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Straw mulching increases precipitation storage rather than water use efficiency and dryland winter wheat yield

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ABSTRACT

Straw mulching is widely used to conserve soil water and increase crop yields. The effects of wheat straw mulching rate and method on dryland soil water storage, winter wheat (*Triticum aestivum* L.) growth and yield, and water-use efficiency (WUE) were examined from 2008 to 2015 in the Loess Plateau of China. Treatments included wheat straw mulching at a high rate of 9000 kg ha^{-1} (HSM) and low rate of 4500 kg ha^{-1} (LSM) throughout the year, straw mulching at a rate of 9000 kg ha^{-1} during summer fallow (FSM), and no mulching (CK). Soil water storage at wheat planting and precipitation-storage efficiency (PSE) were greater with straw mulching than without. Soil water storage at harvest was greater with HSM than CK and FSM. Wheat yield components such as number of wheat seedling, plant, tiller, and spike and thousand-grain weight varied with treatments and years, but wheat aboveground biomass and grain yields were usually greater with mulching than without during years with below-average precipitation. Harvest index and WUE were lower with LSM and HSM than other treatments in most years, but evapotranspiration did not vary with treatments. Overall, the increased PSE due to straw mulching did not increase yield and WUE, and straw mulching could sustain dryland wheat grain yield only in dry years.

1. Introduction

Precipitation is one of the major factors dictating dryland crop production in the world. Reducing soil water evaporation, increasing precipitation storage efficiency (PSE) and improving crop water use efficiency are main challenges for sustaining dryland crop yields. During the last several decades, straw mulching has been widely used to conserve soil water and increase crop yields as well as to improve soil fertility and reduce erosion in arid and semiarid regions of Spain (Jordán et al., 2010), India (Chakraborty et al., 2008; Chakraborty et al., 2010; Sharma et al., 2011), USA (Baumhardt and Jones, 2002), and China (Su et al., 2007; Wang et al., 2012; Li et al., 2013; Wang and Shangguan, 2015; Zhang et al., 2015). In the northern Plain and Loess Plateau of China, it has been shown that straw mulching can improve wheat WUE by 10–20% compared with no mulching (Deng et al., 2006).

However, the effect of straw mulching on soil water conservation and crop yield has been highly variable, depending on mulching practices (Cook et al., 2006; Zhang et al., 2015), climate and soil conditions (Tolk et al., 1999; Stagnari et al., 2014; Wang et al., 2015). Chakraborty et al. (2010) found that wheat (*T. aestivum* L.) grain yield and water-use efficiency (WUE) were 13–25% greater with straw mulching than without in India. Jordán et al. (2010) found that soil available water was related with mulching rates by a polynomial function in southern Spain. In a three-year field experiment on the Loess Plateau of China, Zhang et al. (2015) found that soil water content at the 0–2 m soil layer increased by 1–23%, wheat yield by 13–23%, and WUE by 24–33% using wheat straw mulch compared with no mulch. However, Gao et al. (2009) found that mulching did not have a significant effect on wheat yield when soil water content at planting was high in the Loess Plateau of China. Similarly, Lu et al. (2014) reported that straw mulching increased soil water content, but reduced

Abbreviations: CK, no mulching; ET, evapotranspiration; FSM, wheat straw mulching at 9000 kg ha^{-1} during the summer fallow; HSM, wheat straw mulching at 9000 kg ha^{-1} throughout the year; LSM, wheat straw mulching at 4500 kg ha^{-1} throughout the year; PSE, precipitation-storage efficiency; SWH, soil water storage at harvest; SWP, soil water storage at planting; WUE, water-use efficiency

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corn (*Zea mays* L.) yield and WUE compared with no mulching in silty clay loam soil in northeastern China with an annual precipitation of 573 mm. The neutral or negative effect of straw mulching may attribute to the potential seedlings death due to lower soil temperature in the early period (Gao and Li, 2005; Gao et al., 2009; Awe et al., 2015) and the reduction of soil N availability to crops by increasing N immobilization with straw application in the later growth stage (Lu et al., 2015).

The Loess Plateau of China, with a 6000-yr-old agricultural history, encompasses a vast expanse of 620, 000 km^2 area in northwestern China and is characterized by high precipitation variability (Wang et al., 2017). Winter wheat monoculture is one of the most common cropping systems in the drylands of the Loess Plateau, and wheat yield mainly depends on soil available water (Wang et al., 2011). Wheat straw mulching is typically used during the summer fallow period or throughout the year to conserve soil water and enhance crop yields (Deng et al., 2006; Zhang et al., 2015). Considering about 55–60% of annual precipitation occurred during summer fallow period from July through September in this region (Liu et al., 2010), the effect of straw mulching on soil water conservation and crop yield was not well compared between mulching during fallow and the whole agricultural year. Similarly, seasonal and interannual variability in precipitation may alter effect of wheat straw mulching on PSE, multiyear studies are needed to clarify the effects of straw mulching based on data of the whole year.

In this study, we aimed to evaluate the effects of straw mulching rates and time on soil water storage at planting (SWP) and harvesting (SWH), PSE, evapotranspiration (ET), winter wheat growth and yield, and WUE from 2008 to 2015 compared with no mulching in the Loess Plateau of China. We hypothesized that straw mulching would increase SWP, SWH, PSE, winter wheat growth and yield, and WUE compared with no mulching, regardless of mulching rates and time.

2. Materials and methods

2.1. Experimental site and treatments

The field experiment was carried out from 2008 to 2015 at the Changwu Agro-Ecological Research Station in the Loess Plateau (107° 44.70′ E, 35° 12.79′ N) in Changwu County, Shaanxi Province of China. The experimental site is 1220 m above the sea level and has a slope of < 1%. The site is located in the warm temperate zone with a continental monsoon climate. The average annual air temperature is 9.2 °C. The 24-yr average annual precipitation is 574 mm, more than half of which occurs from July to September (Table 1). The mean frost-free period is 194 d and the annual open pan evaporation is 1440 mm. The soil is a light silt loam (Heilutu series), which corresponds to a Calcarid Regosol in the FAO/UNESCO classification system (FAO/Unesco, 1988). The soil is with 35 g kg^{-1} sand, 656 g kg^{-1} silt, and 309 g kg^{-1} clay at the 0–20 cm depth. The average field capacity, saturation point, and soil wilting point are 0.29, 0.51, and 0.10 $m^3\ m^{-3}$, respectively. The soil has an average bulk density of 1.30 Mg m^{-3}, pH of 8.3, organic matter content of 10.50 g kg^{-1}, total N of 0.80 g kg^{-1}, alkaline dissolved N of 37.0 mg kg^{-1}, total P of 0.66 g kg^{-1}, Olsen P of 3.0 mg kg^{-1}, exchangeable K of 129 mg kg^{-1}, and $CaCO_3$ of 108.4 g kg^{-1} at the 0–20 cm depth.

The study had a randomized complete block design with four treatments and three replications. Treatments included control with no mulching (CK), wheat straw mulching throughout the year at 4500 kg ha^{-1} (LSM) and 9000 kg ha^{-1} (HSM), and wheat straw mulching during the summer fallow period (July to mid-September) at 9000 kg ha^{-1} (FSM). The plot size for each treatment was 6.7 m wide by 10 m long. Plots were tilled with a moldboard plow (Yili 1L-220, Shandong Yili Co.) to a depth of 20 cm after previous crop harvest in late June, hoed manually to 5 cm in mid-August, and cultivated with a rotary tiller to 20 cm in September before planting. Wheat straw cut to a length of 5–10 cm was applied at the soil surface by hand before winter wheat planting in LSM and HSM in September of every year. In FSM, wheat straw was applied immediately after previous crop harvest in late June and removed from the soil surface manually before planting in September. As the presence of decayed wheat straw can affect the germination and growth of winter wheat (Chen et al., 2009), wheat straw was removed at planting with FSM.

2.2. Crop management

Winter wheat (cultivar Chuangwu 134) was sown in late September or early October each year at seed rate of 165 kg ha^{-1} using a no-till disk drill with 20 cm row spacing, and harvested in late June in the following year. At planting, N fertilizer as urea (46% N) at 135 kg N ha^{-1} and phosphorus (P) fertilizer as calcium superphosphate (20% P) at 39 kg P ha^{-1} were broadcast and then incorporated to a depth of 20 cm using the rotary tiller. Potassium chloride fertilizer was not applied because of high potassium (K) content in the soil according to the soil test. All fertilizers were applied before straw mulching with HSM and LSM and after removing mulch with FSM or no mulching with CK in September. Hand weeding was done as needed to control weeds during wheat growing and fallow periods. No irrigation was applied.

2.3. Measurements

During the wheat growing season, seedling number, plant number, tiller per plant, and spike number were measured from two 1 m^2 areas randomly within the plot in late October, early December, late March, and late June, respectively. In late June, total aboveground biomass (grains, stems, and leaves) was harvested by cutting all plants at a height of 2 cm above the ground manually from the entire plot without returning crop residues to the soil and weighed. A portion of the biomass was weighed, dried at 70 °C for 3 d to a uniform moisture level (Wang et al., 2011), and weighed again to determine dry matter yield, from which total biomass yield was determined. Grain yield was determined by threshing plants on the ground and measuring the yield on

Table 1
Precipitation during fallow (P_f, July to mid-September) and winter wheat growing season (P_g, late September to June of the following year) periods and total annual precipitation (P_t), drought index (DI) and precipitation type from 2008 to 2009 to 2014–2015.

Year	P_f (mm)	DI for P_f	Type	P_g (mm)	DI for P_g	Type	P_t (mm)	DI for P_t	Type
2008–2009	324	−0.65	Dry	162	−1.06	Dry	486	−1.04	Dry
2009–2010	280	−1.29	Dry	195	−0.36	Dry	475	−1.17	Dry
2010–2011	458	1.32	Wet	232	0.43	Wet	690	1.22	Wet
2011–2012	449	1.19	Wet	210	−0.04	Normal	659	0.88	Wet
2012–2013	346	−0.32	Normal	154	−1.23	Dry	500	−0.89	Dry
2013–2014	395	0.40	Wet	244	0.68	Wet	639	0.66	Wet
2014–2015	323	−0.66	Dry	287	1.60	Wet	610	0.33	Normal
7-yr average	368			212			580		

Dry, normal and wet year are classified by DI > − 0.35, −0.35 ≤ DI ≤ 0.35, and 0.35 < DI, respectively.