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Effects of water collection and mulching combinations on water infiltration and consumption in a semiarid rainfed orchard

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ABSTRACT

Soil water and its efficient use are critical to sustainable productivity of rainfed orchards under the context of climate change in water-limited areas. Here, we combined micro-catchments for collecting hillslope runoff, named fish-scale pits, with mulches to examine water infiltration and water consumption of fruit trees using *in situ* soil moisture monitoring, the micro-lysimeter and sap flow methods via a two-year experiment in a rainfed jujube orchard on China's Loess Plateau. This experiment included four treatments: fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (CK). The results showed that only about 50% of the rainfall infiltrated the soil for CK during the 2014 and 2015 growing seasons. The fish-scale pit without mulching experienced significantly increased rainfall infiltration by 41.38 and 27.30%, respectively, but also increased evaporation by 42.28 and 65.59%, respectively, compared to CK during the two growing seasons. The jujube transpiration significantly increased by 45.64–53.10% over CK, and the evaporation decreased by 42.47–53.50% when fish-scale pits were mulched with branches or straw. Taken together, the results show that the fish-scale pits and mulching combinations efficiently increased rainfall infiltration and jujube evapotranspiration in the experimental jujube orchard. The findings here provide an insight into the field water management for hillslope orchards in water-limited regions.

1. Introduction

Soil water is an important factor for crop production in arid and semiarid regions (Gao et al., 2016). Water shortage especially during reproductive stage can significantly reduce the yield and quality of fruit trees (Oren and Pataki, 2001; Li et al., 2016). Multiple climate models predict that climate change would amplify the intensity and frequency of droughts and thus decrease water availability particularly in semiarid regions (Guo et al., 2015; Zhang and He, 2016; Huang et al., 2017). In the context of climate change, increasing infiltration from precipitation and decreasing soil evaporation is therefore of great importance to the sustainability of rainfed orchards in water-limited regions.

Land engineering and mulching measures are effective ways of preventing drought in arid and semiarid regions by reducing runoff and decreasing soil evaporation (Stavi and Argaman, 2016; Wei et al., 2016; Huo et al., 2017). Water harvesting techniques by land reprofiling represent an attractive solution for mitigating water shortages in various parts of the world (Stavi and Argaman, 2016). These land engineering measures, including terracing (Strehmel et al., 2016; Zhang et al., 2017; Gao et al., 2018), ridge tillage (Mloza-Banda et al., 2016) and fish-scale micro catchment (Fu et al., 2010) among others, are developed to increase the amount of rainfall infiltration by changing the gradient, slope length, and roughness of slopes. For examples, Zhang et al. (2017) showed that terracing had positive influences on soil water content among layers, and mean soil water content of the terrace site was 25.4% and13.7% higher than that in the slope site. Fu et al. (2010) found that fish-scale pit, a semicircular micro-catchment, could effectively reduce surface runoff and sediment transport during heavy rainstorms and thus increase soil water infiltration. However, Li et al. (2011) showed that the average soil water content inside fish-scale pits was less than that of an external slope during July and August due to the enlarged partial soil water and contact area between soil and air. Alternatively, mulching is an effective way of reducing soil evaporation in arid and semiarid agroecosystems (Wang et al., 2016a; Huo et al., 2017).

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Covering the surface with the materials in terms of straw, film or branches can reduce radiation and wind speed at the surface and, hence, reduce evaporation (Balwinder-Singh et al., 2011). Wang et al. (2015a) reported that straw mulched significantly increased the soil water content by 19.5% compared with the clean tillage water management method during the final stage of rapid fruit growth on the rainfed semiarid Loess Plateau of China. Furthermore, Mahdavi et al. (2017) showed that the straw mulching practice significantly reduced total cumulative evaporation up to 40% as compared to the bare soil plot in a field experimental plot in Japan. However, mulching is usually used on leveled lands since it is susceptible to being taken away by runoff and gravity on hillslopes. If land engineering measure with mulching is combined on hillslope, it has the potential to increase soil water infiltration and reduce soil evaporation concurrently, which is, however, rarely tested in rainfed orchards in semiarid areas (Wang et al., 2015b).

The hilly region of the Loess Plateau of China is a typical semiarid region, with an annual precipitation of around 400–600 mm (Zhang et al., 2014; Gao et al., 2017a,b). Generally, the rain comes seasonally from July to September every year and is mostly heavy or torrential (Gao et al., 2016; Song et al., 2017). In addition, many orchards there are located in hillslopes, and a considerable volume of the rain is lost as runoff during rainstorms, leading to greater water shortages (Chen et al., 2016; Wang et al., 2016a). Furthermore, because of the high cost of irrigation in this hilly region, most orchards are cultivated under rainfed conditions (Gao et al., 2017a,b; Li et al., 2017). Jujube (*Ziziphus jujuba Mill.*) orchards are expanded during the last two decades due to its great benefit in both soil and water conservation and increasing farmer's income (Chen et al., 2015; Wang et al., 2016b). However, the production of jujube trees is greatly regulated by soil water availability since ground water (>50 m) is far beyond the maximum rooting depth in this area (Gao et al., 2016). Therefore, this study here aimed to examine the effects of water collection by fish-scale pits and mulching combinations on soil water infiltration and water consumption by using *in situ* soil moisture observations, microlysimeter and sap flow measurements in a rainfed jujube orchard during the growing seasons of 2014 and 2015. These measurement approaches have been demonstrated suitable in understanding temporal patterns of water use of tree species in hillslopes (Boast and Robertson, 1982; Sun et al., 2012).

2. Material and methods

2.1. Study site

The jujube (cv. Lizao on *Ziziphus* rootstock) orchard under investigation (37°15′N, 110°21′E) is located in the north central part of the Loess Plateau at an elevation of 961–976 m in the northern Shaanxi province of China. This area has a semiarid continental climate with mean annual precipitation of 497 mm (based on data for 1986–2015), 79.9% (396.88 mm) of which falls during the growing season (Fig. 1), a mean annual temperature of 8.6 °C, with mean monthly temperatures ranging from – 6.5 °C in January to 22.8 °C in July, 157 frost-free days and 2720 h of sunshine, on average, each year (Weather Bureau of Qingjian county, Shaanxi province). The soil is typical silt loam loess soils (Inceptisols, USDA) which is primarily composed of loess with a texture of fine silt and silt loam. The amounts of organic carbon, organic matter, total nitrogen, available phosphorus and available potassium were 2.34 g kg^{-1}, 2.60 g kg^{-1}, 35.48 mg kg^{-1}, 5.54 mg kg^{-1} and 109.21 mg kg^{-1}, respectively. A summary of soil properties in the 0–100 cm layer is shown in Table 1.

The jujube orchard was established by manually planting 10-year-old bare-root seedlings on an approximately 20° slope and cultivating under rainfed conditions with spatial intervals of 3 m by 2 m, respectively. Every year, 300 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1} of fertilizer were applied to the cultivated jujube trees. Pest and weed control measures were also taken every year. The trees were pruned every year to maintain their height at about 2 m and a uniform canopy in the shape of a spherosome. According to the sprouting and defoliation times of jujube, the growth season of the jujube in 2014 and 2015 lasted for 161 and 157 days–from 25 April to 3 October in 2014 and from 1 May to 5 October in 2015.

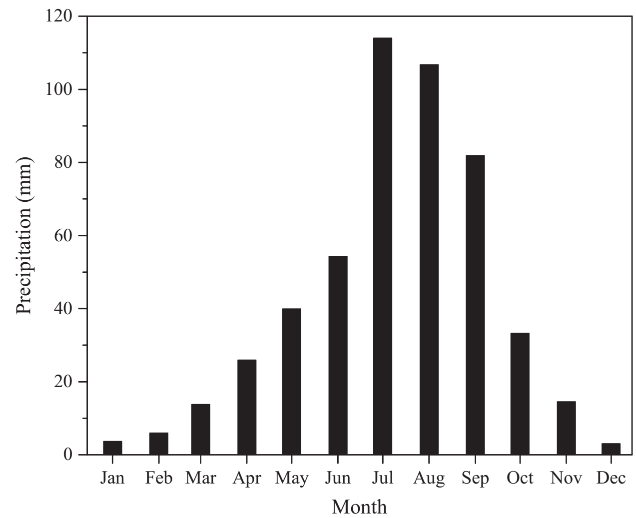

Fig. 1. Distribution of mean monthly precipitation at the experimental site during the 30 years (1986–2015).

2.2. Treatments

The fish-scale pits were established on a cultivated slope in October 2013. Semicircular holes were dug into the slope, and the excavated earth used to form a wall around the semicircles. The pits were built on slopes in an alternating pattern similar to the arrangement of the scales of a fish, thus preventing water from running off. Trees were planted in the fish-scale pits (Fig. 2). Four different treatments were used in this study: a fish-scale pit with branch mulching (FB), a fish-scale pit with maize straw mulching (FS), a fish-scale pit without mulching (F), and bare land treatment (CK). For each treatment, four plots having an area of 24 m^2 (4 m × 6 m) each were established as four replicates with a spacing interval of 5 m between neighboring plots (Fig. 2). Therefore, a total of 16 plots were established on hillslopes with similar slope gradients (16–25°) and slope aspects (0–20°). Based on the jujube plant spacing and the volume of runoff, the fish-scale pit built in 2013 had a volume of 100 cm (length) × 80 cm (width) × 30 cm (depth). Pruned jujube branches and maize straw were used for the mulch, with lengths of 20 cm and a mulching thickness of 15 cm (the trimmed jujube branches volume can maintain around the thickness of 15 cm). To maintain the thickness of mulching, material was added in November every year.

2.3. Soil moisture and meteorological data

An ECH_2O EC-5 sensor (Decagon Devices Inc., USA) was used to measure soil water content. An RR-1008 datalogger (Rainroot Scientific Limited, Beijing, China) automatically recorded the sensor output measured by the EC-5 sensors. A trench with a width of 150 cm and a depth of 300 cm was vertically dug on top of the jujube tree trunk dune to expose the soil profile. Sensors were