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Plastic film cover during the fallow season preceding sowing increases yield and water use efficiency of rain-fed spring maize in a semi-arid climate

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ABSTRACT

Plastic film mulch increases crop yields in rain-fed agriculture in cool semi-arid climates by warming the soil and reducing evaporative water losses. The semi-arid Khorchin area in Northeast China is an important production area for rain-fed maize. Drought stress occurs frequently, even if plastic film mulch is applied at sowing. We hypothesized that the yield and water capture of maize could be increased by reducing evaporative loss of water by use of plastic film cover during the autumn and winter preceding sowing. In this study, we compared maize growth, water uptake and yield in three film cover treatments: (1) film cover from the autumn before maize sowing until maize harvest (autumn mulching: AM), (2) film cover from maize sowing till harvest (conventional practice) (spring mulching: SM), (3) no film cover (no mulch: NM). Field experiments were conducted in Fuxin city, Khorchin region, Liaoning province, China in 2013/2014 and 2014/2015. Autumn mulching increased grain yield on average by 18% when compared to spring mulching and by 36% when compared to no mulching. The 1000-kernel weight in AM was 7% higher than in SM, and 12% higher than in NM. Soil water content in the root zone before sowing was 35 mm greater in AM than in SM and NM. Water uptake during the growing season was 34 mm greater in AM than in SM and NM. Water use efficiency for grain yield (yield per unit water uptake) in AM was on average 2.5% higher than in conventional mulching (SM) and 27% higher than in NM. Autumn mulching advanced development, with an advance of 5 days in tasseling time as compared to SM and 10 days when compared to NM. These results show that film cover during the fallow period before maize sowing can increase crop yield and water use efficiency, and reduce climate risks in rain-fed agriculture under semi-arid conditions.

1. Introduction

Maize (*Zea mays* L.) is one of the worldmost important cereals. It is a major food and feed crop in China and 31% of the grain production amount occurs in the Northeast region, where maize is mainly rain-fed with an average yield of 5.3 t ha^{-1} (Dong et al., 2017). Low spring temperatures and frequent summer droughts are limiting factors for yield in this region (Cai et al., 2017). With global warming, a drying trend with high variation of precipitation was reported (Piao et al., 2010) and an increase in the frequency and severity of droughts was projected for Northeast China (Xu et al., 2013; Song et al., 2014; Yu et al., 2014). Such changes would have a strong negative impact on future maize yield and yield stability (Misra, 2014; Zhu et al., 2015).

Plastic film mulching decreases soil evaporation (Li et al., 2013; Tian et al., 2003; Wang et al., 2008). It is a water-saving measure that improves maize yield and yield stability in dryland agriculture and is widely applied in many countries, but especially in China (Gan et al., 2013; Liu et al., 2014a). Other water-saving measures are also applied, such as straw mulching (Tao et al., 2015), conservation bench terraces (Sharda et al., 2015) or contour furrows (Gebreegziabher et al., 2009).

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The area of plastic film cover in China was approximately 20 million hectares in 2011, and it has increased by 7.1% per year in recent years (Liu et al., 2014a).

Film mulching can significantly improve crop yield and quality (Kar, 2003; Li et al., 2004; Luis et al., 2011; Ramakrishna et al., 2006; Wang et al., 2008). Film mulching accelerates growth and development (Daryanto et al., 2017), and increases water use efficiency (WUE) due to lower water loss through evaporation and a higher proportion of the water that is used for transpiration than would be the case without film cover (Wang et al., 2008; Zegada-Lizarazu and Berliner, 2011; Li et al., 2013). Film mulching increases maize yield by 34% and WUE by 39% across whole China (Liu et al., 2014a). Soil temperature under film increases 1.6–3.5 °C during early growth (Gan et al., 2013; Zhao et al., 2014), resulting in rapid germination and seedling establishment (Wang et al., 2005; Zhao et al., 2012; Bhardwaj, 2013; Liu et al., 2016). The effects of plastic film mulching differ with climate, soil and management (Li et al., 2001; Ren et al., 2008; Zhang et al., 2011).

In semi-arid Northeast China, 20% of the precipitation occurs during the fallow season in autumn and winter, and part of this water is lost due to high soil evaporation caused by high wind speed and a bare soil surface (Li et al., 2004; Dong et al., 2009). Even if the average total precipitation in a whole year generally equals the crop water requirement (approximately 500 mm), the yearly and intra-seasonal variation my still result in drought stress, mostly mild drought stress during the summer (Cai et al., 2017). Rainfall during the maize growing season does not completely satisfy the demand of maize (Zhang et al., 2014), especially not in dry years, even when film cover is applied during the vegetation period (Jia et al., 2017).

The Khorchin area of Liaoning province in Northeast China is suitable for rain-fed maize growing. From 1985 to 2015, the annual precipitation was 483 mm in whole year and the average precipitation during the crop growing season was 407 mm (May to September). The total rainfall during crop growing season is thus not enough for growing high yield maize. We hypothesized that water availability, water use efficiency and maize yield could be improved if the water loss during fallow season was reduced by the use of mulching film during the fallow season. Other advantages of mulching film during fallow season would be the alleviation of drought stress and an increase in soil temperature during early spring, which would allow faster germination and earlier sowing, thus lengthening the growing season. A multi-site and long term experiment in Gansu (Northwest China) showed that plastic film cover during winter and the crop growing season increased maize yield by 30–107 % compared to a treatment without film cover (Wang et al., 2016). On the other hand, film cover at sowing and leaving the film at field during winter and the next crop in no tillage maize showed no significant yield increase compared to a no film control or a treatment with spring film cover from one month before sowing under conventional tillage in Gansu (Liu et al., 2009). A simulation study showed that plastic film mulching increased crop yield from 4 to 254% on the Loess Plateau of China when compared with no film control, and highly associated with the condition of precipitation and air temperature (Zhang et al., 2018).

Previous studies thus indicate variation in benefits of film cover during winter. Previous studies do not elucidate the role of film cover during the winter, and leave questions about the effects of tillage difference. Effects of film mulch vary with climatic conditions. There is no knowledge of the effects of film during the fallow season under the semi-arid conditions of Northeast China, where farmers usually do not use film cover or only during the crop season because of a better hydrothermal condition than in Northwest China. To our knowledge, this is the first study to test the use of film cover during the fallow period before sowing in this type of environment.

The objective of this study was to quantify crop growth, development, yield and water use efficiency of rain-fed maize in a semi-arid region when the film cover was applied during the previous autumn. We used two reference treatments: film mulching at sowing, which is the current practice, and a film free control.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted from October 2013 to September 2015 including two entire crop seasons (2014 and 2015) at the Scientific Observing and Experiment Station of Fuxin Agro-Environment and Arable Land Conservation, Ministry of Agriculture, Fuxin county, Liaoning province, located in the south Khorchin area in Northeast China (121.70N, 42.11E, 213 m altitude). The climate is classified as cold with a dry winter and hot summer (Dwa) in the Köppen-Geiger classification (Peel et al., 2007). On average from 1965 to 2015, the annual mean air temperature was 8.2 °C, sunshine hours were 1488 h from April to September, accumulated temperature above a base temperature of 10 °C was 3373 °C d, the frost-free period was 175 d, and annual rainfall was 429 mm during the crop growing season (1 April to 30 September). The rainfall during the fallow season (1 October to 30 March) was 75.9 mm. The average annual potential evaporation was 1050 mm.

Weather data from 2013 to 2015 were measured with an automatic weather station (WS-STD1, Delta-T, UK) near the experimental field (Fig. 1). The total precipitation during the fallow season was 79.9 mm in 2013/2014 (from 1 October 2013 to 26 April 2014) and 75.2 mm in 2014/2015 (from 1 October 2014 to 28 April 2015). The pan evaporation during the fallow season was similar in the two experimental seasons, on average, 530 mm. The precipitation during the growing

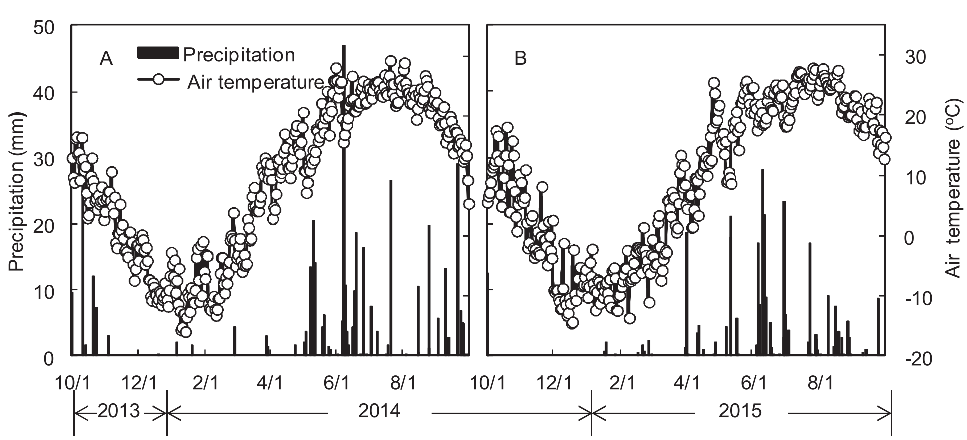

Fig. 1. Daily precipitation and air temperature at Fuxin county, Korchin region, Liaoning province, China in the experimental seasons of 2013/2014 (A), and 2014/2015 (B).