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Seedling characteristics and grain yield of maize grown under straw retention affected by sowing irrigation and splitting nitrogen use

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ABSTRACT

The practice of straw retention often causes seedling issues, including slow seedling establishment and weak seedling. Irrigation shortly after sowing (namely 'sowing irrigation', abbreviated as SI) may help to accelerate the seedling establishment under straw retention, and appropriate split nitrogen (SN) management may further boost crop growth and grain yield. Here, we conducted a 2-year field trial to assess the impacts of SI and SN on crop growth, grain yield and water and nitrogen use efficiencies of a maize hybrid i.e. Zhengdan 958 grown under straw retention. The treatments consisted of two irrigation conditions and three splitting nitrogen regimes, with three replications. SI treatment was composed of 0 mm irrigation (denoted as W0) and 60 mm irrigation (denoted as W1) shortly after sowing. SN management contained a similar total nitrogen rate (300 kg ha^{-1}) but was split in three proportions between sowing and big flare stage, i.e. 10:0 (denoted as N1), 5:5 (denoted as N2) and 3:7 (denoted as N3). Our results indicated that sowing irrigation accelerated seedling emergence by 2–7 days, and increased grain yield by 4.73% (2014) and 5.90% (2015), and water use efficiency by 1.69% (2014) and 3.80% (2015) compared to the treatment without sowing irrigation. N2 and N3 treatments increased grain yield by 9.00–10.12% via greater kernel number, and increased nitrogen partial factor productivity by 9.35–10.20% in both years. The improved grain yield by sowing irrigation or splitting nitrogen was due to greater canopy photosynthetic capacity with higher leaf area index, leaf chlorophyll content and net photosynthesis rate. It was found that the optimal ratio of basal: topdressing nitrogen depended on whether sowing irrigation was used. Without sowing irrigation, W0N2 produced the highest grain yield; while with irrigation, both W1N2 and W1N3 produced a greater production than W1N1. In conclusion, the combination of sowing irrigation and splitting nitrogen to the big flare stage could increase not only maize grain yield, but also resource-use efficiency under straw retention in lime concretion black soil of Huaibei Plain, Anhui Province, China.

1. Introduction

Huaibei Plain is one of the important crop production areas in China, with a winter wheat (*Triticum aestivum* L.) -summer maize (*Zea mays* L.) rotation being dominantly used (Li et al., 2013). The typical soil type in this region is lime concretion black soil, which has high soil compaction, greater cultivation barrier, low soil organic matter and poor soil fertility (Shen et al., 2011; Li et al., 2014). Thus, it is imperative to improve soil quality and fertility for sustainable crop production in this region.

Crop straw is an important agricultural resource containing considerable biomass rich in organic material and nutrients (Saroa and Lal, 2003). Many studies have shown the beneficial effects of crop residue incorporation in increasing the concentration of soil nutrients and organic matter (Ludwig et al., 2011; Malhi et al., 2011), as well as maintaining soil moisture and structural stability (Zhao et al., 2009; Álvaro-Fuentes et al., 2009). This has contributed to improved soil fertility and thus increased crop productivity (Zhang et al., 2009; Abro et al., 2011; Wang et al., 2015b). Multiple year continuous straw retention has been reported to improve crop productivity in many places (Yang et al., 2014; Wang et al., 2015a), including Huaibei Plain (Guo and Wang, 2013).

To extend the usage of straw retention in Huaibei Plain, we are investigating whether straw retention practice can be further optimized. On the one hand, the poor seedling quality is often caused by straw return due to an increase in soil pores affecting emergence and

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seedling growth negatively (Shen et al., 2011; Dai et al., 2013). Moreover, the semiarid Huaibei Plain largely depends on natural rainfall and only limited irrigation may apply when severe drought occurs. Studies have shown that maize emerges quickly while soil moisture falls between 21% and 25%; emerges normally while between 18% and 21%; emerges slowly while between 16% and 18%; and the emergence is markedly postponed while soil moisture is below 16% (Ma et al., 2012). Thus irrigation shortly after sowing may help accelerate seedling establishment, and thus subsequent growth.

On the other hand, nitrogen (N) is one of the most yield-limiting nutrients in crop production, and its proper management is essential for improvement of grain yield (Zhang et al., 2013). Excessive N fertiliser use at early canopy establishment causes N loss from the root zone to the surrounding environment, which results in wasting N resource and associated environmental issues (Sinclair and Rufty, 2012). It has been reported that N use efficiency is as low as 26–31% in China due to irrational use of N in wheat-maize crop rotation system (Miao et al., 2011). Rational N application is essential to improve N use efficiency and the coordination between soil N supply and crop N demand (Fageria and Baligar, 2005; Abbasi et al., 2012). Previous studies have shown that complete nitrogen use as basal fertiliser results in not only low nitrogen utilization efficiency, but also high leaching loss of NO_3^--N (Shi et al., 2012), and topdressing applications can increase N use efficiency and grain yield compared to complete basal applications (Sainz Rozas et al., 2004; López-Bellido et al., 2005; Abbasi et al., 2012, 2013). Furthermore, applying N with two appropriate splits is more suitable for semiarid Loess Plateau, which could produce higher grain yield, and reduce the risk of N_2O emissions compared to three splits (Wang et al., 2016). In addition, soil water can increase the availability of nutrients (Seiffert et al., 1995), in return, nutrient is able to increase water use efficiency (Qiu et al., 2008). And soil moisture can facilitate soil N diffusion and a better contact of water with the root system to increase water and nutrient uptake (Wang et al., 2017). As a consequence, the combined application of sowing irrigation and shifting N may be beneficial for maize growth and grain yield.

In our previous study, we indicated that straw return should be accompanied by fertiliser use, with basal: topdressing N ratio of 5:5 (unpublished). In this study, we used a similar total N rate, but split into different proportions between basal and topdressing at big flare stage, to assess which proportion was optimal with two sowing irrigation conditions under straw return. Within this context, we conducted a 2-year field experiment to assess crop growth and development of maize grown under straw retention subjected to sowing irrigation (SI) and split nitrogen (SN) application. Accordingly, the objectives of this study were: (1) to evaluate the effect of SI on the seedling emergence, grain yield and water use efficiency under straw retention; (2) to investigate the effects of SN on maize grain yield and N use efficiency; and (3) to examine the interaction between SI and SN on maize growth and grain yield.

2. Materials and methods

2.1. Field site

A field experiment was conducted at the experimental station of Mengcheng Agricultural Scientific Institute (33°9′44″ N, 116°32′56″ E), located in the Huaibei Plain region, Anhui Province, China in 2014 and 2015. It has a typical semi-humid, monsoon-prone climate with an average annual precipitation of 821.5 mm (mainly between June and August). During the summer maize growing seasons, the total precipitation is 722.1 mm (2014) and 497.2 mm (2015), the average air temperature is 24.20 °C (2014) and 24.44 °C (2015), respectively (Fig. 1). The soil type is lime concretion black soil. Prior to the experimentation, soil pH is 5.91; soil organic matter content is 18.15 g kg^{-1}; available N is 80.20 mg kg^{-1}; available P is 31.46 mg kg^{-1}; and available K is 135.04 mg kg^{-1} at the top 20 cm soil layer.

2.2. Experimental design

A randomized complete block design was used to arrange the treatments of irrigation and nitrogen regimes, each treatment being three replications. The area of each individual plot was 15.0 m^2 (3.0 m × 5.0 m). Two factors were used in the experiment, i.e. SI and SN regimes, of which the first factor has 0 mm irrigation (denoted as W0) or 60 mm sowing irrigation (denoted as W1); and nitrogen was used at the same rate (300 kg ha^{-1}) but split in three proportions between sowing and big flare stage: 10:0 (denoted as N1), 5:5 (denoted as N2) and 3:7 (denoted as N3). Thus six treatments were denoted as W0N1, W0N2, W0N3, W1N1, W1N2, and W1N3.

The summer maize hybrid Zhengdan 958, used in this study, is a high-yielding, middle-maturity (103 days) and compact-type variety, which is the most widely grown hybrids in China (Wang et al., 2011). The NPK compound fertiliser (N-P_2O_5-K_2O = 15 − 15 − 15%) and urea (46.4% N) were used in N1, N2 and N3 regimes, and calcium superphosphate (12% P_2O_5) and potassium chloride (60% K_2O) were also used in N3 regime. Pure N at a rate of 300.0 kg ha^{-1} was used for basal and topdressing fertiliser according to the experimental design, topdressing N was applied at big flare stage (on July 23th, 2014 and July 22th, 2015). P_2O_5 and K_2O were both used as the basal fertiliser at a rate of 112.5 kg ha^{-1}.

Once wheat crop was harvested, the straw was chopped into small pieces with the length less than 10 cm by a Combine Harvester (Foton Lovol GN60, Foton Lovol International Heavy Industry Co. Ltd, China). The chopped straw pieces were then returned to soil surface evenly at a rate of 7500 kg ha^{-1} in 2014 and 7000 kg ha^{-1} in 2015. The N, P_2O_5 and K_2O content of wheat straw was 0.45%, 0.08%, and 1.14% in 2014; and 0.49%, 0.09% and 1.12% in 2015, respectively. Maize was sown using a seed planting machine (2BYF-4, Hebei Shenhe Agricultural Mechanics Co. Ltd, China) on June 11–12th in 2014 and 2015, and at a density of 67,500 plants ha^{-1} with a row spacing of 60 cm. After complete maturity, maize was harvested by a Combine Harvester (Bo Yuan 30Y0, Hebei Zhongnong Boyuan Agricultural Equipment Co. Ltd, China) on October 4–6th in both years. Maize straw was chopped into small pieces with the length less than 10 cm during harvesting, which was then buried into soil by rotary tillage. The straw returning was applied at a rate of 8000 kg ha^{-1} in 2014, and the N, P_2O_5 and K_2O content of which was 0.88%, 0.11% and 1.68%, respectively. Then wheat was sown with a rotation seed planting machine (SGTNB-200Z4/8A8, Xi'an Ya'ao Rotation Sowing Machine Co. Ltd, China).

Prior to sowing maize, soil moisture was measured on June 12th, 2014 (19.53%) and June 11th, 2015 (14.23%), respectively, at the top 20 cm soil layer. Measurements were performed using a gravimetric method based on the conventional oven-dried weight. Once maize was sown, a total of 600 m^3 ha^{-1} irrigation was implemented, and a sprinkler system was used for all the irrigation treatments. The gap between two adjacent plots of sowing and without sowing treatment was 1.5 m to avoid the interference of sowing irrigation, in addition, the treatment without sowing irrigation was covered by plastic film whilst at irrigation for the sowing irrigation treatment. No further irrigation during maize growth was used for any treatment. The total precipitation of 5 days after sowing (DAS) was 34.9 mm in 2014 and 6.1 mm in 2015, there was 39.3 mm precipitation at 6th and 7th DAS in 2015.

2.3. Data sampling

2.3.1. Seedling emergence rates and growth characteristics

The number of maize seedling emergence was determined according to 2 cm of leaf outgrowth upon the topsoil. In designated rows, plants in a 5 m long row at each plot were assessed at 5^{th}, 6^{th}, 8^{th}, 10^{th}, and 15^{th} DAS in both 2014 and 2015 seasons. The rate of emergence was calculated according to the emergence number divided by sowing seed number along the 5 m long row. At 15^{th} DAS, plant height and aboveground dry matter measurements were taken from five representative