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Effects of plastic film combined with straw mulch on grain yield and water use efficiency of winter wheat in Loess Plateau

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ABSTRACT

The development of effective water management practices is critical for increasing winter wheat production and achieving food security and sustainable development of dryland agriculture in China. A 3-year field experiment was conducted from Sept 2007 to July 2010 at a tableland and a terrace in Loess Plateau to investigate the effects of plastic film combined with straw mulch on soil moisture, temperature, grain yield, and water use efficiency (WUE) of winter wheat in the drylands. The results indicated that grain yield and WUE greatly varied with precipitation and drought indexes among years, but the plastic film combined with straw mulch (FS) invariably increased grain yield (mean 35%) and WUE (mean 25%) with a slight increase of evapotranspiration (ET) (mean 8%) compared with conventional practices (CK). In the fallow period, the ridge-furrow framework in the FS treatment significantly increased rainwater retention in the furrow during periods of high precipitation, and consequently soil water storage was elevated during sowing. In the growing season, the FS treatment created soil conditions that were both cooler in the hot summer months and warmer in the cool winter months and thus effectively reduced soil water evaporation and retained moisture. Therefore, plastic film combined with straw mulch could serve as a water management procedure in the Loess Plateau. Compared with the tableland, a 35% lower mean grain yield and 33% lower mean WUE were recorded at the terrace, which was attributed to differences in soil properties. Thus, there is considerable potential for further improvement in winter wheat production and WUE at the terrace when the FS was adopted with the modification of soil properties.

1. Introduction

The Loess Plateau covers about 40 million ha and is an important cereal production area in China (Huang and Li., 2000). Winter wheat (*Triticum aestivum L.*), one of the most commonly grown crops in the Loess Plateau, occupies 44% of the cultivated area and plays a key role in achieving food security in this region (Jin et al., 2007). Due to the lack of irrigation, winter wheat yield greatly varies among years and entirely depends on natural precipitation. Therefore, the effective capture and detention of the limited precipitation via water management practices is critical to maintain and improve winter wheat production and water use efficiency (WUE) in this region.

Studies have found that soil surface mulch (e.g. straw mulch, plastic film mulch), a widely employed water management practice, effectively reduced soil surface evaporation, increased rainwater detention, and thus increased soil water storage (Li et al., 2009, 2012; Chakraborty et al., 2010; Zhou et al., 2011). However, lower soil temperatures caused by straw mulch froze the seedlings and roots of winter wheat in the cool winter months, which negatively influenced germination and tiller growth (Gao et al., 2009). Moreover, the reduction in evaporation and retention of water were greatly limited and relatively short-lived because of rapid mulch degradation due to high microbial activity stimulated by adequate nutrient supplies (Tolk et al., 1999). These negative effects limited the increase in wheat yield and WUE to a certain extent; moreover, wheat yield greatly varied with climate change (Huang et al., 2005; Chen et al., 2013).

In contrast, significant increases in crop production (especially maize and wheat) and WUE due to improvements in soil water storage and temperature from plastic film mulch have been reported (Deng et al., 2006; Gan et al., 2013). The ridge-furrow framework in plastic film mulch systems increased rainwater detention and infiltration during the crop-growing season; however, during the early growing stage, it did not contribute to the reduction in water

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Table 1
Soil properties (0–20 cm) prior to planting in 2007.

Experiment locations	SOM ($g\,kg^{-1}$)	Bulk density ($g\,cm^{-3}$)	Sand 0.05–2 mm (%)	Silt 0.002–0.05 mm (%)	Clay <0.002 mm (%)
Tableland	18.3	1.20	1.7	75.2	24.1
Terrace	10.0	1.23	10.9	65.1	24.0

loss via evaporation in the furrow where crop was planted. Studies have found that evaporation, rather than transpiration, dominated water depletion when wheat shoots were small in the Loess Plateau (Zhao et al., 1996; Zhou and Xu., 1997; Zhang, 2009).

The positive effects of plastic film mulch on ridges combined with straw mulch in furrows on maize production have been well evaluated and are highly recommended for maize cultivation in the Loess Plateau. However, little is known about the effects of these treatments on winter wheat. Therefore, the objective of this study is to investigate the effects of plastic film combined with straw mulch on the soil hydrothermal regime, grain yield, and WUE of winter wheat. The results can be used to improve winter wheat high-yield and water-saving cultivation systems in the drylands of the Loess Plateau and provide guidance to other drylands.

2. Materials and methods

2.1. Experimental site and design

The experiment was conducted simultaneously at a tableland (1230 m above sea level, 35°14′N, 107°40′E) and a terrace (1162 m above sea level, 35°13′N, 107°41′E) site, located in Changwu County, Shaanxi Province, China. This region has a semiarid continental climate with an average annual temperature of 9.1 °C, pan evaporation of 1500 mm, and precipitation of 542 mm. About 60% of the precipitation is concentrated between July and Sept. The crop rotation was winter wheat–summer fallow–winter wheat. The soil type was silt loam, according to the USDA textural classification system, and the soil properties measured using the recommended methods (Bao, 2000) are shown in Table 1.

The experimental treatments included conventional agricultural practices (control, CK) and the combination of plastic film and straw mulch (FS). Prior to planting in 2007, two replications of each treatment were applied to randomly distributed plots [50.2 m^2 (7.6 m × 6.6 m)] in the tableland. In the terrace, five replications of each treatment were applied to randomly distributed plots [57.6 m^2 (12 m × 4.8 m)]. The total area of the four tableland plots was ~200.8 m^2 and that of the 10 terrace plots was ~576 m^2, and every plot position remained the same throughout the 3-year study.

Before each sowing, the weeds were removed, fertilizers (120 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}) were broadcast and incorporated into ~20 cm deep as the soil was tilled in each plot, after which the wheat was directly sown in the CK plots. However, in the FS treatment, each plot was used for building ridge-furrow framework, in which the ridge (60 cm width and 15 cm height) was covered with non-readily degradable white plastic film (0.005 mm thickness and 80 cm width), and wheat was planted in the furrow (60 cm width and 15 cm depth). During the seeding stage, wheat straw (0.45 kg m^{-2}) from the previous season was chopped into 10-cm pieces and spread evenly between rows of wheat (~7 cm thickness) in the FS furrows. At maturity, the wheat was harvested, leaving the stubble (5–10 cm) and roots in all treatments and the plastic film residues from the FS treatments were removed. The time schedule was shown in Table 2.

After each season's harvest, the air-dried grain weight was recorded for each plot and used to calculate grain yield in all treatments. During the fallow period, all the plots remained bare until the following season. The cultivar of winter wheat was Changhan 58. The sowing depth, sowing rate, and row spacing were 6 cm, 150 kg ha^{-1}, 20 cm, respectively. Weeding and herbicide application followed standard field management practices for this region and all field operations were conducted manually.

Table 2
Experimental time schedule.

Season	Sowing	Straw mulch[a]	Harvest
2007–2008	Sept 23, 2007	Nov 7, 2007	Jun 16, 2008
2008–2009	Sept 20, 2008	Nov 4, 2008	Jun 19, 2009
2009–2010	Oct 3, 2009	Nov 12, 2009	Jun 25, 2010

[a] Straw mulch was only applied in the furrows of FS treatments.

2.2. Soil moisture and temperature measurements and ET and WUE calculation

Neutron probes (CNC503B, DR) recorded the soil water content of all plots every 10 cm in the 30–60 cm layer and every 20 cm in the 60–200 cm layer twice a month throughout the study period (Zhang et al., 2009). The topsoil (0–20 cm) of each treatment (with two replications at tableland and three replications at the terrace) was collected with an auger (diameter of 2.5 cm) and its soil moisture was measured by the drying method. Soil water storage in the 200-cm layer was calculated by summing the soil water storage in different layers.

Fully automatic geothermal pocket data loggers (StowAway TidbiT, USA) recorded soil temperature at three replicate locations in the 10-cm layer of the terrace plots. The instruments were installed in the middle of the selected CK plots and in both the middle of the ridge and the furrow in the selected FS plots. Temperature data was recorded automatically each hour and the average 24-h temperature was used as the daily topsoil temperature.

Evapotranspiration (ET) was calculated by the following soil–water balance equation (Kang et al., 2002; Liu et al., 2010; Zhou et al., 2011):

$$\mathrm{ET} = \Delta W + P,$$

where ΔW (mm) is the soil water depletion (soil water storage in 200-cm layer at sowing minus that at harvest) and P is the precipitation determined at the tableland during the growing season (mm). In addition, WUE (kg ha^{-1} mm^{-1}) was calculated according to:

$$\mathrm{WUE} = Y/\mathrm{ET},$$

where Y is grain yield of winter wheat (kg ha^{-1}).

2.3. Statistical analyses

The data from each site were grouped by season and a one-way analysis of variance using SPSS 17 software was performed to test for differences between treatments. Multiple comparisons were made using the least significant difference at the 5% level.