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Soil water storage and winter wheat productivity affected by soil surface management and precipitation in dryland of the Loess Plateau, China

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ABSTRACT

Because of asynchrony between the winter wheat growing season and precipitation, soil water supply is the main factor constraining winter wheat production. Hence, increasing soil water conservation is a crucial approach for improving winter wheat productivity in dryland. A 5-year-long, location-fixed field experiment was conducted to determine the effects of plastic mulch, straw retention, planting legume, and straw-legume on soil water and winter wheat grain yield. In comparison to the control, average rainfall harvest during summer fallow was increased by 9% by plastic mulch and mainly occurred in wet summers, and not affected by straw retention, but respectively decreased by 22% and 17% by planting legume and straw-legume. Average soil water storage at sowing was increased by 5% in plastic mulch and occurred in most summers, as well as also increased by 3% in straw retention but only occurred in one wet summer, and decreased by 5% in both planting legume and straw-legume and occurred in most cases. Average ET was not affected by plastic mulch and straw retention, but respectively decreased by 7% and 5% by planting legume and straw-legume. As a result, plastic mulch caused a 6% increase in the average grain yield of winter wheat, but straw retention, planting legume, and straw-legume decreased it by 8%, 6%, and 5%, respectively. Overall, plastic mulch is a beneficial measure for increasing rainfall harvest during summer fallow and soil water storage at sowing, and preferable for harvesting more grain yield, but the straw retention, planting legume and straw-legume showed hardly any benefit for grain yield of winter wheat in dryland.

1. Introduction

Wheat is a major global food crop, ranking third after maize and rice. Annual global wheat production is estimated to be 620 million Mg (Uauy et al., 2006), of which about 75% is from dryland agricultural areas (Li, 2004). Thus, dryland wheat production plays an important role in ensuring global food security. The Loess Plateau is a typical dryland agricultural area in China, where winter wheat is one of the main food crops and covers an area of 4.3 million ha, accounting for 20% of the total land. As almost no surface water is available and the underground water table is usually 50–80 m below the soil surface and thus too deep to use, precipitation is the sole water source for winter wheat and other crop production in most areas of the Loess Plateau. Therefore, the predominant constraining factor for winter wheat production is the limited and unevenly distributed annual precipitation (Wang et al., 2009), which is around 200–600 mm. Of this amount, 50–60% occurs between July and September and is concurrent with the summer fallow between two growing seasons of winter wheat. Another problem is the low water use of the crops, which is mainly due to the inefficient rainfall harvest and high soil water loss by evaporation (Kang et al., 2002). Similar problems also exist in other dryland regions of the world (Ciais et al., 2005).

Soil surface management is an effective approach for reducing soil water evaporation, increasing soil water storage, and improving crop productivity in dryland. Mulching the soil surface with plastic film has become a widely used method to improve crop productivity in drylands (Xie et al., 2005), including mulching all of the soil surface or part of it (mulching on the ridges and

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seeding in the furrows) during all or part of the growing season (Li et al., 1999). Plastic mulch typically decreases soil water loss by evaporation, increases crop transpiration (Wang et al., 2009), and thus successfully promotes crop growth and increases crop yield. Owing to plastic mulch applications, spring wheat grain yield was increased by 23% in the west of Loess Plateau (Li et al., 1999) and winter wheat grain yield was increased by 30% in the middle part of Loess Plateau (Zhang et al., 2013). However, additional information is needed, regarding whether plastic mulch always increases crop yields under different precipitation levels. Mulching the soil surface with crop straw is another method to increase soil water retention and promote crop growth, owing to its effective role in controlling soil water evaporation (Salado-Navarro et al., 2013). Wheat straw retention during the maize growing season resulted in a 10% increase in the grain yield in Uzbekistan (Devkota et al., 2013). However, maize straw retention during the wheat growing season had no effect on wheat grain yield in Mexico (Verhulst et al., 2011), and it even decreased the wheat grain yield by 7% in the North China Plain (Chen et al., 2007). However, most studies have mainly focused on straw retention during the crop growing season. Information about the use of straw retention during the fallow season, especially in the rainy summer fallow season before winter wheat sowing, is still sparse. In addition, covering the soil surface with legumes and non-legumes not only lowers the risks of soil erosion during the rainy season (Tonitto et al., 2006), but also reduces soil water evaporation (Alliaume et al., 2014). Owing to planting hairy vetch during the fallow season, sorghum grain yield was increased by 45% in southeastern United States (Sainju et al., 2006). However, wheat grain yield was not affected by planting black bean in northwestern China (Zhang et al., 2009), and even decreased by 73% owing to planting winter pea, filed pea, and hairy vetch during the fallow season in the middle of United States (Nielsen and Vigil, 2005). The effects of planting cover crop during the fallow season on grain yield varied with regions, but it is still unknown in the Loess Plateau under different precipitation levels.

The fallow season is an important time for soil to restore the water that was consumed by crop during the previous growing season. Therefore, increased rainfall harvest during the fallow season and soil water storage at sowing is important for crops in the next growing season. However, water management is usually overlooked during the fallow season, when the cropland is typically left in bare fallow conditions without crop cover or other materials, especially in the Loess Plateau (Zhang et al., 2007). Under the bare fallow conditions, rainfall harvest during the summer fallow is generally low due to the high soil water evaporation under high air temperature and runoff caused by heavy rainfall over short time periods. Therefore, water management during the summer fallow should receive more attention, and year-round water management is of great significance for winter wheat production in drylands. Mulching the soil surface with different materials or cover crops is a practical measure to regulate soil water, promote crop growth, and obtain a good harvest. In this study, we used a 5 year long, randomized complete block-design, location-fixed field experiment in a typical dryland region of the Loess Plateau to determine the soil water storage and winter wheat grain yield affected by different soil surface managements and their responses to precipitation.

2. Materials and methods

2.1. Experimental site

The experiment was initiated in September 2008 and lasted for five consecutive years until September 2013 at Shilipu (35°12′N, 107°45′E), Changwu County, Shaanxi Province, which is a typical dryland and rainfed agricultural area in the central part of the Loess Plateau, China. In this area, the altitude is 1200 m above sea level and the underground water table is around 50–80 m, which means that groundwater is unavailable for crop growth. At the experimental site, the annual average temperature is 9.1 °C and the average annual precipitation (1957–2013) is 579 mm, about 55% of which occurs in the summer from late June to mid September. Winter wheat and spring maize are the major local cereal crops, and each is harvested once per year. Winter wheat is usually sown in late September or early October, and it is harvested in middle or late June of the following year. The experimental field had been used for winter wheat production for a long time prior to this experiment. The soil is loess-derived and classified as a silt loam texture according to the US Department of Agriculture (USDA) soil classification system, and its basic properties in the top 0–40 cm layer are measured with the methods described by Bao (2007) and presented in Table 1.

2.2. Experimental design and management

The experiment included five soil surface management practices in each year: (1) control (the local conventional practice), (2) plastic mulch, (3) straw retention, (4) planting legume, and (5) straw-legume (Fig. 1). In the control, the soil surface was prepared with no mulching and winter wheat was sown with the conventional flat planting, and all the straw was removed from the field at the harvest of winter wheat, and the soil was ploughed to a depth of 40 cm about two weeks after the harvest, and the soil surface was under bare fallow conditions during the summer fallow. In the plastic mulch, the soil surface was formed into alternating ridges and furrows using a plastic mulch machine before winter wheat sowing. The ridges were mulched with clear plastic film (thickness = 0.008 mm) during winter wheat growing season and the furrows were left uncovered for seeding. During the summer fallow, clear plastic film was still left on the ridge continuously along with all the wheat stubble and crushed straw returned to the furrow to cover the soil surface. Until the end of summer fallow (2–3 weeks before the next winter wheat sowing), the plastic film was removed from the field. For the straw retention, planting legume, and straw-legume, the soil surface was prepared and winter wheat was sown as same as the control during winter wheat growing season. In the straw retention, all the wheat stubble and crushed straw was returned to cover the soil surface during the summer fallow. In the planting legume, all the straw was removed from the field at winter wheat harvest and "Huaidou" (a widely used local soybean cultivar (*Glycine max* L. Merr.)) was seeded at a rate 150 kg ha^{-1} as a cover crop. Until the end of summer fallow, the soybean was mowed and chopped into less than 5 cm segments. The straw-legume during the summer fallow combined the straw retention and planting legume, i.e., wheat straw was treated as same as the straw retention and soybean was sown as same as the planting legume. At the end of summer fallow, the soil in the plastic mulch, straw retention, planting legume, and straw-legume were ploughed to a depth of 40 cm, at the same time straw and/or legume on the soil surface were incorporated evenly into soil using a plow. Table 2 shows the average dry matter and N contents of the soybean returned to the soil. Then, soil in each plot was mixed with basal fertilizers and flattened with a rotary tiller. Each treatment was replicated four times in a randomized complete block-design, and the plot size was 22 m × 6 m.

The N and P fertilizer application rates were calculated based on the relevant available soil nutrients and the target winter wheat grain yield of the control with the method proposed by Zhang et al. (2012). The N and P rates were 138 kg N ha^{-1} and 105 kg P_2O_5 ha^{-1} for all the plots in 2008–2009 and 2009–2010, and 150 kg N ha^{-1} and 105 kg P_2O_5 ha^{-1} in 2010–2011, 2011–2012, and 2012–2013, respectively. In the first four experimental years, three fourths of