Summer maize was sown at the end of June and harvested at the beginning of October 2010. Just after harvesting the maize, the soil was plowed with a depth of 10 cm for sowing the winter wheat that was harvested at the end of June 2011. Two fertilization events were conducted for the summer maize and winter wheat according to the local fertilization habit, respectively. In the maize season, compound fertilizers containing NH₄Cl (N: P₂O₅: K₂O = 26: 6: 8% and N: K₂O = 25: 5%) were broadcasted into the NP-NH₄⁺ treatment on 30 June and 6 August 2010, respectively, as basal fertilizer and topdressing. As for the winter wheat, a kind of compound fertilizer containing NH₄Cl (N: P₂O₅: K₂O = 18: 18: 18%) and (NH₄)₂SO₄ (N = 20%) were applied to the NP-NH₄⁺ treatment on 17 October and 13 April, respectively, as the basal fertilizer and topdressing. Correspondingly, a mixture (Ca(NO₃)₂, Ca(H₂PO₄)₂ and KCl) and Ca(NO₃)₂ were applied to the NP-NO₃⁻ treatment in the maize and wheat seasons, respectively. The input amounts of N, P and K elements in the NP-NO₃⁻ were the same with those in

Fig. 2. Variations of soil temperature (a) and WFPS (b) during the maize–wheat growing season from June 2010 to June 2011.

the NP-NH_4^+ treatment during each fertilization occasion. The fertilizer rates of the basal fertilizer and topdressing were 107 kg N ha^{-1} and 69 kg N ha^{-1} for maize, and 60 kg N ha^{-1} and 105 kg N ha^{-1} for winter wheat, respectively. Flooding irrigation was carried out immediately after each fertilization, and other two irrigation events were carried on 21 November 2010 and 23 May 2011 in the wheat season.

The N_2O and NO fluxes were separately measured by static chamber and dynamic chamber techniques, the same with our previous report (Zhang et al., 2011). The sampling time was at 9:30 (LT) for N_2O and 14:30 (LT) for NO . The field experiments were conducted from 22 June 2010 to 26 June 2011. Daily measurements for both N_2O and NO lasted for about 10 days after fertilization, and then twice a week for N_2O and occasionally for NO . The cumulative N_2O emission from each treatment was estimated by linear interpolations between sampling days.

Soil moisture was measured from 0 to 5 cm topsoil of each plot by a ring sampler (5 cm diameter $\times$ 5 cm height) and was expressed as water-filled pore space (WFPS). 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} (Linn and Doran, 1984). The soil temperatures in 5 cm depth were measured simultaneously during the sampling period.

2.1.2. Nitrification inhibitor experiment

In summer maize season, two comparative treatments were designed to further confirm the dominant sources for NO and N_2O emissions from the agricultural field: 1) $(\text{NH}_4)_2\text{SO}_4$ solution (50 ml) was evenly fertilized via spraying to three stainless steel cylinder pedestals (32 cm diameter, 15 cm height), respectively, designated as AM

treatment; 2) $(\text{NH}_4)_2\text{SO}_4$ + DCD solution (50 ml) was evenly sprayed to another three stainless steel cylinder pedestals, respectively, designated as AM + DCD treatment. The application rate of N-fertilizer was the same with previous N-fertilizer amount (107 kg N ha^{-1}) in the maize season, and the application rate of DCD was 10.7 kg ha^{-1} . The time of fertilization was on 27 September 2011. The NO and N_2O fluxes were measured by static chamber method. The chamber cap (32 cm diameter, 40 cm height) is made of stainless steel brackets wrapped with Teflon film, and one fan is fixed in the center of the chamber top to mix the air inside. A silicone tube (6 mm diameter, 1 m length) is connected with a Teflon joint at the bottom to balance the atmospheric pressure in the chamber. Sampling port is at 10 cm below of the chamber top. The sampling time was from 14:30 to 15:30 (LT) from 25 September to 2 October, 2011.

2.1.3. N_2O and NO fluxes measurement from five different agricultural fields in the NCP

To make the investigation to be representative, soil samples from five different agricultural fields (Fengqiu, Yucheng, Luancheng, Beijing and Wangdu) in the NCP (Fig. 1) were collected from the topsoil of 0–15 cm and pseudo-in-situ-fostered in the agricultural field of Wangdu County in June (maize season). The soil properties from the agricultural fields are listed in Table 1. Each soil sample was divided into two parts (each about 50 kg) and each part was put into a stainless steel cylinder pedestal (32 cm diameter, 15 cm height). Subsequently, the pedestals were inserted into the pre-dug holes with a depth of 15 cm in the experimental field. The fertilizer rates were the same with the basal fertilizer applications in the NP-NH_4^+ and the NP-NO_3^- plots during the maize season (107 kg N ha^{-1}). Irrigation ($\sim 60 \text{ mm}$) was conducted after fertilization. N_2O and NO fluxes were also measured by static chamber as mentioned above. After fostering the soils for 20 days (without crops),

Fig. 3. Variations of NO (a) and N_2O (b) fluxes from three treatments (each treatment with triplicates) during the whole year of June 2010–June 2011. Arrows show fertilizer applications. NPK, NK and NS indicate the types of fertilizer and the numbers show the N rates of fertilizers applied.

Fig. 4. N₂O (a) and NO (b) fluxes under ammonium (AM) and ammonium added with DCD (AM + DCD) treatments. Arrow shows fertilization. Vertical bars show standard deviation (n = 3).

the N₂O and NO fluxes from the soils were continuously measured for 3 days before the fertilization and fifteen days after the fertilization. The soil temperature and WFPS were in the range of 27.6–33.6 °C and 55%–77% during the investigation period, respectively.

2.2. Analysis method for N₂O and NO concentrations

N₂O concentrations were analyzed by a gas chromatograph (Model SP3410, Beijing Analytical Instrument Factory) with an electron capture detector (ECD). In order to improve the instrument sensitivity, a makeup gas (979 ppmv CO₂ in N₂) was introduced into the downstream of the analytical column. The N₂O signal increased at least 4 times after the introduction of CO₂. The variation coefficient of our method for analyzing N₂O was less than 0.31% (Zhang et al., 2013). NO concentration was analyzed by a chemiluminescent NH₃ analyzer (Thermo Electron model 17i, USA). The detailed information about the instruments and improved analytical method were elaborated previously (Zhang et al., 2011, 2013).

3. Results

3.1. N₂O and NO emissions from the agricultural field

The variations of the soil temperature and WFPS in the whole year are plotted in Fig. 2. The daily soil temperature in the NP-NH₄⁺ and NP-NO₃⁻ treatments were ranging from 15 °C to 33.7 °C in the maize season, and from -2.4 °C to 28 °C in the wheat season (Fig. 2a). The soil WFPS after fertilization and irrigation always maintained at above 70% in the NP-NH₄⁺ and NP-NO₃⁻ treatments, except for the periods of topdressing in the maize and wheat seasons, where the WFPS were between 50% and 60% (Fig. 2b).

As shown in Fig. 3a, NO emission from the NP-NO₃⁻ treatment is almost the same with that from the CK treatment. In contrast, the application of ammonium fertilizers in the NP-NH₄⁺ treatment greatly elevated NO emission. The maximum NO emissions from this treatment sharply increased from around 0 to 521 ng N m⁻² s⁻¹ on the sixth day after basal fertilizer and to 398 ng N m⁻² s⁻¹ on the third day after topdressing in the maize season. However, only one small NO peak emission (52.5 ng N m⁻² s⁻¹) was observed after the fertilizer application in the wheat season. As for N₂O, evident N₂O emission peaks could be observed after each fertilization event in the NP-NH₄⁺ treatment, whereas only relatively low N₂O peak emissions from the NP-NO₃⁻ treatment were captured on the first day after basal fertilization in the maize season (133 ng N m⁻² s⁻¹) and topdressing in the wheat season (118 ng N m⁻² s⁻¹). The emission peaks of 133 ng N m⁻² s⁻¹ after basal fertilization in the maize season and of 118 ng N m⁻² s⁻¹ after topdressing in the wheat season from the NP-NO₃⁻ treatment were 74% and 20% lower than those from the corresponding NP-NH₄⁺ treatment, respectively. The cumulative NO emissions from the CK, NP-NH₄⁺ and NP-NO₃⁻ treatments (mean ± SE) were -0.41 ± 0.06, 1.5 ± 0.7 and -0.18 ± 0.06 kg N ha⁻¹ year⁻¹, and the cumulative N₂O emissions from the three treatments were 1.3 ± 0.02, 5.0 ± 0.3 and 2.3 ± 0.08 kg N ha⁻¹ year⁻¹, respectively. Compared with the NP-NH₄⁺ treatment, the reductions of NO and N₂O emissions were 100% and 54% from the NP-NO₃⁻ treatment, respectively.

3.2. Influence of nitrification inhibitor on NO and N₂O emissions

NO and N₂O emissions from the AM treatment and AM + DCD treatment are illustrated in Fig. 4. It is evident that the incorporation of DCD significantly reduces the NO and N₂O emissions after the fertilization (T-test, P < 0.05). The mean NO and N₂O emissions were 57.8 and

Fig. 5. NO and N₂O fluxes from five different soils (Fengqiu, Yucheng, Luancheng, Beijing and Wangdu) under NH₄⁺ (a) and NO₃⁻ (b) treatments with the same amount of N input (107 kg N ha⁻¹). Solid arrows show fertilization and dot arrows show rainfall events.

26.4 ng N m⁻² s⁻¹ for the AM treatment and 4.12 and 6.98 ng N m⁻² s⁻¹ for AM + DCD treatment.

3.3. N₂O and NO emissions from five different agricultural soils in the NCP

NO and N₂O emissions from the five different soils (Fengqiu, Yucheng, Luancheng, Beijing and Wangdu) under applications of NH₄⁺ and NO₃⁻ are illustrated in Fig. 5. Similar to the aforementioned results in the field measurements during a whole crop-growing year, remarkable reductions in both NO and N₂O emissions were verified from the various soils after replacing the fertilizer of ammonium with calcium nitrate. In this in-situ field simulation experiment, the N₂O peak emissions were observed on the fourth day after NH₄⁺ fertilization in the soils of Fengqiu and Wangdu, with a close emissions of about 235 ng N m⁻² s⁻¹ (Fig. 5a). Additionally, the N₂O peak emissions occurred on the first or second day after the fertilization from the soils of Beijing, Yucheng and Luancheng, with the corresponding emissions of 361, 320 and 342 ng N m⁻² s⁻¹, respectively (Fig. 5a), which were 37–55% higher than those in Fengqiu and Wangdu. NO peak emissions also postponed several days compared with the N₂O peak emissions, which was in line with our findings in the field above. The NO peak emissions occurred on the 8th or 9th days, with the values of 817, 474, 171, 467 and 678 ng N m⁻² s⁻¹ from the soils of Fengqiu, Yucheng, Luancheng, Beijing and Wangdu, respectively. It is interesting to note that the order of N₂O emission peaks is contrary to that of NO emission peaks from the soils of Fengqiu (or Wangdu), Yucheng and Luancheng (or Beijing), that is, the higher N₂O emission peak is, the lower NO emission is. The cumulative N₂O fluxes from the NO₃⁻ treatments were 78%, 72%, 65%, 75% and 79% lower than those from the NH₄⁺ treatments in the soils of Fengqiu, Yucheng, Luancheng, Beijing and Wangdu, respectively. The cumulative NO emissions almost reduced 100% from NO₃⁻

treatment compared with those from NH₄⁺ treatment in the five different soils.

4. Discussion

The remarkable reduction in both N₂O and NO emissions from the agricultural field provides direct evidences that microbial nitrification is the dominant process for N₂O and NO emissions from the field (Zhang et al., 2011) by replacing the fertilizer of ammonium with calcium nitrate and by the addition of nitrification inhibitor (DCD). The conclusion is consistent with the finding by Cui et al. (2012), who demonstrated that the nitrification dominated the processes driving the N₂O and NO emissions because of the low available carbon in the soil of Shandong province. The results of the in-situ field simulation experiments for the five agricultural soils from different areas of the NCP further confirm that nitrification, as the dominant process for N₂O and NO emissions, is appropriate to the most agricultural fields in the NCP. The contribution proportion of denitrification to N₂O emission from the agricultural field was found to depend on the fertilization events. A small contribution occurred after topdressing for the maize and basal fertilization for the wheat, but evident contribution was evoked after basal fertilization for the maize and topdressing for the wheat. Additionally, other studies also found the important contribution of denitrification on N₂O emission from agriculture soil (Vilain et al., 2014), grassland (Ostrom et al., 2010; Vilain et al., 2014) and forest soil (Cheng et al., 2014; Morse et al., 2014; Vilain et al., 2014). In this study, because each fertilization event is accompanied with immediately irrigation, it is difficult to explain the above phenomena only based on the variation of soil anoxic condition caused by the soil moisture (Figs. 2 and 3). During the period of the maize topdressing (August), a large amount of O₂ is suspected to transport into the deeper soil by the

growing root of the maize, causing the aerobic microenvironment and thus inhibits the denitrification process. During the basal fertilization period for the wheat (October), as the agricultural soil was just after tillage, enough O_2 might exist in the soil and resulted in extremely low N_2O emission from the NP- NO_3^- treatment. Because maize is seeded without plow and the wheat has much thinner root than maize, the agricultural soil will become more anoxic during the periods of the basal fertilization for the maize and topdressing for the wheat, resulting in an evident N_2O emission from the NP- NO_3^- treatment. NO_2^- has been recognized as the key intermediate product of both nitrification and denitrification, and its further reduction will form NO followed by N_2O and N_2 (Russov et al., 2009). Several model experiments using nitrifiers revealed that N_2O emissions depended upon the competition between NO_2^- and O_2 for electrons remove from NH_4^+ during nitrification, resulting in more N_2O formation under less oxygen available (Hooper and Terry, 1979; Goreau et al., 1980; Lipschultz et al., 1981; Anderson and Levine, 1986).

NO emission from soil is ascribed to nitrification process, and the molar ratio of NO/ N_2O has been used as a useful indicator for evaluating the contribution of nitrification and denitrification to N_2O emission (Anderson and Levine, 1986; Zhang et al., 2011). However, it is found that the application of the indicator to the field measurements should be careful in our case. The NO and N_2O emissions showed different characters, e.g. evident N_2O emissions from the NP- NH_4^+ treatment were found after each fertilization, whereas NO emission is extremely low after the basal fertilization for the wheat (Fig. 3). In addition, time sequences of the NO and N_2O emission peaks were also found different, especially after the irrigation following heavy rain events (Figs. 3 and 5). The extremely low NO emission from the NP- NH_4^+ treatment after the basal fertilization for the wheat is mainly ascribed to the low soil temperature which is an important factor affecting soil nitrification and denitrification (Gödde and Conrad, 1999). Because remarkable N_2O emission from the NP- NH_4^+ treatment and extremely low N_2O emission from the NP- NO_3^- treatment occurred after the basal fertilization in the winter wheat season, the relatively low soil temperature is suspected to greatly inhibit the NO diffusion from the soil to the atmosphere, and most of NO formed by nitrification was further reduced to N_2O or N_2 .

The different time sequences of NO and N_2O emission peaks (Figs. 3 and 5) could be rationally explained by the variation of soil moisture. The agricultural soil is usually saturated with water just after irrigation, and then becomes drier with time. According to the nitrification process, NO is first produced by nitrifier denitrification of NO_2^- followed by N_2O and N_2 formation by the further reduction of NO. The evident later NO emission peaks than N_2O emission peaks from the NP- NH_4^+ treatment (Figs. 3 and 5) implied that the diffusion of NO from the soil to the atmosphere must be largely suppressed under the initially high soil moisture after the irrigation. Compared with the time gap (1–2 day) between the NO and N_2O emission peaks in the field measurements, NO emission peaks even postponed more than 5 days from the in-situ simulation soils, which was due to two consecutively strong rain events (5 mm) just after the irrigation (Fig. 5). Furthermore, the contrary order of N_2O and NO emission peaks from the five different soils (Fig. 5) indicates that a competition mechanism between the emissions of NO and N_2O . NO and N_2O emissions were found to correlate with soil bulk density, and higher N_2O peaks (or lower NO peaks) occurred with lower soil bulk density (Fig. 5 and Table 1). As it is known, there is a negative relationship between soil porosity and soil bulk density. Therefore, the higher soil porosity is, the greater soil water can be kept, the less NO emission and larger N_2O emission occur.

In brief summary, NO and N_2O emissions from the agricultural fields in the NCP are mainly from nitrification, and the effective control measures for mitigating NO and N_2O emissions from the agricultural fields can be achieved by replacing the local prevailing compound fertilizer with nitrate fertilizer or mixing the compound fertilizer with the nitrification inhibitor of dicyandiamide. Based on the direct emission factors as N_2O -N in this study (1.09% and 0.29% for NP- NH_4^+ and NP- NO_3^-

treatments, respectively) and the current fertilizer application rate of $10.77 \text{ Gg N year}^{-1}$ in the NCP (Liu et al., 2001; Ding et al., 2013), the total amount of N_2O reduction in the NCP would be $135.5 \text{ Mg year}^{-1}$ by replacing the prevailing compound fertilizers with nitrate fertilizer, which would be equal to CO_2 reduction of about $11 \text{ Gg C year}^{-1}$. Additionally, the effect of nitrifier inhibitor DCD is still needed for further field measurements under local cultivation manner. If the reduction is similar to our short time simulation experiments, the addition of DCD to the currently prevailing fertilizer will be more practical for reduction both NO and N_2O emissions from agricultural field in the NCP. The reduction of both gas emissions will make a great contribution to improving the regional and global air quality and prevent the agricultural soil from acidification.

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