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Ammonia volatilization and atmospheric N deposition following straw and urea application from a rice-wheat rotation in southeastern China

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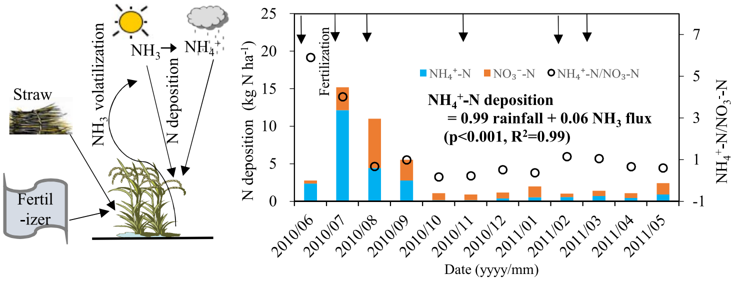
GRAPHICAL ABSTRACT



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ABSTRACT

Ammonia is a vital component of the nitrogen (N) cycle of terrestrial ecosystems in terms of volatilization and deposition. Here, a field experiment was undertaken to simultaneously investigate the effects of rice straw and urea incorporation on ammonia volatilization, atmospheric N deposition, yields and agronomic nitrogen use efficiency (NUE) under a rice-wheat system in China. The experiment involved four treatments: control (0 N, 0 straw), NS0 (250 kg N ha^{-1} $season^{-1}$, 0 straw), NS1 (250 kg N ha^{-1} $season^{-1}$, 3 t ha^{-1} yr^{-1} straw), and NS2 (250 kg N ha^{-1} $season^{-1}$, 6 t ha^{-1} yr^{-1} straw) in the rice-wheat annual rotation system. The results indicated that the NS0, NS1 and NS2 treatments emitted cumulative ammonia of 14.0%, 16.4%, and 19.2%, respectively in the rice season and 7.6%, 11.1%, and 12.3%, respectively in the wheat season among the total urea-N application. Compared to the NS0 treatment, the NS1 and NS2 treatments significantly increased the cumulative ammonia emissions by 15.5% ($p < 0.05$) and 33.5% ($p < 0.05$), respectively in the rice season and 39.9% ($p < 0.05$) and 53.1% ($p < 0.05$), respectively in the wheat season. There was no significant difference between the NS2 and NS1 treatments during the wheat season. The amount of NH_4^+-N deposition accounted for 56.1% of the total inorganic N deposition during the whole rice-wheat system. The bulk NH_4^+-N deposition during the period of fertilization contributed 73.9% and 5.7% to the total NH_4^+-N deposition in the rice and wheat season, respectively. Overall, straw incorporation increased ammonia volatilization, not affecting the crop grain yield or NUE. The seasonal variation in NH_4^+-N bulk deposition was closely related to N fertilizer application.

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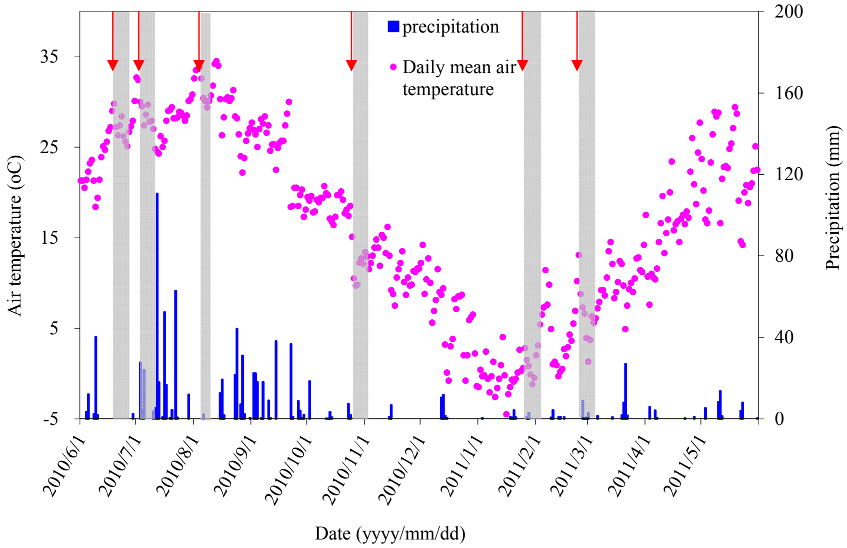

Fig. 1. Average air temperature and daily precipitation during the rice-wheat system from June 2010 to May 2011 in the experimental area. The red arrows represent basal fertilizer, first top-dressing and second top-dressing in the rice and wheat seasons. The shadow area represents the period of measuring NH_3 volatilization. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

1. Introduction

In most agricultural ecosystems, nitrogen (N) is an essential nutrient for crop growth. Large inputs of synthetic N fertilizer have induced various problems, such as rain acidification (Ju et al., 2009; Sundarambal et al., 2010) and large amounts of N losses through ammonia (NH_3) volatilization (Bouwman et al., 2002) and nitrous oxide emissions (Sun et al., 2015; Pan et al., 2016). Previous studies have shown that NH_3 volatilization accounts for 15–40% of the applied N in paddy fields (Chien et al., 2009; Xue et al., 2014). Volatilized NH_3 plays an important role in the N cycle in terrestrial ecosystems (Krupa, 2003) and may have an effect on the global climate by altering the earth's radiation budget (Hauglustaine et al., 2014).

Straw incorporation to soil has been widely used in agricultural ecosystems all over the world (Bhattacharyya et al., 2012; Wang et al., 2015). The long-term use of straw incorporation can enhance soil quality, carbon sequestration, crop productivity and biological activity in agriculture (Blanco-Canqui and Lal, 2009; Wang et al., 2015; Xia et al., 2016). However, NH_3 volatilization fluxes might be increased by straw incorporation into the paddy fields due to the increasing $NH_4{}^+$-N concentration, pH of the floodwater and the activity of microbes (Khind and Bajwa, 1993; Xu et al., 2016, 2017). For example, Wang et al. (2012) found that straw incorporation significantly increased NH_3 volatilization from rice paddy field at the same N fertilizer levels. Xu et al. (2017) also found that the seasonal NH_3 volatilization loss increased by 54–90% under straw returning treatments. To the contrary, Tian et al. (2001) reported that straw incorporation reduced NH_3 volatilization in the wheat season while increased NH_3 emissions in the rice season compared to the treatment without straw in the wheat-rice rotation system. No consistent results have been reached on the influence of straw application on NH_3 volatilization which also depends on straw rates and soil properties.

Atmospheric bulk N deposition has been increasing significantly, with an increase of 0.41 kg N ha^{-1} yr^{-1} between 1980 and 2010 due to large inputs of synthetic N fertilizer and rapidly increasing consumption of fossil fuels in China (Liu et al., 2013). Elevated atmospheric N deposition has induced a series of environmental problems, such as rain acidification, water eutrophication (Elser et al., 2009; Guo et al., 2010). In agricultural ecosystems, atmospheric N deposition (include inorganic N and organic N) is important environmental N sources which can be used by crop directly or after transformation in the soil (He et al., 2007; Jenkinson et al., 2004). Thus, elevated atmospheric N deposition not only induces a series of environment problems, but also become an important N source in agricultural ecosystems (Ju et al., 2009).

Both NH_3 volatilization and atmospheric N deposition are intensively influenced by agronomic management, such as N fertilizer and straw incorporation (Liu et al., 2006; Pan et al., 2016; Sun et al., 2014; Wang et al., 2012; Xu et al., 2017). Many studies have investigated NH_3 volatilization from chemical N fertilizer in rice or upland fields separately (Rochette et al., 2009; Viero et al., 2014; Xu et al., 2012; Zhao et al., 2010). N deposition has also been studied separately in agricultural ecosystems (He et al., 2010; Liu et al., 2006). To our knowledge, however, few studies have simultaneously investigated the effects of chemical N fertilizer and straw incorporation on NH_3 volatilization and atmospheric N deposition from agricultural ecosystems, particularly in the whole rice-wheat system.

Therefore, the objectives of this study were as follows: 1) to observe the seasonal variation and fluxes of NH_3 volatilization as affected by N fertilizer and straw incorporation; 2) to quantify the fluxes and seasonal variation of atmospheric N bulk deposition and its relations with NH_3 volatilization; and 3) to examine the effects of straw incorporation and N fertilizer application on grain yield and agronomic N utilization efficiency (NUE).

2. Material and methods

2.1. Experimental site

A field experiment was conducted in a rice-wheat rotation in the town of Mo Ling, Nanjing, China (31°52′N, 118°50′E), from June 1st, 2010 to May 31st, 2011. The rotation of rice-wheat has been carried out for several years at this experimental site. The region belongs to a typical subtropical humid marine monsoon climate. The total precipitation and mean temperature were 915.6 mm and 16.4 °C, respectively from June 1st, 2010 to May 31st, 2011 (data from the local weather station). The physio-chemical properties of the soil in the 0–15 cm depth were as follows: pH (1:2.5, H_2O), 5.7; total K, 13.5 (g kg^{-1}); total P, 0.36 (g kg^{-1}); organic C, 14.6 (g kg^{-1}); and bulk density, 1.28 (g cm^{-3}). The daily mean air temperature and precipitation during the whole rice-wheat growing season are given in Fig. 1.

2.2. Experimental design and management

A randomized block design was conducted in triplicate for the rice and wheat crops. The area of each plot was 20 m^2 (5 m × 4 m). There were four treatments established during the rice (R) and wheat (W) season: R(W)-control (0 N, 0 straw), R(W)-NS0 (250 kg N ha^{-1} $season^{-1}$, 0 straw), R(W)-NS1 (250 kg N ha^{-1} $season^{-1}$, 3 t ha^{-1} yr^{-1}