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Short Communication

Mixture of controlled release and normal urea to optimize nitrogen management for high-yielding (>15 Mg ha^{-1}) maize

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Continued population growth and the corresponding increase in consumption will mean increases in the global demand for food crops, especially maize, which is used as a food, feed and bioenergy crop. Optimal nitrogen (N) management for high-yielding maize (>15 Mg ha^{-1}) is a challenge because the N demand at post-silking will increase significantly, and synchronization of the N supply with such demand will become more difficult. In this study, treatment variables consisted of one solely urea (split application before sowing and at 6 leaf stage) and two CRU-N (nitrogen from controlled-release urea (CRU))/Urea-N (nitrogen from urea) mixtures (1:2 and 2:1) with one-off application at two N rates (180 kg ha^{-1} and 240 kg ha^{-1}) in two experimental years (2013 and 2014). The results indicated that an one-off application of the blend of CRU and urea before sowing was able to satisfy the N demand of a high-yielding maize system (>15 Mg ha^{-1}); the results also showed a greater percentage of N accumulation at post-silking (51%–63%) with the grain yields ranging from 16.9 Mg ha^{-1} to 19.3 Mg ha^{-1}, and one-off application a mixture of CRU and urea with 2:1 at 180 kg N ha^{-1} achieved the lowest N losses (80 kg N ha^{-1} and 12 kg N ha^{-1}), while a mixture of CRU and urea with 1:2 at 240 kg N ha^{-1} got highest economic return in both years. This work demonstrates that blending CRU and urea in an one-off application could potentially improve grain yields and create a simpler, more efficient and business-friendly system of high-yielding maize production.

1. Introduction

Because it is a C4 plant, the projected yield potential of maize (*Zea mays* L) is much higher than that of wheat and rice (Gowik and Westhoff, 2011). Grassini et al. (2011) estimated that the average yield potential of irrigated maize ranged from 14.6 Mg ha^{-1} to 15.1 Mg ha^{-1} in the Corn Belt of the Western US. In 50 simulations of high-yield sites across China, the yield potential for irrigated maize averaged 16.5 Mg ha^{-1}, with 19.5 Mg ha^{-1} particularly in Northwest China (Meng et al., 2013). Recently, a maize yield >15 Mg ha^{-1} was reported in field experiments in the US (Grassini and Cassman, 2012; Ciampitti and Vyn, 2012) and in China (Chen et al., 2012). In practice, the maize yield increased quickly in the US (5.0 Mg ha^{-1}–0.2 Mg ha^{-1}), Brazil (1.6 Mg ha^{-1}–4.0 Mg ha^{-1}), and China (1.7 Mg ha^{-1}–5.0 Mg ha^{-1}) from 1965 to 2011 (Grassini et al., 2013). A maize yield of over 15 Mg ha^{-1} could be possible in the future.

However, N management for such a high-yielding system is a great challenge in terms of being economically reasonable, practical, and environment friendly. A high-yielding system not only means a higher total nitrogen demand but also greater demand in the later growth stage (after silking) (Ciampitti and Vyn, 2013; Mueller and Vyn, 2016). In general, approximately 50% of dry matter in a mature maize plant is obtained during the post-silking stage, with the majority of that gain occurring in the grain (Lee and Tollenaar, 2007). Our recent results show that as the maize grain yield level improved from 7.0 Mg ha^{-1} to 13.0 Mg ha^{-1}, the dry matter accumulation during the post-silking stage increased from 47% to 60%; additionally, aboveground N uptake increased from 12% to 32% (Meng et al., 2016). This N demand increment during the post-silking stage makes N management more challenging because the soil N supply normally cannot meet such high demands. Fur-

Abbreviations: CRU, controlled-release urea; GDD, growing degree days; PFP_N, nitrogen partial factor productivit.

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thermore, increasing the frequency of top-dressing applications is usually not acceptable due to practical and economic reasons.

Using controlled release fertilizer (CRU) is a specific practice to synchronize crop nitrogen demand that could minimize early season N availability when crop uptake is slow, thereby reducing the loss potential (Akiyama et al., 2010) and saving labor in an one-off application. However, CRU may release from the polymer coating too slowly to be an effective N source during early growth periods (Farmaha and Sims, 2013) and could also be more expensive than conventional fertilizer (Noellsch et al., 2009). Therefore, blending CRU and urea may synchronize the N demand of high-yielding maize (Payne et al., 2015). It is important to understand the proportion of CRU and urea that could meet the N demand of a maize production system with a yield level >15 Mg ha^{-1} in a given ecological region, in order to maximize agronomic and economic benefits as well as to minimize environmental costs.

Therefore, the objective of this study was to evaluate the effects of different combinations of CRU and urea at various N rates on maize grain yield, N uptake (before and after silking) and N use efficiency. The economic cost will also be considered. A two-year field experiment in Northwest China was conducted for this purpose.

2. Materials and methods

2.1. Site description

The experiment was conducted in 2013 and 2014 in Yongning (38.4°N, 106.4°E; 1090 m elevation), Northwest China, which is in a typical irrigation region along the Yellow River. Excellent temperature and solar radiation conditions make this region famous for its high-yielding irrigated maize (Liu et al., 2009). In 2013 and 2014, the average temperatures were 20.4 °C and 19.9 °C, while solar radiation was 2692.5 MJ m^{-2} and 2717.5 MJ m^{-2}, and the gain in available growing degree days ($GDD_{available}$) for maize growth was 1716 °C and 1740 °C, respectively. The average precipitation was 148.3 mm and 157.7 mm between April and September in 2013 and 2014, respectively, and irrigation was applied four times (approximately 90 mm per time) during the maize growth period (Fig. 1). The soils at the site are Cumuli-Orthic Anthrosols (Gong et al., 2007), and the soil properties in the top 30 cm are as follows: pH 8.1, organic matter 17.6 g kg^{-1}, total N content 0.8 g kg^{-1}, Olsen-P 24.0 mg kg^{-1}, and NH_4OAc-extracted K 158 mg kg^{-1}. The soil testing methods followed those of Page et al. (1982).

2.2. Experimental design and field management

Experiments were conducted using a factorial arrangement of treatment factors in a randomized complete block design. Each of seven treatments (three types of fertilizer × two application rates, plus a no-nitrogen treatment as described below) were represented by 40-m^2 (5 by 8 m) plots by four replicate plots. The three types of fertilizer treatments, hereafter referred to as “N sources”, included one solely urea treatment, which was applied as a split application, and two CRU-urea mixtures in 1:2 and 2:1 ratios (N from CRU: N from urea). Each of these three N sources was applied at two N rates (180 and 240 kg ha^{-1}), while 240 kg ha^{-1} was a normal optimized N rate according to our previous studies (Cui et al., 2013; Guo et al., 2016), and we selected 180 kg ha^{-1} for testing the possibility for saving 25% N by using CRU. In the solely urea treatments, 40% of the total N was applied as a basal dressing before sowing, and the remaining 60% was applied at the 6-leaf stage, which corresponded to growth stage V6; the high and low rates for this treatment were designated N180U and N240U, respectively. The CRU treatments were applied in just one application before sowing and were designated N180C1, N240C1, N180C2, and N240C2; C1 represents CRU-N: Urea-N at 1:2, and C2 represents CRU-N: Urea-N at 2:1. The CRU was manufactured by Agrium Inc., Calgary, AB, Canada (Environmentally Smart Nitrogen [ESN]), a polymer coated fertilizer, coating 44% N as urea. The coating releases the urea from the prill over a 60-day period at a rate controlled by 25 °C water culture method. The non-coated urea was commercial grade fertilizer containing 46% N. The basal N fertilizer was applied together with 90 kg P_2O_5 ha^{-1} in the form of $Ca(H_2PO_4)_2$ and 90 kg K_2O ha^{-1} in the form of KCl.

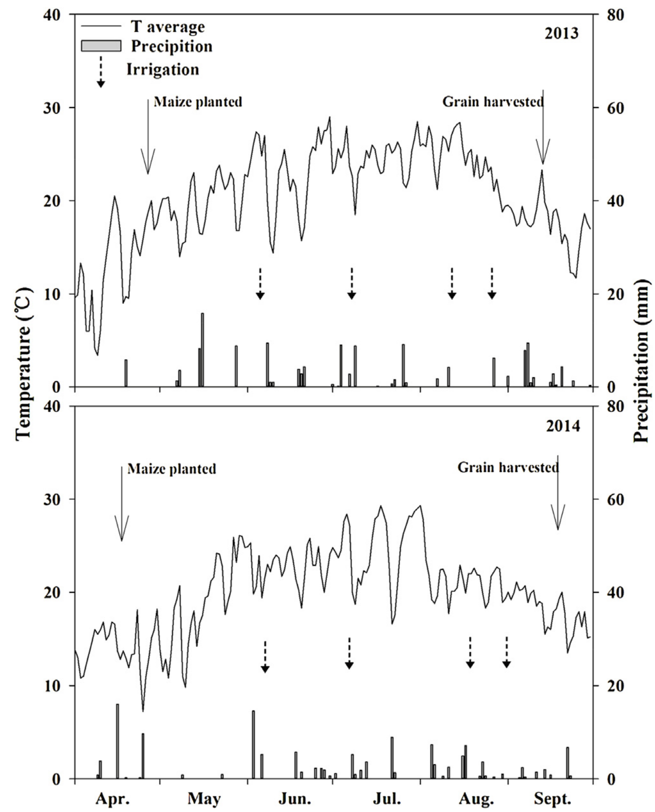

Fig. 1. Daily precipitation (bars), average temperature (line) and irrigation (dotted arrows) for the growing season from planting to grain harvest in 2013 and 2014. Solid arrows show the time of planting, grain harvest and fertilizer application.

The maize hybrid (Pioneer 335, GDD 1700 °C) was seeded at a depth of 3–5 cm and at a density of 82,500 plants ha^{-1} with a row spacing of 60 cm on both April 20, 2013, and April 16, 2014. Maize was harvested on both September 13, 2013, and September 15, 2014.

2.3. Plant sampling and analysis

Plant samples were taken at the silking stage (R1) (on July 8 and 16 in 2013 and 2014, respectively) and physiological maturity (R6) (which was divided into grain and straw). Three adjacent plants in each plot were selected randomly, dried initially at 105 °C for 30 min and then oven-dried to a constant weight at 80 °C. In all treatments, N concentrations in dry grain and straw were measured using the Kjeldahl method (Horowitz, 1970). At harvest, 20 m^2 in the middle of each plot was manually harvested to determine the grain yield (GY) and yield components. The GY was expressed at 15.5% moisture content, according to the standard moisture for maize grain (Koide and Peoples, 2012).

The following equations were used to calculate partial factor productivity from nitrogen (PFP_N), recovery efficiency from