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Effects of pre-sowing irrigation and straw mulching on the grain yield and water use efficiency of summer maize in the North China Plain

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ABSTRACT

To develop water-saving agriculture in the North China plain, we conducted field experiments using three pre-sowing irrigation applications (30, 70, and 110 mm) on summer maize, with and without straw mulching, during the 2014 and 2015 growing seasons. We studied the effects of pre-sowing irrigation and straw mulching on soil moisture before sowing (SMBS) consumption, evapotranspiration (ET), grain yield, and water use efficiency (WUE). The results indicated that straw mulching and increased pre-sowing irrigation significantly improved grain yield. Increasing amounts of pre-sowing irrigation increased ET, whereas straw mulching had no significant effect on ET. Conversely, while pre-sowing irrigation showed no linear correlation with WUE, straw mulching increased it significantly. The combination of straw mulching and the 70-mm pre-sowing irrigation treatment (70M) improved grain yield at a significantly higher rate than with the combination of 110-mm and the non-straw mulching treatment (110N); moreover, significantly more deep soil water was absorbed with 70M than with the other pre-sowing irrigation treatments. These results indicate that the combination of straw mulching and 70-mm pre-sowing irrigation is the ideal water-saving agricultural technique for growing summer maize in the North China Plain.

1. Introduction

The North China Plain is one of the most important maize production areas in China. Over the last few decades, this area has suffered from serious water shortages; despite this fact, it remains one of the core areas with potential for increasing national agricultural production in the future (Cao et al., 2012). Further improvement on agricultural water use efficiency (WUE) in this region depends on the effective conservation of moisture and the efficient use of the limited water supply (Deng et al., 2006). Several researchers have explored various methods of improving WUE through advanced agricultural technologies. Although water-saving agricultural technology has expanded rapidly in recent years, there is still considerable room for further development (Blanke et al., 2007).

Drought in the North China Plain negatively affects the stability of grain production in summer maize; thus, many scientists have researched the use of straw mulching as a water-saving technology to combat this problem. Straw mulching is known to play an important role in increasing grain yield (Stagnari et al., 2014), WUE (Prosdocimi et al., 2016; Fernandez and Vega, 2016), and soil moisture (Fernández et al., 2016), while reducing soil erosion, conserving soil moisture, and restraining runoff and total sediment yield (Zhang et al., 2015). It can also reduce the soil-temperature swing between the maximal and minimal and minimize the soil-temperature flux between day and night (Chen et al., 2004). The combination of straw mulching and other agricultural management techniques also has a largely positive effect on grain yield and WUE. For example, scientists found that furrow planting and straw mulching led to an increase in water availability for maize growth and improved maize yield and precipitation-use efficiency (Wang et al., 2011). Moreover, spring maize systems with subsoil tillage and 50% chopped straw mulching (maize straw mulching was used at 4210 kg/ha and chopped with a multi-function mill before being evenly spread) seemed to have a great potential for improving yield and WUE in North China (Tao et al., 2015). Thus, the combination of straw mulching and a suitable planting pattern may potentially improve the water-saving ability and grain yield of summer maize.

The monsoon climate in the North China Plain concentrates precipitation mainly between July and September. This means that the water needs of summer maize in the early growing stages cannot be met; thus necessitating additional moisture to improve grain yields. Soil moisture before sowing (SMBS) considerably influences seedling emergence rate and the growth of maize. However, once a

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certain soil moisture content was attained, its effects decreased. Ma et al. (2012) indicated that below field capacity, a greater soil moisture content resulted in a greater rate of emergence in maize. Soil drought delays the period of emergence and decreases the emergence rate of maize; therefore, in the early growth stages of summer maize, SMBS is a very important factor in determining a high and stable grain yield.

Few studies have focused on the combined effects of SMBS and straw mulching on the seedling emergence rates, grain yield, and WUE of summer maize. Pre-sowing irrigation is an agricultural technique that can change the content of SMBS. This study aimed to explore the effects of the combination of pre-sowing irrigation techniques and straw mulching on the grain yield and water consumption of summer maize, in order to provide a theoretical basis and technical support for water-saving agriculture in the North China Plain. We hypothesized that combining straw mulching and pre-sowing irrigation techniques will improve grain yield and water use efficiency in summer maize.

2. Materials and methods

2.1. Experimental site

The study area was located at the Experimental Station of Shandong Agricultural University (36°10′19”, 117°9′03”) in the North China Plain, which experiences a temperate, continental, semi-humid, monsoon climate, where the mean precipitation in summer (July to September) is 453.7 mm, and makes up approximately 65.1% of the annual precipitation. In summer maize, the average temperature and potential evapotranspiration in the 2014 growing season were 24.8 °C and 414.9 mm, and in 2015, 24.1 °C and 349.0 mm, respectively. The site had a light loamy soil texture and the concentration of rapidly available phosphorous, potassium, and nitrogen were 108.1, 92.4, and 16.1 mg/kg, respectively. Field capacity of the soil in the 0–20-cm, 20–40-cm, and below 60-cm profiles was −0.72, −0.65, and −0.59 MPa, respectively. The average permanent wilting point of the root zone soil was −67.9 MPa, the pH value at this experiment site was approximately 6.9, and the organic matter content was 1.4% in weight. The experiment involved the use of the summer maize variety DengHai661, which was seeded manually on June 13, 2014, and June 15, 2015. Summer maize was sown at a density of 7.5×10^4-plants/ha with a plant and row spacing of 22.2 cm and 60.0 cm, respectively, following the harvest of the winter wheat crop.

2.2. Experimental design

The experiments were conducted in experimental plots (3.0 × 3.0 × 1.5 m; length × width × depth), and cement slabs were placed around each plot to prevent surface runoff. We adopted a split plot design, and arranged them in randomized blocks with three replications per block. The main blocks were subjected to one of the following three pre-sowing irrigation treatments: 30-, 70-, and 110-mm. The sub-plots were split into straw mulching and non-mulching treatments. Thus, there were six treatments in the experiment: pre-sowing irrigated treatments at 30-mm with (30M) and without (30N) straw mulching, 70-mm with (70M) and without (70N) straw mulching, and 110-mm with (110M) and without (110N) straw mulching. Irrigation water was provided via a pump outlet near the experiment site, and directed using plastic pipes, which were controlled by a flow meter. Irrigation was carried out, as we designed above, on the day before sowing. Available soil water contents on the day of sowing in the 2014 summer maize growing season for the 30M, 30N, 70M, 70N, 110M, and 110N treatments in the 0–160-cm soil profile were 276.5, 280.3, 316.4, 305.7, 341.3, 350.1 mm, and in 2015 were 258.1, 274.1, 305.7, 295.9, 343.5, and 328.9 mm, respectively. During the summer maize five-leaf stage, straw mulching was applied at a rate of 0.6 kg/m^2 by spreading winter wheat straw that was chopped into 3- to 5-cm pieces. During the summer maize growing seasons, the sites were not irrigated.

2.3. Measurements

2.3.1. Soil moisture content

The volumetric soil moisture content of samples collected every 10 cm from the top 160 cm of the soil profile was measured using a CNC503 B neutron moisture meter (Super Energy Nuclear Technology Ltd., Beijing, China). A 2.0-m neutron tube was installed in the soil in each plot to quantify soil moisture content. Before taking measurements in the field, a calibration was performed in the laboratory. The first soil moisture measurement was taken on the same day as manual sowing, and the last measurement on the day of harvesting. Measurements were carried out at approximately seven-day intervals. Following precipitation events, additional measurements were taken. The moisture content within the upper 20-cm soil layer was measured using the oven-drying method.

2.3.2. Evapotranspiration

Evapotranspiration of summer maize was calculated using the following equation (Li et al., 2010):

$$ET = P - R - D - SW,$$

where: ET, evapotranspiration (mm); P, precipitation (mm) measured with a standard rain gauge at the weather station at the site; R, surface runoff (mm) (there were no major runoff events in the summer maize growth seasons owing to the cement slabs placed around each plot, so we assumed surface runoff was insignificant); D, downward flux below the crop root zone (mm) (deep percolation was ignored as we found negligible drainage at the site); and SW, water storage change in the 0–160-cm soil profile (mm).

2.3.3. Grain yield and yield composition

We manually harvested the two central lines of each experimental plot on October 1, 2014, and October 2, 2015, to determine the maize grain yields. The number of spikes per square-meter and per row, kernel number per spike, air-dry weight of grain yield, and 1000-kernel weight were recorded.

2.3.4. Water use efficiency

Water use efficiency was defined as follows (Zhou et al., 2011):

$$WUE = Y/ET,$$

Where; Y, grain yield (kg/m^2); and ET, total evapotranspiration (mm).

2.3.5. Soil moisture before sowing consumption

SMBS consumption was defined as the soil water consumed by summer maize in the 0–160 cm soil profile throughout both growing seasons. This was calculated by subtracting the value of the final soil moisture content (measured every 10-cm depth interval during harvesting) from the value of the initial soil moisture content (measured every 10-cm depth interval during sowing) (Li et al., 2012).

2.4. Statistical analysis

Analysis of variance (ANOVA) was used to quantify the effects of each treatment. The ANOVA was performed at a 0.05 level of significance to determine whether the effects of each treatment