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Efficacy of planting date adjustment as a cultivation strategy to cope with drought stress and increase rainfed maize yield and water-use efficiency

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ABSTRACT

Given the frequent drought pressure caused by the unpredictable and limited precipitation concurrent with global climate change, highly efficient cultivation technologies have been increasingly recognized by various levels of scientific communities. Understanding plant–environment relationships in rainfed dry land may help maximize crop productivity while improving water utilization of farmland. Field experiments were conducted in 2012–2014 at the Dryland Maize Experimental Station of the Northwest A&F University, China to determine the effects of possible drought stress and the environmental factors involved during sowing at different sowing dates on maize vegetative growth and grain yield (*Zea mays* L.), as well as water-use efficiency (WUE = grain yield per unit of seasonal evapotranspiration). Six planting date (PD) treatments with sowing performed for 6 days from April 10 to May 10 were designed. Results showed that the maize growth period was shortened with the postponement of planting time. The vegetative growth stage and the overlapping stages of vegetative and reproductive growth varied by 4–19 days among various PD practices. However, the reproductive growth stage duration was relatively stable and varied by 3–5 days only among the different PD practices. Within a certain time range, dry matter production per plant did not obviously change across the different PD treatments. However, the dry matter accumulation in the ear after flowering, the yield, and the WUE in the treatments under appropriate PDs (April 16–April 28) were 2.2%–28.8%, 2.3%–24.7%, and 6.6%–15.2% higher, respectively, than those in the early or delayed PDs. These findings resulted from the changes in soil water content with PD adjustment. Yield was highly correlated to the soil moisture content during PD, the rainfall before silking, the effective accumulated temperature after silking, and the sunshine hours after silking. Moreover, the thousand-grain weight was highly correlated with the sunshine hours after silking. In the early PDs, the main factor that affected maize yield was the low content of soil moisture, which generated low effective ear number per unit area and seedling emergence ratio. In the late PDs, the main factors that influenced maize yield were the low effective accumulated temperature and the short sunshine hours during the reproductive growth stage, which produced less dry matter accumulation after silking and lower thousand-grain weight. Under suitable sowing time, the actual harvest ear number per hectare and dry matter accumulation of female ear after silking increased. Similarly, the maize yield and WUE increased. By considering the ecological factors and study results, we recommend that the most suitable sowing time for maize should be determined on the basis of the soil moisture content before April 28. As such, we can effectively achieve high yield and avoid drought in the study region. Overall, the results can provide effective cultivation techniques to prevent drought stress in spring maize in the present agro-ecosystem of northern China and other similar areas.

1. Introduction

China covers a large region of dryland farming in the north, and this region accounts for approximately 56% of the nation's total land area (Xin and Wang, 1999). The dry semi-humid zone with 500–600 mm annual rainfall covers about half of the dry-

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land area. This region is characterized by mono-cropping systems mainly composed of maize (*Zea mays* L.) or wheat (*Triticum aestivum*). Water stress is the main limiting factor for crop production in rainfed farming systems in arid and semi-arid areas (Debaeke and Aboudrare, 2004). Crop yield is primarily affected by annual rainfall and rainfall distribution (Huang et al., 2011). As the main crop, maize typically grows from early April to late September, whereas 60%–70% of annual precipitation mainly falls during summer from July to September. Spring droughts have occurred in most years, and the seasonal drought periods have reduced both spring maize seedling emergence and yield during those years (Gao et al., 1991). In addition, dry periods are expected to become more frequent because of climate change (Solomon et al., 2007).

Studies have shown that climate warming varies significantly among the regions and seasons in China, particularly the north warming and the south cooling versus winter warming and summer cooling (Sha et al., 1980). The degree of climate change influence on agricultural production differs among crops (Schlenker and Lobell, 2010; Thornton et al., 2011) and agricultural systems (Thornton et al., 2010). Therefore, the farmers' choices of adequate cropping systems and crop cultivars, especially in precipitation-limited areas, might be an important adaptation strategy to modify climate conditions (Thomas et al., 2007). Duan et al. (2000) noted that adaptation strategies for cropping systems should be prioritized for the regions affected by climate change. However, few studies have investigated the effects of climate change on agriculture in north China, considering the cropping system applied. The selection of better crops and more effective cropping systems may serve as an important adaptation strategy to address climate change, hence, management options should be considered in studies on climate change influence on agriculture (Waha et al., 2013). Climate change and its effects on water resources are major forces which China and the rest of the world must cope in the 21st century (Editorial board, 2007). Drought is projected as the most important environmental stress in future agriculture. Drought effects can be minimized by adjusting the planting date (PD), as such, flowering occurs when drought risk is observed to be minimal. Hence, by adjusting the sowing time, we may hope to find important links between natural precipitation and corn's growing water demand, perhaps even to discover that they coincide in time, thereby increasing soil moisture at maize planting and flowering. In this context, a suitable PD should be determined to increase the crop yield and WUE.

Maize is sensitive to water stress (Cakir, 2004). Plant-available water in soil is a key driver for maize production in water-limited environments. Technologies for improving crop WUE are critical for sustainable crop production and local food security. Management practices such as mulching (Zhang et al., 2014), row spacing reductions (Barbieri et al., 2012), and nitrogen supply (Mueller et al., 2012) display potential for increasing the WUE in maize (Hatfield et al., 2001). However, in some dry years, the above strategies are useless because of water deficiency in soil derived from less rainfall in the field at some lengthy stages. Thus, determining how to adjust the PD to achieve maize growth requires conformity with the rainfall in the site under study. Rainfall effectiveness is the chief obstacle in arid and semi-arid areas. Therefore, improving the utilization efficiency of precipitation should be considered as a key to determine the optimum PD for crops (Wu et al., 2005). Many studies have explored the PD of maize, but most of these works were conducted to understand the grain yield and dry matter (DM) production mechanism under sufficient rainfall or irrigation (Krupnik et al., 2015; Tsimba et al., 2013; Li et al., 2012). Furthermore, no report was noted about the crop WUE and its relation to soil water and the precipitation change under different PD cultivation systems in the dryland area. Increasing the crop WUE by correctly ascertaining the PD is an effective way to address the lack of water supply in the dryland area of north China.

Few studies have delved on the mechanisms underling the technology that increases crop WUE at appropriate maize planting times in arid and semi-arid areas. Therefore, the present experiment was designed and conducted in the field to (i) analyze the yield, water use, and WUE responses to various PDs; (ii) discuss the relationships among environmental factors of various PDs and yield components and (iii) determine an appropriate planting date for maximum WUE and maize yields in the Loess Plateau, China.

2. Materials and methods

2.1. Description of the experimental site

The experiment was conducted from 2012 to 2014 at the Northwest A&F University Arid Maize Research Station (34°59′N, 107°38′E and altitude 1220 m) in Changwu County of Shaanxi Province, China. The climate is temperate semi-arid with a mean monthly maximum temperature of 22 °C (July) and a mean monthly minimum temperature of −7 °C (January). The mean annual long-term temperature (1960–2014) was approximately 9.4 °C. The precipitation was 546 mm, the annual sunshine was 2124 h, and the frost-free period was 171 days (Fig. 1). The mean annual rainfall was more than 64.0%, which occurred in July, August, and September. Irrigation was unavailable in this area. The site was covered with loess sandy soil of 11.56 g kg^{-1} mean organic carbon and pH 8.2. The mean substrate contained 46.66 mg N kg^{-1}, 16.94 mg P_2O_5 kg^{-1}, and 122.35 mg K_2O kg^{-1}. The mean rainfall values per month in 2012–2014 are presented in Fig. 2.

2.2. Experimental design and field management

The range of planting dates evaluated in this study were designed to create contrasting environmental conditions that represent a wide range of situations for maize growth and development. Thus, PDs were widely spread to a month, according to local usual sowing time (at the beginning of April, planting is completed about a week). In this experiment, sowing was performed for 6 days from April 10 to May 10, which gave a total of six PDs (April 10, 16, 22, and 28 and May 4 and 10) designated as A, B, C, D, E, and F, correspondingly. The maize cultivar Shaandan 609, which is planted most commonly in the area, was used as experimental material. The planting density was 6.00×10^4 plants ha^{-1}, and the plot size was 19.5 m^2 (3.0 m × 6.5 m). Six PD systems (treatments) were arranged in a randomized, complete block design with four replicates. The crop was fertilized with urea at the rate of 225 kg N ha^{-1} and superphosphate of 120 kg P_2O_5 ha^{-1}. Both P and 40% N were applied as base fertilizers, and the remaining N was applied at the jointing stage (30%) of the sixth extended leaf and grain-filling stages (30%) 10 days after silking. The seeding rate was the same among all the treatments, each yielding 320 grains. Maize was harvested on September 28, 2012; September 27, 2013; and September 27, 2014. No irrigation was performed in the entire growing season. Diseases, pests, and weeds in each treatment were well controlled by managers.

2.3. Sampling and measurement

The dates of sowing, emergence, jointing (sixth extended leaf stage), flare opening (thirteenth extended leaf stage), silking, and maturity were recorded. The emergence date refers to the day when 60% of the plants emerged. The silking date corresponds to the day when 60% of the ears showed silk emergence. The maturity date is the date at which the kernel achieved its peak DM accumulation. The hard starch layer reached the cob, and a black abscission layer,