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Ammonia emissions from paddy fields are underestimated in China☆

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ABSTRACT

Excessive nitrogen (N) fertilizers are often used in China, and a large proportion of the N can be lost as ammonia (NH_3). However, quantifying the NH_3 emission from paddy fields is always affected by large uncertainties due to different measuring methods and other factors such as climate. In this study, using a standardized method, we measured the NH_3 emissions in three typical annual rice cropping systems: single rice, double rice and rotation with other crops. The measurements were conducted for 2 years with a total of 3131 observations across China. Results showed that NH_3 emissions accounted for 17.7% (14.4–21.0%) of the N applied under current farm practice, which was 33.1% (10.6–52.6%) higher than previous estimates. Nitrogen application rate was the dominant factor influencing NH_3 emission rate, which exponentially increased with the N fertilizer rate ($p < .001$). Total NH_3 emissions from paddy fields were estimated at 1.7 Tg N yr^{-1} in 2013 in China, several times the amount of N lost through leaching or runoff. This suggests that mitigation measures for non-point source pollution from cropland should take into account not only the N lost to water, but also to air, thereby improving air quality.
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1. Introduction

China produced 208.2 million tons of rice in 2014, accounting for 28.1% of global production (FAO, 2017). However, excessive amounts of nitrogen (N) fertilizers are being used in paddy fields, with an average N fertilizer rate of over 300 kg N ha^{-1} yr^{-1} (Deng et al., 2011), and over 50% of this input N is lost to the environment through multiple pathways. Ammonia volatilization is one of the dominant pathways of N loss in paddy fields (Yan et al., 2011; Soares et al., 2012; Xu et al., 2012). NH_3 volatilization increases farmers' production costs and causes environmental degradation (Xu et al., 2015). NH_3 is a major atmospheric pollutant that plays an important role in the formation of secondary inorganic aerosols, leading to poor air quality and adverse impacts on human health (Behera et al., 2013; Gu et al., 2014). The emitted NH_3 can also return to land and surface water through deposition, resulting in soil and water acidification, eutrophication and biodiversity loss (Hellsten et al., 2008; Guo et al., 2010).

NH_3 emission is affected by a number of factors, such as fertilizer application rate (Dattamudi et al., 2016; Huang et al., 2016; Jiang et al., 2017), climate conditions (e.g. temperature, wind speed) (Fan et al., 2011; Louro et al., 2013), and soil properties (e.g. pH, soil type) (Fan et al., 2011; Zhang et al., 2013; Webb et al., 2014). Inventories of NH_3 emissions from paddy soils in China have been conducted (Zhang et al., 2011; Chen et al., 2014). However, large uncertainties exist in these inventories due to the variations in emission factors derived from different measuring methods (Hayashi et al., 2011; Zhao et al., 2012). For example, Chen et al. (2014) calculated that NH_3 lost from paddy fields accounted for

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approximately 16% of N input by compiling over 265 measurements across China, while the results derived from Zhou et al. (2016), with an even bigger dataset, showed that the average NH_3 loss accounted for only 12% of N input for paddy soils. However, the methods of measuring these NH_3 emissions were quite different, and whether the results of these measurements could be comparable for a meaningful inventory is unclear. Therefore, refining the understanding of these variations is crucial for reducing the uncertainty in NH_3 emissions from paddy fields.

We established a Nationwide NH_3 Emission Monitoring Network (NNEMN) for paddy fields in 2012–2013, and measured NH_3 emissions for 2 years continuously, by using a standardized measuring method. The network included 12 field sites, which covered three types of rice cultivation (single, double and rotation with wheat or potato or a vegetable crop) located in the main rice planting regions across China (Northeast China, Southeast China and Yangtze River Basin). The objectives of this study were to (i) quantify NH_3 loss and its uncertainties from paddy fields in different types of rice cultivation, (ii) explore the influence factors affecting NH_3 emission rate, including N application rate, soil properties and climate factors and (iii) estimate total NH_3 volatilization from paddy fields in China.

2. Materials and methods

2.1. Study sites

The distribution of the 12 field sites used in this study is shown in Fig. 1. There are great regional differences in NH_3 emissions resulting from the differences in environmental factors and management practices. In order to determine the spatial variation in NH_3 emissions from paddy soils, we divided the 12 sites into three types according to the environmental conditions, cropping system and cultivation history: (i) Single-cropping rice; (ii) Double-cropping rice and (iii) Rice-upland crop (wheat/potato/vegetable rotation). Details for the rice types are given in supplementary information. The number of study sites in each region was mainly determined by the total planting area of rice and heterogeneity of the environmental factors and management practices, and 1, 3 and 8 field sites were set up for single rice, double rice and rice-upland rotation system, respectively. The sowing areas of the above systems in China were 4.6, 10.9 and 11.1 million ha, respectively (NBS, 2014). Compared with the latter two systems, the single rice system is commonly planted over smaller areas with little variation in climatic conditions and soil type. Therefore, only one typical field site was chosen for the study. In view of the large variations in climatic conditions in the rice-upland growing regions and different crops used for rotation, 8 field sites were chosen for the study.

2.2. Experiment design

Basic information about climate, soil properties, and fertilization for each site is shown in Tables S1–3. The experiments were performed during 2012–2013, and urea, superphosphate, and potassium sulfate were used. Prior to rice transplantation, soil was irrigated and plowed, followed by basal fertilization. Based on local farmers' practices, some sites applied tillering topdressing and anthesis topdressing fertilization. Six fertilization rates were used: zero N-fertilizer (CK), local farmers' practice (FT), and another four treatments with 50, 66.7, 83.3, and 133.3% of FT. Although each site had 6 treatments, the local farmers' practice treatment (FT) included a range of rates due to the variations in local practice in the various regions. Consequently, the treatments with 50, 66.7, 83.3, and 133.3% of the local FT rates also varied (Table S2). At each experiment site, the treatment plots (20–40 m^2 in area) were arranged by a randomized complete block experimental design with three replicates. There were bunds between each plot.

2.3. Field measurements

A standardized dynamic chamber method, with a continuous

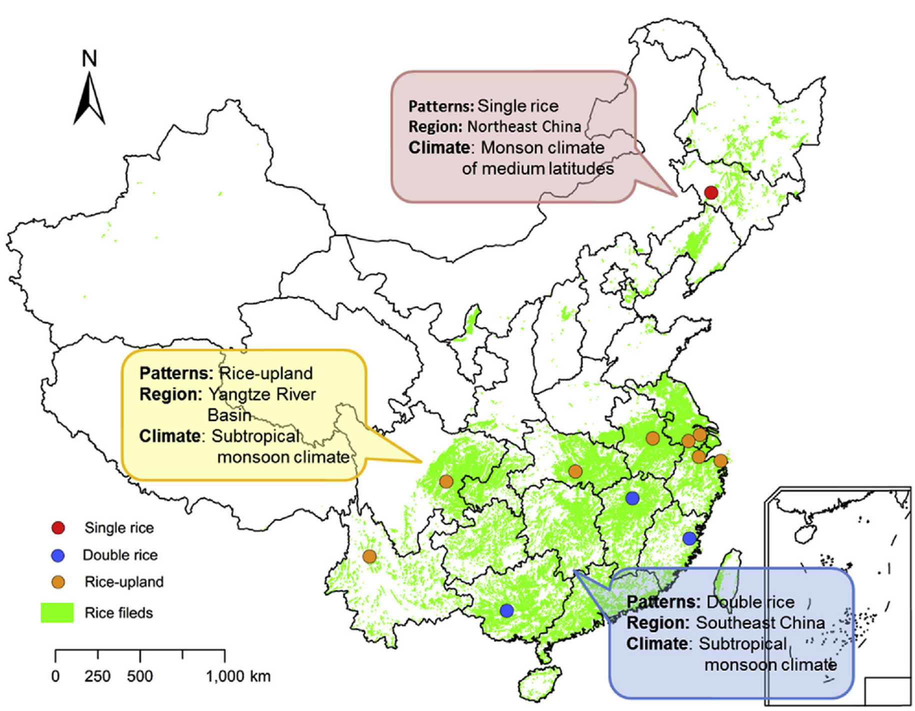

Fig. 1. Geographical distribution of the 12 monitoring sites in China.

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