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Impact of dicyandiamide on emissions of nitrous oxide, nitric oxide and ammonia from agricultural field in the North China Plain

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ABSTRACT

Nitrous oxide (N_2O), nitric oxide (NO) and ammonia (NH_3) emissions from an agricultural field in the North China Plain were compared for three treatments during a whole maize growing period from 26 June to 11 October, 2012. Compared with the control treatment (without fertilization, designated as CK), remarkable pulse emissions of N_2O, NO and NH_3 were observed from the normal fertilization treatment (designated as NP) just after fertilization, whereas only N_2O and NH_3 pulse emissions were evident from the nitrification inhibitor treatment (designated as ND). The reduction proportions of N_2O and NO emissions from the ND treatment compared to those from the NP treatment during the whole maize growing period were 31% and 100%, respectively. A measurable increase of NH_3 emission from the ND treatment was found with a cumulative NH_3 emission of 3.8 ± 1.2 kg N/ha, which was 1.4 times greater than that from the NP treatment (2.7 ± 0.7 kg N/ha).

Introduction

Nitrous oxide (N_2O) is an important greenhouse gas and also participates in the destruction of stratospheric ozone (Crutzen, 1970). The current atmospheric mixing ratio of N_2O is about 310 nmol/mol with a rate of increase of 0.2%–0.3% per year (Vergé et al., 2007). Nitric oxide (NO) plays a critical role in tropospheric chemistry and is the key species governing formation of tropospheric ozone (Aneja et al., 1998; Gupta et al., 2003), which is known to have adverse effects on health, vegetation and materials (Benton et al., 2000). Ammonia (NH_3), being the only alkaline gas in the air, plays an important role in neutralizing atmospheric acid components to form ammonium aerosols (Brasseur et al., 1999; Yang et al., 2010). Globally, agricultural systems are important sources of atmospheric N_2O, NO and NH_3 (Jones et al., 2005; Dawar et al., 2011). It has been estimated that approximately 35% of N_2O, 41% of NO and 18% of NH_3 originate from agricultural soils (Yienger and Levy, 1995; Kroeze et al., 1999; Bouwman et al., 2002).

N_2O and NO are byproducts of the soil microbial nitrification process, and intermediate products of the denitrification process. Due to diffusion restrictions of N_2O and NO produced by denitrification in soils, field measurements have revealed that N_2O and NO emissions from upland soils are mainly ascribed to the nitrification process (Dong et al., 2001; Wrage et al., 2001; Cai et al., 2002; Shaw et al., 2006). Dicyandiamide (DCD, $C_2H_4N_4$) has been found to inhibit nitrification since 1918, while it was widely applied as a product in agriculture after the 1970s in the USA (Huang et al., 2002). It has been well

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confirmed that DCD can delay the oxidation of NH_4^+ to NO_2^- and NO_3^- by slowing the activities of ammonia oxidizers in the nitrification process (Kelliher et al., 2008). DCD has been shown to effectively reduce N_2O emissions from pasture (Zaman et al., 2008; Cameron et al., 2014; Robinson et al., 2014), grassland (Di and Cameron, 2003; Di et al., 2010), paddy fields (Kumar et al., 2000; Li et al., 2009) and upland soil (Majumdar et al., 2002; Vallejo et al., 2005; Meijide et al., 2007). Both NO and N_2O are important byproducts of nitrification; however, only few studies (Vallejo et al., 2005; Meijide et al., 2007) have investigated the reduction effect of DCD for both N_2O and NO from agricultural fields. As mentioned above, DCD can inhibit oxidation of NH_4^+, and hence the persistence of NH_4^+ in soil with DCD application may lead to increased NH_3 volatilization (Banerjee et al., 2002; Mkhabela et al., 2006). However, the results measured by limited studies were inconsistent. For example, DCD addition is reported to stimulate NH_3 emissions in pasture (Zaman et al., 2008) and arable soil (Soares et al., 2012), while reduction of NH_3 volatilization was observed in laboratory simulations (Dendooven et al., 1998; Tao et al., 2008). Therefore, to comprehensively estimate the effect of DCD application on the regional and global atmospheric environment, further investigations on N_2O, NO and NH_3 emissions from various soils with addition of DCD are still needed.

The North China Plain (NCP), with an area of 35 million hectares, is one of the most important agricultural regions in China (Du et al., 2009). The croplands in the NCP are being treated with increasing amounts of N fertilizer, which can cause increased emissions of N_2O, NO and NH_3 (Zou et al., 2005; Zhang et al., 2011). Many studies have mainly focused on the gaseous loss of N_2O from different types of N fertilizer (Cai et al., 2002; Ding et al., 2007; Zhang et al., 2012; Wang et al., 2013), whereas there are few reports about the effect of DCD on N_2O emission from agricultural fields in this region (Ding et al., 2011; Li et al., 2013; Yan et al., 2014). To our knowledge, there is no investigation on the effects of DCD on NO and NH_3 emissions from the soils in the NCP. The aims of this study were to quantify the effect of DCD on N_2O, NO and NH_3 emissions from a maize field in the NCP.

1. Materials and methods

1.1. Experimental site and field treatments

The experimental site is located in Wangdu County (38°71′N, 115°15′E), Hebei Province, China, and belongs to a typical region of the NCP. The field soil is classified as a sandy loam soil with pH (in a 1:2.5 soil-to-water ratio) of 8.7, soil organic C of 7.71 g/kg and total N of 0.98 g/kg. In this region during the maize season, the mean temperature is about 23.4°C, and the mean rainfall is about 338 mm (accounting for about 65% of the annual rainfall), and the mean irrigation is about 800 m^3/ha.

The field experiment was conducted including three treatments: control (CK, without fertilization), compound fertilizer (NP), and DCD combined with compound fertilizer (ND). Three replicates were designed in each treatment (6.4 m × 3.5 m) for investigating emissions of N_2O, NO and NH_3. Furthermore, each treatment was separated by a 1.2 m wide zone to prevent nutrient transfer between treatments. Maize was sown on 28 June 2012 and harvested on 11 October 2012. During the summer maize season, compound fertilizer (N: P_2O_5 K_2O = 14% 16% 15%) was broadcast to the NP and ND treatments as basal fertilizer (764 kg/ha) and topdressing (493 kg/ha) on 28 June and 12 August 2012, respectively. DCD (the application rate of DCD was equal to 10% of N fertilizer) was simultaneously applied to the ND treatment during the two fertilizations. Flooding irrigation was carried out immediately after the basal fertilizer application, while the field was not irrigated after the topdressing because of a strong rain event with rainfall of 37 mm. All the above field management was carried out strictly according to the cultivation practices of local farmers.

1.2. Measurements and analysis of N_2O, NO and NH_3

Three opaque static chambers were used for investigating N_2O emission (Zhang et al., 2011). The chambers (length × width × height: 60 cm × 60 cm × 90 cm) were placed on corresponding pedestals, which were inserted into soil at about 10-cm depth during the whole maize growing period. The pedestal, made of stainless steel, has a grooved gutter around its upper rim for a water seal. The pedestals of the static chambers covered four maize plants. Four air samples were collected into polyethylene-coated aluminum bags (2L, Dalian Delin Gas Packing Co., Ltd., China) by a mini-pump (NMP 830 KNDC, KNF Technology Co., Ltd., Germany) at 10-min intervals after the chambers were enclosed (5, 15, 25 and 35 min). The daily fluxes were measured between 9:00 and 11:00 am (local time). Measurements lasted for 14 days after the application of basal fertilizer, 15 days after the topdressing and twice a week during the rest of the growing season. N_2O concentrations were analyzed by a gas chromatograph (GC) (Model SP3410, Beijing Analytical Instrument Factory, China) with an electron capture detector (ECD) (Zhang et al., 2012, 2013).

Twin dynamic chambers were designed to investigate NO and NH_3 fluxes: one with the bottom covered with Teflon film was used as reference chamber, and the other one with the bottom open was used as sample chamber. The sample chamber (inner diameter of 32 cm, and length of 80 cm) was placed on a corresponding pedestal, which was inserted into the soil at about 10-cm depth during the whole maize growing period, and covered one maize plant. Both the reference chamber and the sample chamber were simultaneously flushed by the ambient air at a rate of 15 L/min, and the concentrations of NO and NH_3 in the chambers would achieve a steady state after flushing of about 12 min, when the air samples (each of 3 L) from the reference and sample chambers were collected simultaneously into Teflon bags. The air samples were analyzed immediately by a chemiluminescent NH_3 analyzer (Model 17i, Thermo Fisher Scientific, USA) in the field laboratory. The NO and NH_3 fluxes were derived from the difference of their concentrations at the outlets between the sample chamber and the reference chamber (Zhang et al., 2011). The daily sampling time was from 14:00 to 16:00 (local time), and measurements lasted for 14 days after the application of basal fertilization and 15 days after the topdressing. During the sampling period, soil temperature at 5-cm depth and air temperature inside the chambers were simultaneously recorded.