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Mulching increases water-use efficiency of peach production on the rainfed semiarid Loess Plateau of China

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ABSTRACT

We examine the water-use balance, fruit yield and water-use efficiency of five-year-old peach trees with two different mulching systems: plastic film mulched ridge, with furrows (PFM) and straw mulched (SM). Compared with the clean tillage (CT) water management method, PFM increased, and SM significantly decreased, the soil temperature ($P < 0.05$). Both mulching systems increased the gravimetric soil water content (1.9–2.9%) with a reduction in the average annual evapotranspiration (ET) of 82.5 mm and 49.3 mm through SM and PFM, respectively. The water-use efficiency (WUE) was improved from 5.7 (CT) to 8.1 (PFM) and 9.0 kg m^{-3} (SM), resulting in a reduction in ET and an increase in fruit yield from 25.2 (CT) to 32.2 (PFM) and 32.5 t ha^{-1} (SM). Thus, both mulching systems could serve as models for peach production in semiarid rainfed areas, due to the high soil water content during bloom and fruit expansion.

1. Introduction

Peaches are produced on approximately 1 million ha in China. Most of the orchards are located in northern China where the climate is arid or semiarid. Land suitable for crop production is limited, and many peach orchards have been planted in terrain that is either hilly or otherwise unsuitable for crop cultivation (Ouyang et al., 2013). For example, the hillside peach orchard in Qin'an county of Gansu Province is an important peach tree cultivation region in the semiarid Loess Plateau of China and is under a rainfed production system (without irrigation), where precipitation is the major water source for peach tree growth.

Over the last 50 years, certain parts of China have experienced declining rates of precipitation (Zhang et al., 2014), severely adverse environments, and low and unevenly distributed rainfall. Thus, better use of the limited rainfall, a reduction in non-beneficial evaporation and higher water-use efficiency are urgently needed. There is a growing interest in increasing the crop productivity and rain water conservation in the rainfed Loess Plateau of China (Ren et al., 2005; Zou et al., 2013).

In Qin'an county, the peach-growing season coincides with the rainy season from May to October, when more than 80% of the annual precipitation is received (Table 1). Limited rainfall with uneven frequency causes drought stress during bloom in April. The availability of adequate soil water content at critical stages of plant growth optimizes the metabolic process in plant cells and increases the effectiveness of the mineral nutrients applied to the crop. Consequently, any degree of water stress might produce deleterious effects on the growth and yield of the crop (Yaghi et al., 2013). It has been demonstrated that deficit irrigation during stages I and II of peach fruit growth does not affect the yield (Li et al., 1989), whereas deficit irrigation during stage III decreases fruit size (Berman and DeJong, 1996; Naor et al., 1999). However, locally, the gravimetric soil water content was less than 10% (equal to approximately 35% relative humidity) during bloom, causing flower drop and negatively affecting fruit set.

Numerous strategies have been proposed for reducing agricultural water use (Tejero et al., 2011), including the minimization of evaporation (E) to reduce evapotranspiration (ET), improving irrigation methods and optimizing irrigation schedules (Fereres and Soriano, 2007; Geerts and Raes, 2009; Sun et al., 2012). Under most circumstances, clean tillage exhibits low water-use efficiency. In rainfed areas, more effective practices are necessary to maximize the value of rainfall (Wang et al., 2005), as no supplementary irrigation is practiced. Therefore, increasing crop water-use efficiency through water conservation is an important component of dry land farming (Zou et al., 2013). Water-use efficiency can be increased by harvesting rainfall, reducing runoff, increasing soil infiltration, and improving soil water utilization by root systems (Deng et al., 2006; Wang et al., 2009).

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Table 1
Average seasonal rainfall, and the rainfall received in 2011 and 2012, by portion of the year, at the experiment site, Qin'an County, Gansu Province, China.

Year	From February to April (mm)	From May to July (mm)	From August to October (mm)	From November to January (mm)	Total (mm)
2011	51.9 (15.3%)	137.4 (40.5%)	147 (43.4%)	2.8 (0.8%)	339.1
2012	12.3 (2.6%)	200.3 (42.8%)	206.3 (44.1%)	48.9 (10.5%)	467.8
30 years average	53.3 (11.9%)	194.5 (43.3%)	182.5 (40.7%)	18.7 (4.1%)	449.2

Source: Gansu Meteorological Bureau, China.
Note: The values in parentheses are the proportions of the annual rainfall received in each year (or with respect to the 30-year average rainfall), within each period.

Mulching can increase water-use efficiency (WUE). Mulch is referred to as any material spread onto the surface of soil for protection against solar radiation or evaporation. Mulches can include wheat straw, rice straw, plastic film, grass, wood, or sand (Yaghi et al., 2013). Mulches moderate soil temperature and increase infiltration during intensive rain (Khurshid et al., 2006). Many studies have demonstrated that rainwater collection and conservation practices are sufficient for improving nutrient use and increasing yield and water-use efficiencies (Ding et al., 2007; Duan et al., 2006; Hou et al., 2010; Wang et al., 2007, 2011). However, to effectively apply these water management strategies on peaches in the semiarid rainfed loess region of northwest China, a basic understanding of the water-use characteristics of this fruit tree is needed. Therefore, we conducted a two-year experiment on a hillside peach orchard to (1) characterize the soil water content and soil temperature states under plastic film and wheat straw mulching in a semiarid rainfed environment, and (2) assess the effects of mulching treatments on evapotranspiration (ET) and water-use efficiency (WUE).

2. Materials and methods

2.1. Site description

Field experiments were performed in 2011 and 2012 in Qin'an County (105°41′51″ N, 34°49′88″ E, 1360 m above sea level), located in the southwest Loess Plateau in Gansu Province, China. This semiarid region is characterized by a continental, monsoonal climate. The mean annual temperature is 11.4 °C, and the average annual precipitation is 449 mm (Table 1). The soil is loessial, with 1.31 g cm^{-3} soil bulk density, 12.3 g kg^{-1} average organic matter content, 26.1% field water holding capacity and a pH of 8.7.

The experimental orchard was planted with peach trees (*Prunus persica* cv. 'Qinwang' + rootstock '*Prunus davidiana* (Carr.) Franch') five years prior to the study. The experimental area was approximately 40 m × 50 m and was surrounded by peach orchards. The row and planting spacing was 400 cm and 300 cm, respectively, with a north-south row orientation and an average tree height of 2.5 m. Trees with cross sectional areas (0.45 m above the ground surface) of approximately 98 ± 2 cm^2 were selected for the experiment.

2.2. Mulching methods

Three field systems were designed:

(1) Wheat straw mulching on flat land (SM), (2) a plastic film mulched ridge system, with furrows for rainfall harvesting (PFM, Fig. 1), and (3) clean tillage (CT) without mulch.

Wheat straw, at 45,000 kg ha^{-1}, was used to cover the flat soil surface at the beginning of the experiment, and the field was subsequently supplemented with 15,000 kg ha^{-1} of mulch on February 26, 2012. The PFM system was comprised of one ridge and two furrows; the ridge served as a rainwater-harvesting zone, and the furrows served as storage zones (Fig. 1). Polyethylene black plastic film was used at a thickness of 0.008 mm (equal to 75 kg ha^{-1}).

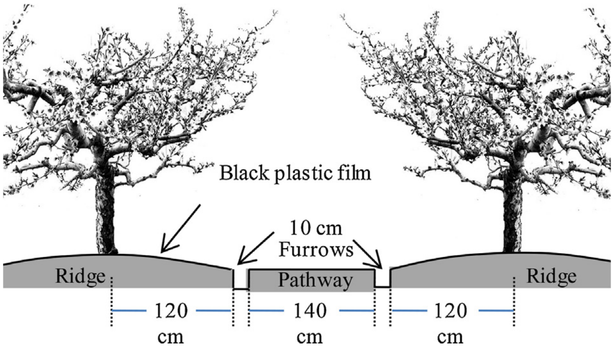

Fig. 1. Schematic view of plastic film mulched ridge with furrow for rainfall harvesting (PFM) system.

The ridges were formed and covered with plastic film on February 22, 2011 and the film was replaced on February 26, 2012, before the frozen soil thawed. All of the treatment plots were identically managed, and typical pruning and pest and disease control were practiced. Weed control was manually performed. Fertilizer was applied at rates of 225 kg N ha^{-1}, 60 kg P ha^{-1} and 90 kg K ha^{-1} in trenches (30 cm in depth) on both sides of the ridges, 120 cm away from the tree trunks.

2.3. Soil water content, temperature and ET measurements

The gravimetric soil water content was measured at 10 cm intervals to a depth of 100 cm, at distances of 40 cm, 80 cm, and 120 cm from the tree trunk toward the row space. Soil samples were obtained every 10 days and were oven-dried at 105 °C for 24 h.

Soil temperature at a depth of 20 cm was recorded daily at 08:00 h, 14:00 h and 20:00 h using a data logger (L95-22, Loggertech Co., Ltd., Hangzhou, CHN). The probes were installed at a distance of 40 cm, 80 cm, and 120 cm away from the trunk toward the row space. The mean daily soil temperature was calculated as the mean of the three daily readings at the three distances.

Soil evaporation was measured during the 2011 and 2012 growing seasons. Micro-lysimeters, made of PVC tubes with an inner diameter of 10 cm and a height of 15 cm, were used for the measurements (Sun et al., 2012). Measurements were taken in four locations, at 75 cm and 150 cm from the trunk toward the south and east for the SM and CT treatments. For the PFM treatment, micro-lysimeters were placed in the centers of the furrows (130 cm) and pathways (200 cm) on the both sides of the tree because the plastic film could have completely prevented evaporation. At 3-day intervals during March and October, the micro-lysimeters with soil samples were weighed in the morning between 7:30 and 8:00, using an electronic balance with a precision of 0.1 g. The daily soil water evaporation (Wed) was calculated using the formula: $Wed = \Delta We/3$, where ΔWe is the soil weight difference between the two consecutive measurements with 3-day intervals. Soil evaporation was calculated as $(E) = Wed/S$, where S is the surface area of the micro-lysimeter. The soil evaporation value was then converted