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Effect of a new urease inhibitor on ammonia volatilization and nitrogen utilization in wheat in north and northwest China

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ABSTRACT

Field experiments were conducted at three typical wheat–maize double-cropping sites in north and northwest China to investigate ammonia (NH_3) volatilization from urea and from urea amended with 0.12% (w/w) Limus® (a new urease inhibitor consisting of 75% N-(n-butyl) thiophosphoric triamide (NBPT) and 25% N-(n-propyl) thiophosphoric triamide (NPPT)) in winter wheat. Grain yields and nitrogen (N) budgets of all N treatments were also evaluated to investigate the effects of urea-N application rates and Limus during one wheat season. Cumulative NH_3 losses after two weeks for conventional urea were 11–25% of applied N, while those for urea amended with Limus were only 0–6% of applied N. The urease inhibitor increased fertilizer N retention more strongly when soil and environmental conditions promoted extensive NH_3 losses. However, grain yields were not significantly ($P > 0.05$) enhanced by Limus compared to conventional urea at all three sites. A clear increase in apparent N recovery efficiency (RE_N) with Limus (ranging from 10 to 16%) resulted at the Quzhou (QZ) site compared to equal amounts of optimized urea-N, with an increase in RE_N of up to 65% under a further 20% N-reduced urea amended with Limus treatment. The study also demonstrated the urgency of appropriate fertilizer N management in China.

1. Introduction

The global 'Green revolution' of the late 1950s and early 1960s generated unprecedented growth in food production; however, these achievements have come at some cost to the environment (Clarke et al., 2011; Sutton et al., 2011). For example, during the last three decades the use of mineral nitrogen (N) fertilizer has more than doubled in China for food security (Liu et al., 2013), while overuse of N fertilizer is also causing numerous environmental problems (Guo et al., 2010; Cui et al., 2013). Driven by an urgent need to produce more food, it is still difficult to change the attitude of farmers and extension service personnel for a more rational use of mineral N fertilizers in China. Unfortunately, fertilizer sources are not utilized efficiently in agricultural systems, and plant N uptake of fertilizer in China seldom exceeds 50% of N applied, while much of the rest is lost from plant–soil system (Ju et al., 2009). With increasing pressure on food security and environmental safety, China has to substantially improve its cereal crop production as well as the fertilizer N use efficiency (NUE).

Urea fertilizer is the most common global N source today due to its high N content (46% N), relatively low cost, and its ease of use. However, the volatilization of ammonia (NH_3) can be a significant N loss pathway for urea, amounting to more than 30%, in calcareous and alkaline soils (e.g., Bouwman et al., 1997; Harrison and Webb, 2001; Sommer et al., 2004; Soares et al., 2012). As one of the key air pollutants, ammonia contributes to acidification in terrestrial systems and eutrophication of aquatic ecosystems, to a decrease of biodiversity and also makes an important contribution to secondary aerosols or particles (e.g., $PM_{2.5}$), with their associated human health risk (Sutton et al., 2011; Liu et al., 2011a). Urea is currently the main synthetic N fertilizer in China, accounting for over 50% of total N fertilizer consumption. Uniform incorporation by ploughing, deep point placement of N fertilizers subsequently covered by soil, or broadcast followed by irrigation are

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recommended fertilization practices in China. These application methods have been proven to largely reduce NH_3 volatilization from croplands (Zhu, 1997; Rees et al., 1997; Roelcke et al., 2002; Pacholski et al., 2006, 2008). However, due to constantly increasing farm labor shortages in China, that are reducing practices such as soil covering soon after fertilization and often delayed irrigation, NH_3 emissions are expected to remain high with urea surface application. Moreover, the above-mentioned loss-reducing practices are more difficult to carry out during top-dressing or split applications of fertilizer at a later growing stage of the crops, which would be most recommended for increasing the low fertilizer NUE in China. Thus, there is a strong interest to decrease NH_3 emissions in order to achieve a higher NUE and to increase grain yields. The use of a urease inhibitor could be an appropriate measure to achieve these goals, as it could delay the hydrolysis of urea and increase time available for sufficient rainfall to move surface-applied urea into the soil, thereby reducing the potential for NH_3 losses and improving N use efficiency (Chien et al., 2009). A major German chemical company, BASF SE (Badische Anilin-und-Soda-Fabrik, Societas Europaea), has recently developed a new urease inhibitor (Limburgerhof Urea Stabilizer, short named: Limus®) which as chemical compound consists of 75% N-(n-butyl) thiophosphoric triamide (NBPT) and 25% NPPT (N-(n-propyl) thiophosphoric triamide). With the application of urea + Limus no extra irrigation is necessary. Previous applied research on urease inhibitors in China was mostly carried out with pot experiments or on small experimental plots (Cai et al., 1992; Xu et al., 2000; Ding et al., 2011). No large-scale field trials have been undertaken to examine the effectiveness of a urease inhibitor under dynamic and varied environmental conditions and covering a range of different soil properties. On the other hand, most methods (e.g., integrating methods using samplers, acid traps, etc.) to determine NH_3 volatilization in situ largely underestimated actual NH_3 losses. Only a few studies using reliable NH_3 measurement techniques (e.g., Integrated Horizontal Flux, Wind Tunnels, Calibrated Dräger-Tube Method, etc.) have been conducted in Chinese croplands (Cai et al., 1992, 1998; Su et al., 2007; Pacholski et al., 2006, 2008).

In this paper we report a study conducted across three typical maize–wheat rotation sites in north and northwest China, to investigate NH_3 volatilization from winter wheat fertilized with urea (three or four split applications at different growth stages) and to quantify the effect of urea amended with 0.12% (w/w) of the urease inhibitor Limus® on NH_3 loss. Ammonia volatilization losses were determined with the calibrated Dräger-Tube Method (DTM) (Pacholski et al., 2006). The main objectives of our study were to test the following hypotheses: (1) NH_3 volatilization is highly variable among split application dates, amount of N application and weather conditions across experimental sites; (2) application of urea amended with Limus is a robust approach for reducing NH_3 volatilization through delaying urea hydrolysis, but its effects may largely depend on soil and weather conditions; (3) urea amended with Limus has potential to save at least 20% of fertilizer N input with one N application in the whole growth season to achieve the same wheat yield as splitting N applications, due to decreased N losses and improved N use efficiency.

2. Materials and methods

2.1. Experimental sites

Field experiments were conducted on local farmers' fields during one winter wheat growing season (October 2011–June 2012) in three different agricultural areas in north and northwest China dominated by winter wheat–summer maize double cropping systems. The sites were (1) Xiping (XP, 33°23′ N and 114°01′ E, 61 m a.s.l.) in central Henan Province, (2) Quzhou (QZ, 36°58′ N and 112°12′ E, 40 m a.s.l.) in southern Hebei Province (both XP and QZ are located in north China), and (3) Yangling (YL, 34°16′ N and 108°04′ E, 460 m a.s.l.) in central Shaanxi Province of northwest China. Soil characteristics of the three experimental sites are listed in Table 1.

Table 1
Characteristics of topsoils at the three experimental sites.

Parameter	XP (farmer's field)	YL (farmer's field)	QZ (experimental station)
Soil texture (%)			
Clay (<2 μm)	1	6	3
Silt (2–20 μm)	73	53	37
Sand (20–2000 μm)	26	41	60
CEC (cmol(+) kg^{-1})	19.7	15.0	11.0
pH (H_2O)	5.8	7.7	8.0
$CaCO_3$ (%)	0.0	5.5	5.8
SOM (g kg^{-1})	21.4	18.2	12.0
Total N (g kg^{-1})	1.2	1.2	0.7
Urease activity (μg N g^{-1} soil h^{-1})	3.2	15.8	13.0

Note: XP, YL and QZ are abbreviations of Xiping, Yangling and Quzhou, respectively.

2.2. Fertilizer N treatments

Before sowing, all the wheat plots were supplied with phosphorus and potassium fertilizer (60 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}), according to local (uniform incorporation in 0–10 cm soil depth) practice. Detailed information on fertilizer N treatments at the three experimental sites is listed in Table 2. At each of the three winter wheat field sites, seven N treatments were applied in a randomized block design with four replications, with each plot 30–40 m^2 in size: Zero N fertilizer or control (N_0), conventional farmers' N practice as plain urea (N_{con}: 240–270 kg N ha^{-1}), a reduced N fertilization (compared to farmers' N practice) as optimized N treatments with plain urea ($N_{opt\text{-}1}$, $N_{opt\text{-}2}$: 150 kg N ha^{-1}) or urea amended with Limus ($N_{opt/L\text{-}1}$, $N_{opt/L\text{-}2}$: 150 kg N ha^{-1}) at different application dates (including seeding, regreening, shooting and flag leaf wheat developing stages), and a further reduced (by 20% N) treatment of urea amended with Limus ($N_{80\%opt/L}$: 120 kg N ha^{-1}) applied only once during regreening stage. The amount of reduced N fertilization was based on local experts' recommended N fertilization practice research together with their own experience, not based on soil N_{min} or plant test (Liu et al., 2003a). Farmers' N practice was conducted by applying urea twice, at seeding and shooting stages. To further evaluate the impact of N application timing on NH_3 loss and yield response, the $N_{opt\text{-}1}$ and $N_{opt/L\text{-}1}$ treatments followed the same application timing as farmers' practice (N_{con}), but the other three treatments ($N_{opt\text{-}2}$, $N_{opt/L\text{-}2}$ and $N_{80\%opt/L}$) shifted the timing of N application to later stages ($N_{opt\text{-}2}$ and $N_{opt/L\text{-}2}$: N applied at regreening and flag leaf growing stage; $N_{80\%opt/L}$: N applied at regreening stage).

2.3. Crop and soil management

The wheat variety *Xinong979* was used at the XP and YL sites, at a sowing rate of 150 and 190 kg seeds per hectare, respectively, with 20 cm row spacing for both sites. At the QZ site, wheat variety was *Liangxing99* sown at a rate of 250 kg seeds per hectare with 15 cm row spacing, based on the local practice. Winter wheat was sown in mid-October 2011 and harvested in early June 2012. Crop management, including pesticides and herbicides application, was conducted according to conventional agricultural practice at all three sites. Total precipitation at XP, YL and QZ during the wheat season was 322, 179 and 120 mm, respectively. No irrigation was carried out at XP and YL while a total of 120 mm irrigation water