THE CROP JOURNAL 3 (2015) 445–450

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The Crop Journal

Tillage and straw mulching impacts on grain yield and water use efficiency of spring maize in Northern Huang–Huai–Hai Valley

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A R T I C L E I N F O

Article history:
Received 24 January 2015
Received in revised form 30 July 2015
Accepted 6 August 2015
Available online 16 August 2015

Keywords:
Northern Huang–Huai–Hai valley
Spring maize cropping system
Straw mulching
Subsoil tillage

A B S T R A C T

A two-year field experiment (2012–2013) was conducted to investigate the effects of two tillage methods and five maize straw mulching patterns on the yield, water consumption, and water use efficiency (WUE) of spring maize (*Zea mays* L.) in the northern Huang–Huai–Hai valley of China. Compared to rotary tillage, subsoil tillage resulted in decreases in water consumption by 6.3–7.8% and increases in maize yield by 644.5–673.9 kg ha^{-1}, soil water content by 2.9–3.0%, and WUE by 12.7–15.2%. Chopped straw mulching led to higher yield, soil water content, and WUE as well as lower water consumption than prostrate whole straw mulching. Mulching with 50% chopped straw had the largest positive effects on maize yield, soil water content, and WUE among the five mulching treatments. Tillage had greater influence on maize yield than straw mulching, whereas straw mulching had greater influence on soil water content, water consumption, and WUE than tillage. These results suggest that 50% chopped straw mulching with subsoil tillage is beneficial in spring maize production aiming at high yield and high WUE in the Huang–Huai–Hai valley.

1. Introduction

Food security is challenged by increasing global population, climate change, and resource shortages [1,2]. In particular, severe water scarcity occurs in 45% of the global land resources [3]. The Huang–Huai–Hai valley is one of the major grain production areas in China, with a traditional double cropping system of winter wheat (*Triticum aestivum* L.)–summer maize (*Zea mays* L.). In recent years, water shortage has become the most important constraint to agriculture in this area [4]. Since the late 1980s, high temperature, high evaporation levels, and uneven distribution of rainfall have resulted in more frequent droughts during the maize-growing season, affecting the stability of food production [5,6]. More than 70% of irrigation water are used during the winter wheat season [7]. Recently, spring maize cultivated from the end of March to May has been introduced to serve as an alternative crop to winter wheat–summer maize because it produces 76.7% of the annual grain yield and reduces irrigation water consumption by 50% compared to the winter wheat–summer maize cropping system

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Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.
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http://dx.doi.org/10.1016/j.cj.2015.08.001
2214-5141/

[8]. However, yields in the spring maize cropping system consistently account for only 56.9–66.3% of those in the winter wheat–summer maize system in the Huang–Huai–Hai valley, owing mainly to drought stress [9]. Thus, optimal agronomic practices are desirable for the new cropping system.

Subsoil tillage (ST) and straw mulching are typical cultivation methods used to improve crop yields in arid areas [10,11] and may mitigate drought in the spring maize season. After ST, soil moisture content increased [8], and water infiltrated into deep soil layers [11–13]. With ST, the final yield of spring maize may be markedly improved. Straw mulching can reduce evaporation, increase soil moisture content, and enhance maize growth and development, leading to increased grain yield and water use efficiency (WUE) [4,14,15]. However, the quantity of straw mulch used should be limited within a certain range to prevent deleterious effects on seedling growth, WUE, and ultimately crop productivity [16,17]. The form of straw residue also alters the soil microclimate. Normally, straw mulching is expected to reduce the temperature at 0–10 cm soil depth, to reduce evaporation, and to increase dry matter accumulation during the growth period [18].

In this study, we conducted a two-year field experiment to investigate ST and straw mulching techniques in spring maize in the north Huang–Huai–Hai valley. To our knowledge, this is the first report on the effects of ST combined with straw mulching on spring maize yield and WUE in the Huang–Huai–Hai valley, where drought seriously affects the stability of grain production.

2. Materials and methods

2.1. Site description

A field experiment was conducted at the Agricultural Experimental Site of the Scientific Observation Station of Environment at Langfang, Hebei Province, China (39°06′ N, 116°06′ E), in 2012 and 2013. The area has warm-temperate continental monsoon climate characteristics. The mean annual temperature is 12.0 °C, annual sunshine is 2660 h, and the frost-free period is 183 days. The mean annual precipitation is 556.2 mm, of which more than 70% falls during June–September. The site has a sandy loam soil [19] with the following properties (0–20 cm top layer): 13.8 g kg^{-1} organic matter, 1.1 g kg^{-1} total nitrogen (N), 75.0 mg kg^{-1} available N, 140.6 mg kg^{-1} available potassium (K), and 40.8 mg kg^{-1} available phosphorus (P).

2.2. Experimental design and field management

A spring maize hybrid (ZD958) was used. The experiments used a split-plot design, in which the main plot was tillage method, including ST (to 35 cm depth before sowing) and rotary tillage (RT, to 15 cm depth). The split plot included maize straw mulching at rates of 0% (0C), 50% (50C), and 100% chopped straw mulching (100C), and 0% (0P), 50% (50P), and 100% prostrate whole straw mulching (100P). The average maize stover yield was 8420 kg ha^{-1}, so that 50% and 100% straw coverage represent 4210 and 8420 kg ha^{-1}, respectively. Maize was the previous crop. Maize seeds were planted in narrow (40 cm) and wide rows (80 cm) with maize straw mulching before sowing (Fig. 1). Maize straw was chopped with a multi-function mill (Yulong SG40 type, Yulong Machinery Co., Ltd., Zhangqiu, Shandong Province, China) before being evenly spread in wide rows. Prostrate whole maize straw was manually cut from the maize stalk base and then spread in wide rows. ST and RT were performed in narrow rows in the spring, without incorporation of stubble or main roots into the soil.

The planting density was 82,500 plants ha^{-1}. The experiment was a randomized block design with three replicates and 24 m^2 experimental plots. N fertilizer at 225 kg ha^{-1} was applied in a split ratio of 1:2 before sowing and at 12-leaf stage (with visible leaf collars). Total phosphorus and potassium fertilizers were applied before sowing at 173 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O. Maize was sown on May 11 and May 2 and harvested on September 13 and September 3 in 2012 and 2013, respectively. Herbicide application (42% propisochlor + atrazine, suspension) and manual weeding were performed during the growth period.

Reference evapotranspiration (ET_0) was measured by the Penman–Monteith method [20]. Daily rainfall, maximum and minimum temperatures, air humidity, wind speed, sunshine hours, and Class A pan evaporation were recorded daily at a meteorological station (HL20; Jauntering International Corporation, Tokyo, Japan) located within 100 m of the experimental field (Table 1).

2.3. Data collection

Each plot was harvested manually at maturity. Grain samples were air-dried to a uniform moisture content of 14% for yield evaluation. Soil water content from 0 to 30 cm depth in 10 cm increments was measured before sowing and after harvest using the oven-drying method, whereas soil water content at the 30–120 cm depth in 30 cm increments was measured with a neutron probe (NMM 503 DR; Campbell Pacific Nuclear International Inc., Concord, CA, USA). The locations of soil augering are shown in Fig. 1.

The total actual evapotranspiration over the whole growing season (ET_c, in mm), the amount of infiltration (Dw), and WUE were calculated as follows:

$$ET_c = Pe + I + S – Dw \tag{1}$$

$$Dw = 0.1 \times Pe \text{ [21]} \tag{2}$$

$$WUE = Y/ET_c \text{ [22]} \tag{3}$$

where Pe is the effective precipitation (mm) measured at the meteorological station, I is the irrigation quota (0 mm), ΔS is the change in soil water stored in the 0–120 cm soil layer (mm) before sowing and after harvest, and Y is grain yield (kg ha^{-1}). When a single rainfall event is greater than or equal to 40 mm, the soil will permit deep infiltration.

2.4. Statistical evaluation

Yield, water consumption, and WUE were determined for each plot and analyzed with the analysis of variance (ANOVA) procedure of SPSS 13.0 (SPSS Inc., Chicago, IL, USA). Comparisons among different treatments were performed with Duncan's