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Effects of pruning and mulching measures on annual soil moisture, yield, and water use efficiency in jujube (*Ziziphus jujube* Mill.) plantations

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ABSTRACT

Soil desiccation and water shortage are major challenges of rain-fed crop production in the semi-arid areas of the Loess Plateau of China. Mulching and pruning were considered effective strategies to improve harvest by reducing soil water evaporation and plant transpiration rates. In the present study, the possible synergistic effects of the combination of mulching and pruning on soil water status, growth, yield, and water use efficiency were explored in the jujube plant. Field experiments were conducted in a typical hilly semi-arid region over three growing seasons and two dormancy seasons in 2015–2017. The three treatments applied to mountain jujube plantations throughout the year were grassland (CK), regular pruning (PR), and pruning and mulching (PM). Soil water storage (0–200 cm) was higher in the PM than the PR treatment but lower than that of the CK in all three growing seasons. Relative to PR and CK, PM significantly decreased soil water loss during the dormancy season. The soil moisture infiltration depths were 300 cm, 160 cm, and 420 cm in 2016 and 420 cm, 280 cm, and 460 cm in 2017 for PM, PR, and CK, respectively. Soil desiccation was substantially reduced under the PM treatment in the deep soil layer but was less effectively mitigated under the PR treatment. In the CK treatment, soil desiccation appeared at 0–200 cm but was alleviated by heavy rainfall. Fresh fruit yield ranged from 6643–11,056 kg ha^{-1} for the PM treatment in 2015–2017. This range was 1221–2628 kg ha^{-1} higher than that for the PR treatment. Water use efficiency was 2.28 kg m^{-3}, 2.05 kg m^{-3}, and 2.22 kg m^{-3} under the PM treatment in 2015, 2016, and 2017, respectively. These rates were 1.27 ×, 1.26 ×, and 1.39 × higher, respectively, than those for the PR treatment. These results suggest that the combination of mulching and pruning is an alternative strategy for mitigating soil desiccation in the hilly regions of the Loess Plateau of China. This alternative land management system may be critical for the sustainable cultivation of economically important forest trees in the Loess Plateau region and elsewhere.

Abbreviations: DOY, day of year; DSL, dried soil layer; ET, evapotranspiration; PM, pruning and mulching; PR, regular pruning; SWS, soil water storage; WUE, water use efficiency.

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1. Introduction

The Loess Plateau regions of China have suffered continuous and severe soil erosion and desertification. Consequently, the Chinese government has launched a series of vegetation rehabilitation projects such as the Grain for Green Project and the Natural Forest Conservation Program (Li, 2001a; Wang et al., 2007). These initiatives have produced significant progress by planting and aerial seeding to augment the forest cover area and reduce erosion (He et al., 2003; Liu et al., 2008). However, the use of inappropriate species and the overemphasis of tree and shrub planting may actually exacerbate environmental degradation in the environmentally fragile Loess Plateau region. In fact, these practices can cause soil desiccation (Cao et al., 2011; Li, 2001b; Normile, 2007; Wang et al., 2010). Global warming and poor land management have compounded this problem, contributed to greater soil available water deficits, aggravated soil desiccation, and formed dried soil layers (DSL) in certain regions (Jovanovic et al., 2008; Wang et al., 2011; Zavaleta et al., 2003). A new quantitative index (QI) of DSL severity showed that most of the Loess Plateau regions in China were characterized by extensive dried soil layers (Wang et al., 2018). Similar cases of soil desiccation have been observed in other countries (Jipp et al., 1998; Robinson et al., 2006; Yang and Han, 1985). DSL formation has seriously hindered the biological small circulation of terrestrial ecosystems, weakened hydrological systemic circulation, and impeded sustainable development (Chen et al., 2008; Li, 1983; Hou et al., 1999; Shao et al., 2016).

Jujube (*Ziziphus jujube* Mill.) is an important traditional forest crop widely cultivated in the northern Shaanxi Province of the Loess Plateau region of China (Li et al., 2014). Jujube is the pillar of the local agroforestry industry and is the main source of income for local residents (Zhang et al., 2013). It is also drought-resistant and used extensively in regional afforestation (Feng et al., 2004). However, long-term disorganized planting and poor management models have caused severe soil desiccation in jujube plantations. Liu et al. (2014) reported a virtual lack of water in the 2–4 m soil layers of a nine-year-old jujube plantation. Several other researchers also reported similar conclusions (Ma et al., 2012, 2015; Niu et al., 2014; Wang et al., 2015b; Wei et al., 2015).

Some water-saving measures have been proposed to alleviate soil desiccation (Fang et al., 2010; Jin et al., 2016; Wang et al., 2008). Plastic film and straw mulching are the most frequently used measures for reducing soil evaporation in vegetable crops (Cai et al., 2015; Sun et al., 2017). However, widespread use of plastic film imposes environmental risks (Scarasciamugnozza et al., 2004; Moreno and Moreno, 2008). Straw mulching is comparatively more environmentally friendly than plastic film. Nevertheless, its application is impractical in large mountainous areas. Recently, ground cloth mulching has been recognized as a superior soil water conservation measure in orchards. It is highly efficient at conserving water, has a long lifespan, restrains weed growth, and has excellent diathermancy and air permeability (Wang et al., 2015a; Xi et al., 2017).

Pruning has been used in horticulture to increase the yield, improve the quality of crops and fruit trees (Ahirwar and Hedau, 2015; Maboko and Duplooy, 2008; Patidar, 2017; Schupp et al., 2017) and applied in pest control (Eyles et al., 2013). Because it could improve canopy translucency and adjust the relative proportions of fruit-bearing branches and vegetative shoots. In recent years, pruning has also been recognized as a water-saving measure since it reduces stand transpiration (Alcorn et al., 2013; Lopez et al., 2008; Shelden and Sinclair, 2000). Jackson et al. (2000) noted that the severe pruning of *Grevillea robusta* significantly reduced water demand. Namirembe et al. (2009) stated that wet season pruning suppressed the crown expansion of senna (*Senna spectabilis*) and narrowed its xylem vessels, therefore reduces its hydraulic conductivity and transpiration rate. Hipps et al. (2014) reported that pruning conserved soil water on a London Plane (*Platanus* × *acerifolia*) plantation by reducing the total canopy leaf area and changing the canopy architecture. However, in the study of pruning and water use in rain-fed jujube plantations, Chen et al. (2016) suggested that pruning significantly reduced the transpiration rate per unit ground area, but it also increased the soil evaporation rate by thinning the canopy cover. These findings imply that the combination of mulching and pruning may be synergistic and superior to either treatment alone in terms of water conservation and DSL recovery. To the best of our knowledge, however, no experiment has yet been conducted to validate the efficacy of these combined measures on soil water in ecologically fragile areas.

To this end, we designed a field experiment with the following objectives: (1) analyze annual dynamics (three growing seasons and two dormancy seasons) and vertical distribution of soil moisture in jujube plantations; (2) measure soil water deficits and degree of recovery from DSL under three treatments; and (3) determine the effects of combined pruning and mulching on jujube growth dynamics, yield, and water use efficiency.

2. Materials and methods

2.1. Site description

The field study was conducted at the Mizhi Experimental Station of the Northwest Agriculture and Forestry University, Shaanxi Province, Northwestern China (37.25°N, 108.49°E). The station lies 892 m above sea level and has a slope of 8–12°. It is located in the hinterland of the Loess Plateau which is a typical semi-arid temperate climate region characterized by hills,