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Annual nitric and nitrous oxide fluxes from Chinese subtropical plastic greenhouse and conventional vegetable cultivations

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As intensive vegetable cultivation is rapidly expanding in China and elsewhere worldwide, its environmental consequences on nitrous oxide (N_2O) and nitric oxide (NO) emissions deserve attention. We measured N_2O and NO fluxes simultaneously for a full year from Chinese subtropical vegetable fields. Clearly, both N_2O and NO emissions varied greatly in different vegetable crop seasons within a year, highlighting the importance of whole-year measurement for achieving temporally accurate annual direct emission factors. A revised "hole-in-the-pipe" model well described quantitative relationships between N_2O plus NO fluxes and soil-specific conditions. Annual background N_2O and NO emissions were 0.73–5.0 and 0.26–0.56 kg N ha^{-1} yr^{-1}, respectively, for the vegetable cultivations. The farmers' fertilization practice increased N_2O and NO emissions. Annual direct emission factors for greenhouse and conventional vegetable fields, respectively, were 1.1% and 1.9% for N_2O, and 0.36% and 0.32% for NO, indicating there is a need to consider a differentiation of emission factors for managed vegetable cultivations.

1. Introduction

It is well documented that agricultural activities have had a pronounced influence on the global nitrogen cycle which produces a great deal of nitrogenous gases including nitrous oxide (N_2O) and nitric oxide (NO) (Bouwman et al., 2002). Both N_2O and NO play important roles in regional and global changes of environment and climate, such as increases in temperature and changes in precipitation pattern and air quality (IPCC, 2013). As exchanges of N_2O and NO between the soil and the atmosphere are closely interrelated (Firestone and Davidson, 1989), it is important to investigate these two gases simultaneously so as to improve our understanding on both atmospheric chemistry and biogeochemical nitrogen cycling. Agriculture accounted for an estimated emission of 4.1 (1.7–4.8) Tg N yr^{-1} for N_2O and 3.7 Tg N yr^{-1} for NO, contributing 60% and 10% to the total global anthropogenic emissions, respectively (Ciais et al., 2013). The estimates for N_2O and NO emissions from agricultural sector are highly uncertain because of limited data availability, especially in tropical and subtropical regions (Stehfest and Bouwman, 2006). Also, the large uncertainties of these estimates are thought to result from a wide variability of field observations. For example, annual N_2O and NO emissions from agricultural fields could vary by several times or even orders of magnitude at different sites (Stehfest and Bouwman, 2006; Wang et al., 2011a). It is well recognized that N_2O and NO emissions from agricultural fields were affected by a set of environmental factors and strongly depend on cultivated species (Fang and Mu, 2007, 2009; Pang et al., 2009; Lin et al., 2010). To reduce the uncertainties for emission inventories of nitrogen-containing trace gases, therefore, year-long field measurements of N_2O and NO fluxes from different agricultural species in tropical/subtropical zone are urgently demanded improvements.

China is a major agricultural producer in the world and its vegetable harvested area accounts for 45% of the world total (Wang et al., 2011b). Since 1976, the cultivated area for vegetable crops at 3.33 M ha in China has increased to 18.22 M ha in 2006 which occupies 11.5% of all Chinese cultivated land (Zhu et al., 2011). Over this time period, plastic greenhouse vegetable cultivation, converted from cereal grain cultivation or conventional vegetable cultivation by covering open field with plastic film, was developed and expanded dramatically. By 2005, the greenhouse vegetable area has reached 2.5 M ha in China, accounting for 85% of the total greenhouse area worldwide (He et al., 2009). Vegetable cultivations are characterized by high nitrogen fertilizer inputs, intensive

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cropping productions and frequent irrigations. For instance, it is estimated that the nitrogen fertilizer inputs for intensively managed vegetable cultivations in the rapidly developing area are 3–5 times higher than those of cereal grain cultivations in China (Diao et al., 2013). Although the characteristics of vegetable fields are considered to be important sources of N_2O production (e.g., Zhu et al., 2011), there have been far fewer investigations on N_2O emission from typical vegetable cultivations than from cereal grain fields, leading to the largest uncertainties in the national N_2O inventory for Chinese croplands (Zheng et al., 2004; Liu et al., 2013). As suggested by Wang et al. (2011b), therefore, the emission factors and background emissions of N_2O from different types of vegetable cultivations should be specifically determined for accurate national N_2O inventories. Also, intensively managed vegetable field is an NO source (Li and Wang, 2007; Fang and Mu, 2007, 2009; Mei et al., 2009). So far, however, few studies have measured N_2O and NO fluxes simultaneously from Chinese vegetable cultivations (Pang et al., 2009). That is, the N_2O and NO fluxes from vegetable fields were mostly separate determination in previous studies. Furthermore, the majority of field N_2O or NO measurements were focused only in a certain individual vegetable cropping season, limiting our knowledge about full annual N_2O and NO estimates as a result of high inter-seasonal variability derived from multiple vegetable crop productions within a year (e.g., Mei et al., 2009, 2011; Min et al., 2012). Clearly, it is necessary to extend the earlier findings by integrating evaluations of the entire year estimates for N_2O and NO fluxes in different kinds of vegetable cultivations.

To meet these research needs, we launched a field campaign in which annual N_2O and NO fluxes were determined simultaneously from subtropical plastic greenhouse and conventional vegetable cultivations. The main aims of this study were to characterize and quantify annual N_2O and NO fluxes and the emission factors of applied nitrogen, and to improve understanding of the key regulatory factors on N_2O and NO emissions from vegetable fields.

2. Materials and methods

2.1. Site description and field management

Field experiments were carried out in a local farmer's vegetable farm at a suburban site (32°35′ N, 119°42′ E) of Jiangdu city, Jiangsu province, China. The region is characterized by a northern subtropical monsoon climate (exhibiting warm summers and cool winters), with mean annual precipitation of 924 mm and air temperature of 15.9 °C. In 2007–2008, one experiment was performed in a conventional open vegetable field and the other in an adjacent greenhouse vegetable field (width 6 m × length 30 m). The conventional vegetable field had approximately 20 years history of continuous vegetable cultivation following the regime of local field management. Before conventional vegetable cultivation, the field had been cultivated with rice–winter wheat or rice–oilseed rape rotation cropping system. The greenhouse type used in this study is the solar greenhouse, which was covered with polyethylene plastic film and had no supplementary lighting or heating, and this plastic greenhouse vegetable field was converted from rice–winter wheat rotation cropping system in 2006. Table 1 presents the primary soil properties of each field site.

Table 1
Primary soil properties (0–15 cm soil depth) of the plastic greenhouse and conventional vegetable fields.

Vegetable cultivations	Greenhouse	Conventional
Soil type[a]	Shajiang Hapli-Stagnic Anthrosol (Fluvisols)	Shajiang Hapli-Stagnic Anthrosol (Fluvisols)
Texture of cultivated horizon	Sandy loam	Sandy loam
Particle fraction (%)		
2–0.02 mm	57.8	57.0
0.02–0.002 mm	28.5	29.0
<0.002 mm	13.6	14.0
Bulk density ($g\ cm^{-3}$)	1.16	1.20
Total porosity (%)	54%	51%
Soil organic carbon ($g\ C\ kg^{-1}$)	20.1	15.6
Total nitrogen ($g\ N\ kg^{-1}$)	1.51	1.58
pH (H_2O)	8.0	7.9

[a] Classification of the Chinese Soil Classification System (Cooperative Research Group on Chinese Soil Taxonomy, 2001), with the classification of World Reference Base for Soil Resources 2006 (IUSS Working Group WRB, 2006, http://www.fao.org/ag/Agl/agll/wrb/doc/wrb2006final.pdf) given in the parentheses.

In each vegetable field, two fertilizer treatments were arranged in a completely randomized block design with three replications (each with a size of 3 m × 3 m). One treatment followed the local vegetable cropping regimes and farmers' fertilization practices. The other was treated as a control without fertilizer application, but additional field management practices were the same as those of fertilized treatment. Table 2 details the cultivation and fertilization management events that occurred in the studied greenhouse and conventional vegetable fields. Three vegetable crops were grown in each field over the full year experiments, including green soybean (*Glycine max*), pepper (*Capsicum annuum*) and broccoli (*Brassica oleracea*) for the plastic greenhouse field and amaranth (*Amaranthus mangostanus*), turnip (*Brassica campestris*) and garlic (*Allium sativum*) for the conventional field. All the vegetable fields were plowed before each vegetable crop was transplanted or sown. In the greenhouse vegetable systems, synthetic N fertilizers comprised compound fertilizer and urea were applied at the common rate for each vegetable crop of the fertilized plots, amounting to 705 kg N ha^{-1} over the annual scale. For the fertilized plots of conventional systems, compound fertilizer, rapeseed cake and urea were applied for each vegetable crop and totally amounted to 929 kg N ha^{-1} yr^{-1} (Table 2). According to the local practice, some water was manually supplied following vegetable seeding in the conventional cultivation in order to ensure germination; while irrigation were usually coupled with fertilizer applications in the plastic greenhouse cultivation.

2.2. Measurements of NO and N_2O fluxes

The NO and N_2O fluxes were in situ measured simultaneously from each vegetable cultivation using a static opaque chamber method (Zheng et al., 2008; Yao et al., 2009). Flux measurements were taken over the periods of 10 May 2007–6 May 2008 and 2 June 2007–25 May 2008 in the greenhouse and conventional cultivations, respectively. As the NO and N_2O fluxes exhibit a high degree of spatial variability, it is recommended that a minimum of two chambers per treatment in site scale studies (Parkin and Venterea, 2010). For the present study, therefore, three chambers per treatment were established in each experimental field which has been homogeneously and intensively cultivated with crops for a long time. That is, for each replicate plot a square stainless steel frame with a cross-sectional area of 0.25 m^2 was permanently driven into the soil to a depth of 20 cm over the entire annual vegetable cultivation. There was no difference in the planting density of vegetable between inside and outside the frame. Square chambers with a bottom area of 0.25 m^2 and a height of 50 or 100 cm depending on vegetable growth were temporarily mounted on the frames for gas flux measurements. To measure N_2O flux, five gas samples were collected from the headspace of chamber