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Using maize hybrids and in-season nitrogen management to improve grain yield and grain nitrogen concentrations

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ABSTRACT

Understanding the dynamics of biomass and nitrogen (N) accumulation in maize cultivars and the relationship of these parameters to N management is essential to improve our ability to increase maize grain yield and grain N concentration (GNC). We conducted a field experiment in 2010 and 2011, using five rates of N application and three maize hybrids (YD13, ZD958, and XY335) in Quzhou County, the North China Plain, to evaluate grain yield and GNC under different N managements and with different hybrids. The maximum grain yield in 2010–2011 averaged 8.85 and 8.90 Mg ha^{-1} for ZD958 and XY335, respectively, which was approximately 45% higher than the yield of YD13 (6.10 Mg ha^{-1}). GNC in XY335 was highest among the three hybrids. The maximum GNC for 2010–2011 averaged 1.62% for XY335, 1.42% for ZD958, and 1.48% for YD13. Compared to YD13, XY335 and ZD958 had higher biomass and N accumulation during the grain-filling period and at harvest, and the apparent amount of N remobilization from stover (leaf plus stem) after silking was greater in XY335 than in ZD958, which contributed to high yield and GNC in XY335. The optimal N application rate (ONR) based on in-season N management was 149 kg ha^{-1}, and split at the 3-leaf (V3), 6-leaf (V6), and 10-leaf (V10) stages. All maize hybrids achieved their maximum grain yield and >95% of their maximum GNC with ONR treatment. Selection of appropriate hybrids such as XY335 in combination with optimal N management can increase grain yield and GNC obtained on the North China Plain.

1. Introduction

Improvement in crop grain yield and grain nitrogen (N) concentration (GNC) provides a promising strategy for combating hunger and malnutrition (Pinstrup-Andersen, 2000; Onimisi et al., 2009; TWumasi-Afriyie et al., 2011). Worldwide, approximately one of every eight people lacks access to food or is chronically malnourished as a result of poverty and increasing food prices (FAO, 2013). A negative correlation between GNC and increased grain yield under N fertilization is common for many crops such as wheat, rice, maize, and sorghum (Simmonds, 1995; Fowler, 2003; Guarda et al., 2004). On the North China Plain (NCP), the concentration of N in summer maize (grain) has decreased from 13.1 g kg^{-1} (yield < 6.0 Mg ha^{-1}) to 11.0 g kg^{-1} (yield > 12 Mg ha^{-1}) (Yue, 2013). Similar results have also been reported in the United States, where the maize grain yield increased significantly from the 1930s to 1990s, while the grain protein concentration decreased from 10.3% to 8.8% (Duvick and Cassman, 1999). Therefore, understanding the dynamics of biomass and N accumulation in relation to N management and cultivar is important for improving both maize grain yield and GNC.

Incremental addition of available soil N can increase both yield and GNC, and GNC was shown to be increased even further at the highest grain yield by increasing the concentration of available N (Duarte et al., 2005; Berenguer et al., 2009; Masoero et al., 2011). However, excess N application often leads to high nitrate in the stalk (Blackmer and Mallarino, 1997) and to lower N-use efficiency (NUE), which increases the risk of N pollution (Ju et al., 2009). Some field studies have also indicated that increased yield and GNC of maize could be achieved by split application of fertilizer (Randall et al., 2003; Gehl et al., 2005). For example, compared to a single or double application of fertilizer, grain yield and N uptake increased by 15–31%, respectively, when N was applied in ratios of 3:5:2 or 2:4:4 at the 6-leaf stage (V6), 10-leaf stage (V10), and 10 days after silking (Lü et al., 2012).

Genetic improvement can also increase the uptake of N and grain yield in maize (Moll et al., 1982; Duvick, 2005; Lee and Tollenaar, 2007; Worku et al., 2007). Normally, newer cultivars have higher N-uptake efficiency and achieve higher grain yield than older cultivars (Moll et al., 1982; Lafitte and Edmeades, 1994;

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Gallais and Coque, 2005; Haegele et al., 2013). However, the GNC of new maize cultivars can decrease with increasing grain yield (Dudley and Lambert, 2004; Scott et al., 2006; Gallais et al., 2008) because of the higher energy requirements for synthesis of protein compared to carbohydrate (De Vries et al., 1974). Duvick and Cassman (1999) reported an overall decrease in GNC from 1.03% in the 1930s to 0.88% in the 1990s.

For cultivars supplied with similar amounts of available soil N, GNC is determined based on the ratio of grain N yield to total grain yield. As a result, higher-yield cultivars will have lower GNC than lower-yield cultivars unless they have an increased ability to extract N from the soil or translocate it to the grain (Fowler, 2003). Maintenance of leaf N concentration is necessary for leaves to remain photosynthetically active during the grain-filling period (Ding et al., 2005), but this physiological requirement may impede remobilization of N from stalk and leaves to grain (Pommel et al., 2006). Stay-green cultivars often achieve higher grain yield because of greater accumulation of dry matter and N uptake during the grain-filling period that result from prolonged retention of N in the leaves and higher rates of photosynthesis (Tollenaar, 1991; Rajcan and Tollenaar, 1999a,b; Echarte et al., 2008). Biomass production is influenced by leaf N concentration since a large proportion of the N in leaves is incorporated into photosynthesis-related functions (Vos et al., 2005). However, lower efficiency in the remobilization of N has often been observed in stay-green cultivars compared to senescent cultivars (Mi et al., 2003).

We hypothesized that proper maize cultivars and N management could improve grain yield and GNC synchronously by balancing dry-matter production and N uptake or remobilization. In this study, we used three typical maize hybrids, including a senescent hybrid typical of those used in the 1980s and 1990s, a stay-green hybrid, and the current high-yield hybrid on the North China Plain (NCP) with high NUE (Zhang et al., 2013). Five N treatments were implemented, including the typical N dose used by farmers on the NCP, along with low, intermediate, and high rates of application and a control. Our objectives were to evaluate (1) the response of grain yield and GNC in the three maize hybrids under different N management practices; (2) variations in the biomass and N accumulation among maize hybrids under the optimal N rate (ONR); and (3) variation in stover (leaf plus stem) N remobilization among maize cultivars during the period of silking and harvest under the ONR. Our results may help farmers improve both grain yield and GNC.

2. Materials and methods

2.1. Field experiments

Field experiments were conducted in 2010 and 2011, as part of a long-term N-fertilization experiment initiated in 2007 in Quzhou (QZ) County (36.9°N, 115.0°E), Hebei Province, China. Maize was planted without tillage after harvest of winter wheat in mid-June, with a row spacing of 60 cm (about 75,000 plants ha^{-1}); maize was harvested at the beginning of October, and the average harvest densities were 7.1, 7.5, and 7.6 plants m^{-2} for YD13, ZD958, and XY335, respectively. Irrigation (90 mm) was applied after sowing of maize in 2010 and 2011. The soil was clay loam with the following characteristics: organic matter content, 14.2 g kg^{-1}; total N, 0.83 g kg^{-1}; Olsen-P, 7.2 mg kg^{-1}; NH_4OAc-K, 125 mg kg^{-1}; pH 8.3; and bulk density, 1.36 g cm^{-3}. Meteorological conditions were automatically recorded using a standard agro-meteorological station located in the experimental field. Daily mean temperature, solar radiation, and precipitation during the two growing seasons are presented in Fig. 1. During the two growing seasons, the daily mean temperature was 25.4 and 24.0 °C, the total solar radiation was 1544 and 1451 MJ m^{-2}, and the total precipitation was 277 and 333 mm in 2010 and 2011, respectively.

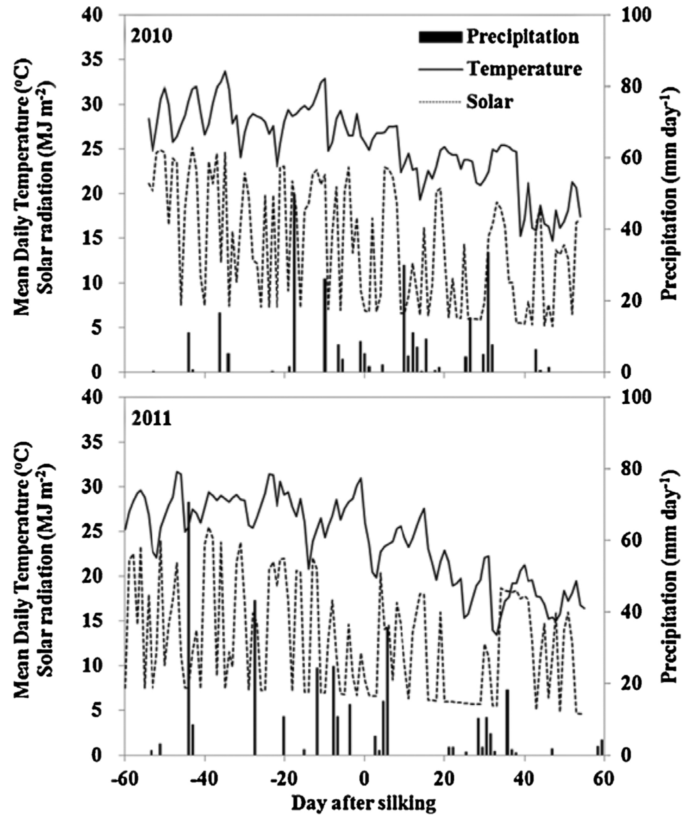

Fig. 1. Daily mean temperature, solar radiation and precipitation during the maize growing seasons in 2010 and 2011 at Quzhou (QZ) County (36.9°N, 115.0°E), Hebei Province, China.

The experimental design was a split plot design with three replicates. Five N treatments were applied as the main plot, and the three hybrids were designated as subplots. The plot size of the main plot was 300 m^2 (15 m wide × 20 m long) and the subplot size was 100 m^2 (5 m wide × 20 m long). The N treatments were as follows: control (0 N), 70% optimal N rate (ONR), ONR based on in-season root-zone N management (INM, see below), 130% ONR, and the typical N dose used by farmers on the NCP (FNP). The FNP was set at 250 kg N ha^{-1} (100 kg N ha^{-1} applied at the 3-leaf stage and 150 kg N ha^{-1} applied at the 6-leaf stage), which is typical for Hebei Province (Cui, 2005). The ONR was determined according to Cui et al. (2008) as follows. The maize-growing season was divided into three periods (stages): planting to the 6-leaf stage, 6-leaf to 10-leaf stage, and 10-leaf to the mature stage. At the 3-leaf stage, 45 kg N ha^{-1} was applied; ONR was determined using the 6- to 10-leaf and the 10-leaf to harvest stages by subtracting measured soil nitrate-N content in the root zone (0–60 cm and 0–90 cm for the two growth stages, respectively) from the target N value. The target values for each successive growth period, estimated based on the target yield and crop N uptake, were 50, 120, and 190 kg N ha^{-1}, respectively. Detailed descriptions of the field experiments have been reported previously (Zhang et al., 2013). Urea was applied deep (10 cm) into the soil with a furrowing machine at the 3-leaf (V3), 6-leaf (V6), and 10-leaf (V10) stages according to the N treatments. Details on root-zone NO_3^--N content and N application rates are provided in Table 1. Based on the soil P and K test results, all plots received appropriate amounts of triple superphosphate (45 kg P_2O_5 ha^{-1}) and potassium chloride (90 kg K_2O ha^{-1}) at the V3 stage, accompanied by the application of urea.