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Ridge and furrow planting pattern optimizes canopy structure of summer maize and obtains higher grain yield

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ABSTRACT

Ridge and furrow planting patterns could improve the micro-environment effectively, and ultimately affect maize grain yield. Previous studies mainly focused on planting only on ridges or in furrows aiming to improve the water and temperature conditions, while research on effects of planting in both ridges and furrows on canopy structure and photosynthetic characteristics of individual plants was relatively few. Hence, we hypothesized that planting in both ridges and furrows would (1) optimize maize canopy structure (better light conditions within canopy and delayed leaf senescence), (2) enhance individual leaf photosynthetic characteristics during grain filling, and (3) obtain higher grain yield. To test this hypothesis, we conducted ridge and furrow planting pattern experiments in 2013, 2014 and 2015 growing seasons in Shaanxi, a province in the Northwest of China. Zhengdan958, a corn cultivar planted widely across China, was grown at a density of 67500 plants ha^{-1}. Three planting patterns were arranged as follows: the conventional planting pattern with row spacing of 60 cm (T_0 as control), the ridge and furrow planting pattern with one row plants in each ridge and furrow (T_1) and the ridge and furrow planting pattern with one row in a ridge and two rows in a furrow (T_2). The three-year investigations found that significantly higher relative chlorophyll content and green leaf area per plant were observed in plants of furrows compared to T_0 as well as those on ridges, leading to an advantage in terms of individual photosynthetic capacity for plants in furrows, while no significant differences about them in furrows were found between T_1 and T_2. In addition, we also found that plants in ridge and furrow planting patterns (T_1 and T_2) exhibited a significantly higher transmission of light to lower layers of the canopy (LT) than that of conventional planting pattern (T_0), leading to better light conditions within canopy. Moreover, plants in furrows maintained significantly higher LAI during grain filling, leading to longer LAI duration in T_2 planting pattern than other treatments due to more plants in furrows. The highest yield was observed for T_2 planting pattern during three experimental years. Relative to control, plants in T_2 treatment obtained 27.2%, 18.3% and 31.9% higher grain yield in 2013, 2014 and 2015 growing seasons, respectively. In conclusion, for the tested growing conditions, the planting pattern with one row in a ridge and two rows in a furrow (T_2) optimized canopy structure (higher LT and longer duration of LAI), enhanced photosynthetic capacity per plant (higher P_n) during grain filling, and accumulated higher aboveground dry matter at physiological maturity, leading to a greater grain yield.

1. Introduction

In 2050, the global demand for grain growth would increase by 56%, and that for corn would account for 45% (Hubert et al., 2010). How to dig corn yield potential in order to meet the huge demand for food has becoming the key problems to be solved in the process of high-yield cultivation. Photosynthesis is the basis of crop yield formation, and the canopy structure is an important factor that affects light distribution and photosynthetic characteristics (Maddonni et al., 2001; Yang et al., 2010). Therefore, how to improve light conditions within canopy, maintaining high efficient corn canopy structure and high plant productivity in mid and late grain-filling, is one of the key scientific problems needed to be resolved.

Micro-topography reconstruction is reconstruction of the original

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morphological structure of an underlying surface by humans based on scientific research or the actual demands of transforming nature, forming micro-topographies with different sizes and shapes (Bruland and Richardson, 2005; Wei et al., 2013). Different ridge and furrow planting patterns depended on micro-topography reconstruction, has been used in semiarid areas to improve the microenvironment of crop growth (Ren et al., 2010a,b; Zhou et al., 2012; Mo et al., 2016). For example, the 60 cm ridge with 60 cm furrow (serving as planting zones) planting system could significantly increased soil moisture, decreased evapotranspiration, and the soil temperature conditions were also improved when plants were sowed under another ridge and furrow planting pattern (ridges were covered with plastic film and the furrows were mulched with straw), leading to higher water use efficiency (WUE) and yield (Li et al., 2013; Ren et al., 2016a,b). Previous study also found that double ridge–furrow with whole-year plastic-film mulching could maintain soil water balance in semiarid environment and sustain high grain yields in maize with approximately 110 kg N ha^{-1} (Liu et al., 2014a,b). Moreover, the total dry matter amount per plant was also significantly increased when plants were sowed under plastic-covered ridge–furrow farming systems compared with that in conventional flat farming (Ren et al., 2016a,b).

Previous studies have mainly focused on planting only on ridges or in furrows aiming to improving the microenvironment of crop growth (the water and temperature conditions of soil) and water use efficiency (Moser et al., 2009; Zhou et al., 2009; Zhang et al., 2013a,b; Zhao et al., 2014), while the three-dimensional planting pattern with both ridges and furrows planted crops reduces the competition among individuals by directly changing the ecological niche of individuals in the crop population. However, the research about the effects of planting in both ridges and furrows on canopy structure and photosynthetic characteristics of individual plant was relatively few. Thus, we hypothesized that planting in both ridges and furrows would (1) optimize canopy structure (better light conditions within canopy and delayed leaf senescence), (2) enhance individual leaf photosynthetic characteristics during grain filling, and (3) obtain higher grain yield compared to conventional planting pattern. We tested this hypothesis by arranging three different planting patterns as follows: the ridge and furrow planting pattern with one row plants in each ridge and furrow (T_1) and the ridge and furrow planting pattern with one row in a ridge and two rows in a furrow (T_2), with the conventional planting pattern with row spacing of 60 cm as the control (T_0). We assessed whether population canopy structure, individual plant photosynthetic characteristics and grain yield were improved due to the optimized ridge and furrow planting pattern, to provide a theoretical basis for the construction of high light use efficiency population and super-high-yield corn cultivation.

2. Materials and methods

2.1. Experimental site

A 3-year field experiment was conducted with summer maize between 2013 and 2015 at the Agricultural Experiment Station of Northwest A&F University, located in Yangling, Shaanxi Province (34°20′N, 108°04′E, 454.8 m altitude) in northwestern China. The mean annual temperature over the last 20 years was 13.5 °C. The total annual sunshine was 2196 h and the frost-free period was 211–220 days. The mean annual precipitation at the site was 580.5 mm, and the mean annual evaporation was 993.2 mm. Most of the rainfall occurred from July to September. The experimental field was flat according to the FAO/UNESCO Soil Classifcation (FAO:Rome, 1993), and the soil type was a dark loessial soil. An analysis of soil samples (0–60 cm depth) taken from the same experimental area in September 2013 were showed in Table 1. The precipitation (mm) and sunshine (h) during the growing seasons were measured by an automatic weather station (climate data, Fig. 1).

Table 1
Basic soil nutrients of the tilth soil (0–60 cm depth) in the experimental site (2013).

Soil layer (cm)	Organic matter (g kg^{-1})	Total nitrogen (g kg^{-1})	Alkali-hydrolyzable nitrogen (mg kg^{-1})	Available phosphorus (mg kg^{-1})	Available potassium (mg kg^{-1})
0–20	15.06	1.193	63.61	11.69	161.17
20–40	13.85	0.935	44.87	8.92	117.21
40–60	13.19	1.051	46.77	5.76	102.67

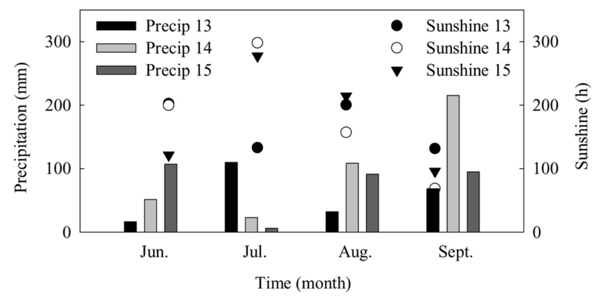

Fig. 1. Monthly sunshine and precipitation recorded during 2013, 2014 and 2015 growing seasons (from June to September). Precip13, Precip14 and Precip15 indicate the monthly precipitation during 2013, 2014 and 2015 growing seasons (from June to September), respectively. Sunshine 13, Sunshine 14 and Sunshine 15 indicate the monthly sunshine hours during 2013, 2014 and 2015 growing seasons (from June to September), respectively.

2.2. Experimental design

The experimental design was a randomized block with three replications. Each plot was 10 m long and 5.4 m wide with row spacing of 60 cm, and the same plots were used for the three years and the treatments were the same on each plot. All plots were supplied with 225 kg N ha^{-1}, 120 kg P_2O_5 ha^{-1} and 96 kg K_2O ha^{-1}. All P and K fertilizers and 60% of the N fertilizer were applied at pre-sowing. At the twelfth leaf stage (V12; Ritchie and Hanway, 1982), the remaining 40% of urea (N 46%) was applied as a top dressing.

Zhengdan 958, a compact maize cultivar planted widely in local production, was selected in this experiment. Maize seed was over-planted with hand planters on 8 June 2013, 16 June 2014, and 10 June 2015, and subsequently thinned at V3 (the third leaf stage; Ritchie and Hanway, 1982; 28 June 2013, 2 July 2014 and 29 June 2015) to a uniform density of 67500 plants ha^{-1} (a normal density for the growing conditions of the northwestern China). Three planting patterns were arranged as follows (Fig. 2): the conventional planting pattern with row spacing of 60 cm (T_0), the ridge and furrow planting pattern with one row plants in each ridge and furrow (T_1) and the ridge and furrow planting pattern with one row in a ridge and two rows in a furrow (T_2). The ridge height of all ridge and furrow planting patterns was 15 cm. The plot was bordered on each side by one guard row of the selected cultivar, and plants from these lines were not included for any sampling. The date of harvest was 28 September October 2013, 15 October 2014 and 16 October 2015. During the entire growth period, disease, pest and weed control in each treatment were well controlled by managers. Irrigation was applied when it was necessary.

2.3. Measurements

2.3.1. Plant height and plant population height

The plant height of maize at tasseling stage (5 August 2013, 3 August 2014 and 7 August 2015, respectively) was measured, and the plant population height was calculated as follows:

Plant population height (cm) = plant height (cm) + ridge height (15 cm)