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Performance of matrix-based slow-release urea in reducing nitrogen loss and improving maize yields and profits

Yang Yang, Xiaoyu Ni, Zijun Zhou, Lixiang Yu, Binmei Liu, Ye Yang, Yuejin Wu*

Key Laboratory of High Magnetic Field and Ion Beam Physical Biology, Hefei Institutes of Physical Science, Chinese Academy of Sciences, Hefei, Anhui Province 230031, PR China

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ABSTRACT

To reduce N loss in field crop production, application of slow-release fertilizers with acceptable cost is a possible option. Matrix-based urea is a novel, low-cost, slow-release urea developed in the past 10 years. However, there is little consensus about the effects of matrix-based urea on N loss, field maize yields, N use efficiency and profitability. The current study aimed to (i) determine the effects of matrix-based urea on N loss, maize yields, and N use efficiency and elucidate the possible mechanisms; and (ii) assess whether the profitability is acceptable to maize growers. A 2-year field experiment was conducted during 2015–2016 following a randomized block design with three treatments: control test (CK, without urea application), common urea treatment (CU, 195 kg N ha^{-1}) and matrix-based urea treatment (MU, 195 kg N ha^{-1}). Additionally, two laboratory tests were conducted to assess N leaching and ammonia emission from matrix-based urea. The results showed that due to increases in grain number per ear and 1000-grain weight, grain yields with MU were 6.3 and 14.7% greater than those with CU in 2015 and 2016, respectively. Agronomic efficiency (AE) and apparent recovery efficiency (ARE) were greater with MU than with CU. Greater grain yield, biomass, AE, and ARE with MU were attributed to better plant development, i.e., greater plant height, leaf area, root area, chlorophyll concentration, carotenoid concentration, nitrate reductase activity, and glutamine synthetase activity. Better plant development with MU was related to greater available N in the 0–20-cm top soil layers, due to decreased N leaching and ammonia emission. The profitability of maize production with MU was 118.7 and 176.0 USD ha^{-1} greater than with CU in 2015 and 2016, respectively. Overall, matrix-based urea performs well at reducing N loss and improving maize yields, AE, ARE, and profitability, and is thus suitable for application in field maize production.

1. Introduction

N is an essential element for crop growth. Rational application of N fertilizer enhances food security. During the last 3 decades, application of N fertilizers in China has doubled to increase crop yield in order to feed the increasing population (Liu et al., 2013). Urea is the most widely used N fertilizer, partly due to its high N content (46.4%) and relatively low cost (Ni et al., 2013). For example, urea accounts for more than 50% of N fertilizer consumption in China (Li et al., 2015). However, common urea (CU) applied in soils carries the risk of N leaching and ammonia emission (Yang et al., 2015b; Zhang et al., 2013), leading to economic loss and environmental pollution (Geng et al., 2015; Ju et al., 2009). How to reduce N loss has become a focus of worldwide concern.

Application of slow- or controlled-release urea is a possible option to alleviate N loss (Grant et al., 2012; Zhang et al., 2009). Slow- or controlled-release urea mainly reduces N loss via the functional materials added to urea or the polymerization of urea (Li et al., 2015; Ni et al., 2013; Yamamoto et al., 2016). For instance, stabilized urea amended with a nitrification inhibitor or urease inhibitor such as N-(*n*-butyl)thiophosphoric triamide (NBPT), polyphenol, and pomegranate fruit powder, reduces ammonia emission and increases fertilizer N retention (Chagas et al., 2016; Kiran and Patra, 2003; Li et al., 2015; Sabahi et al., 2017); while coated urea, such as polyethylene-coated urea and sulfur-coated urea, reduces the N release rate via the functional materials coated on the surface of urea granules (Gao et al., 2015; Ni et al., 2013). However, the cost of slow- or controlled-release urea is high, limiting its application in field crop production (Naz and Sulaiman, 2016; Ni et al., 2013; Zheng et al., 2016). Furthermore, some coated materials, such as polyethylene, carry a risk of pollution, while the production of some eco-friendly plant nitrification or urease inhibitors struggle to meet the huge demand for fertilizer production.

It is necessary to develop slow- or controlled-release urea, which is produced with eco-friendly materials with ample supply, and can

* Corresponding author.
E-mail addresses: yangyang19860207@163.com (Y. Yang), yjwu@ipp.ac.cn (Y. Wu).

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reduce N loss with acceptable cost. Matrix-based fertilizer (MF) is a novel, low-cost, slow-release fertilizer. MFs mainly consist of matrix-based urea (MU) and matrix-based compound fertilizer, which are produced based on similar mechanisms and matrix materials (Bai et al., 2017; Ni et al., 2013). MU reduces N loss via the functional materials added to urea granules (Golbashy et al., 2017; Ni et al., 2013; Qin et al., 2012). The functional materials mainly consist of silicate minerals (such as bentonite, attapulgite, and montmorillonite) and organic polymers (such as polyacrylamide) (Golbashy et al., 2017; Qin et al., 2012; Xiang et al., 2014; Zhang et al., 2009). The performance of silicate minerals is highly dependent on their dispersion capacity. Natural silicate minerals tend to aggregate with each other, leading to low dispersion capacity (Chen and Shu, 2012; Xiang et al., 2014). Hence, natural silicate minerals are usually modified using physical and chemical methods (such as high-energy electron beam irradiation and sodium-activation conversion) to enhance their dispersion capacity (Qin et al., 2012; Xiang et al., 2014).

MF is a novel slow-release fertilizer developed in the past 10 years, and mainly consists of MU and matrix-based compound fertilizer (Bai et al., 2017; Chen and Shu, 2012; Golbashy et al., 2017; Ni et al., 2013; Qin et al., 2012). To date, MF has mainly been produced and applied in seven provinces in China, with Xinlianxin being the largest producer (Fig. 1). MF is produced with eco-friendly silicate minerals and organic polymers. Ni et al. (2013) found that MU has a three-dimensional lattice structure and a lower specific surface area than CU, which is partly responsible for its lower N release rate. Cai et al. (2014) reported MF forms a micro-nano network in soils, which can adsorb nutrients via hydrogen bonds, surface tension, viscous force, and molecular force. Golbashy et al. (2017) also reported that MU has a good slow-release behavior. The effects of MF on field crop yields have been tested in some studies (Bai et al., 2017; Liu et al., 2016; Xu et al., 2014; Zhou et al., 2016). Although slow-release fertilizers are beneficial to crop production, their actual effects are highly affected by field conditions, such as various meteorological conditions in different growing seasons (Grant et al., 2012; Guo et al., 2016). Therefore, the effects of MFs on crop yields should be tested via field experiments conducted in multiple seasons or environments. To determine whether MU is suitable for field maize production, we need detailed information about its effects and mechanisms on grain yields, as well as whether the profitability is acceptable.

Previous studies have provided valuable information about the production of MU and the effects of MU on crop yields. However, most field experiments have focused on crop yield performance, with little explanation about possible mechanisms; while most laboratory experiments have focused on the chemical process or microscopic characterization, without field crop validation. We conducted a 2-year field experiment and two laboratory trials with the following objectives: (i) to investigate the effects of MU on N loss, field maize yields, and N use efficiency, and elucidate the possible mechanisms; and (ii) to assess whether the profits from MU application are acceptable to maize growers.

Fig. 1. Major producers of matrix-based fertilizers in China.