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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, micro-lysimeter 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.

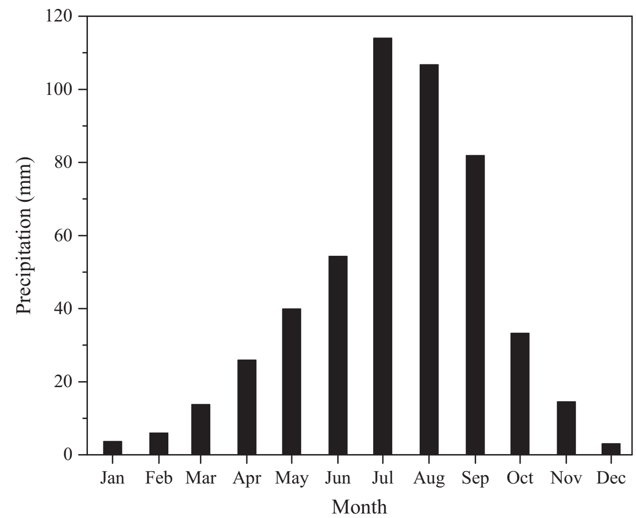

Fig. 1. Distribution of mean monthly precipitation at the experimental site during the 30 years (1986–2015).

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

Table 1
Soil properties of 0–100 cm layer at the study site.

Depth	BD	Soil texture			K_{sat}	θ_s	$\theta_{33\ kPa}$	$\theta_{1500\ kPa}$
cm	(g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	(mm min^{-1})	(cm^3 cm^{-3})	(cm^3 cm^{-3})	(cm^3 cm^{-3})
0–10	1.26 ± 0.04	20.14 ± 1.25	62.9 ± 3.54	17.24 ± 2.14	1.52 ± 0.13	51.62 ± 1.64	28.63 ± 1.64	7.54 ± 0.47
0–20	1.38 ± 0.09	19.82 ± 2.14	62.5 ± 5.25	17.78 ± 1.54	1.36 ± 0.14	53.84 ± 2.22	26.91 ± 2.27	8.14 ± 0.54
20–40	1.3 ± 0.03	19.97 ± 1.52	61.6 ± 2.54	18.51 ± 2.81	1.18 ± 0.08	51.84 ± 1.87	27.85 ± 1.64	8.31 ± 0.56
40–60	1.36 ± 0.04	18.42 ± 1.14	63.8 ± 3.66	17.81 ± 1.38	1.15 ± 0.11	58.24 ± 2.28	28.94 ± 2.47	8.67 ± 0.37

BD: bulk density; Soil texture: Sand% (2–0.02 mm), Silt% (0.02–0.002 mm), and Clay% (<0.002 mm); K_{sat}: saturated hydraulic conductivity; θ_s: saturated water content; θ_{33} kPa: soil water content at 33 kPa; θ_{1500} kPa: soil water content at 1500 kPa.
The data are the means ± SD of three replicate samples.
Sample date: 11st August 2014.

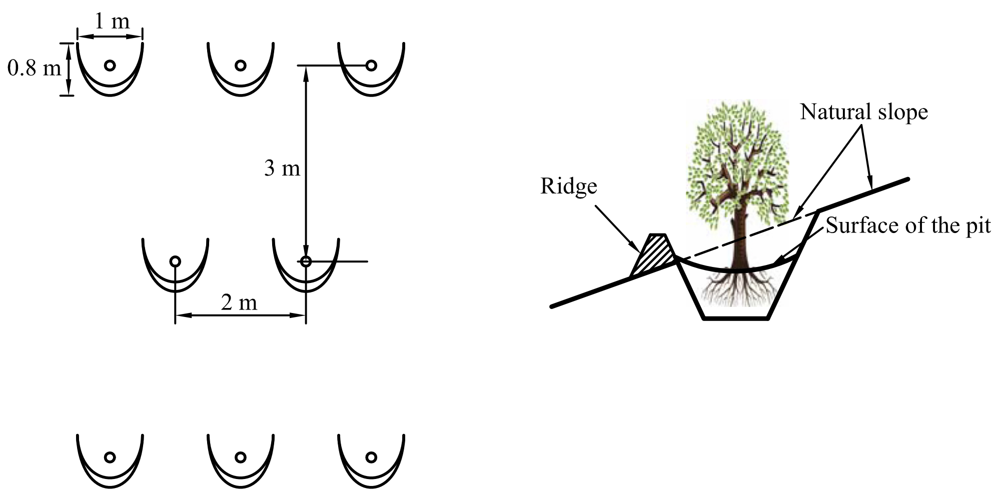

Fig. 2. Diagram and layout of the slope and the fish-scale pit in the experiment plot.

vertically inserted into the soil profile at depths of 5, 10, 20, 40, 60, 100, 160, 220 and 280 cm, and they were kept 20 cm from the tree trunk at the horizontal direction. The system sampled data every 2 min, and logged them every 10 min.

Also, a 1 m deep profile was excavated on the same slope to collect undisturbed soil cores in order to obtain measurements of the dry soil bulk density and gravimetrical soil water content (θ_g, g g^{-1}). An EC-5 sensor was deployed at corresponding depths to the main trench. The values of θ_g were then transformed to volumetric moisture contents (θ_V, cm^3 cm^{-3}), and a calibration curve was obtained by plotting the measured moisture values (θ_E, cm^3 cm^{-3}) by the EC-5 sensor against the volumetric moisture contents, measured using the oven drying method (θ_V).

Solar radiation, relative humidity, air temperature, precipitation and wind speed were measured every 10 min using an automated weather station (Rainroot Scientific Limited, Beijing, China) close to the experimental field. Vapor pressure deficit (VPD) was calculated from air temperature and relative humidity.

2.4. Estimation of soil water infiltration and water consumption

To calculate the soil water storage, the hypothesis in this work is that (1) the soil water content in the 0–5 cm layer is equal to the calibrated value of the sensor at a depth of 5 cm, and (2) the soil water content between the adjoining sensors changes linearly below 5 cm. The soil water storage (SWS) of the 0–280 cm profile was calculated using the following equation:

$$SWS = 5 \times \theta_5 + 5 \times \frac{\theta_5 + \theta_{10}}{2} + \cdots + (h_2 - h_1) \times \frac{\theta_{h_1} + \theta_{h_2}}{2} + \cdots + 60 \times \frac{\theta_{220} + \theta_{280}}{2} \tag{1}$$

where SWS is the soil water storage of 0–280 cm profile, cm, θ_h is the calibrated volumetric water content at the depth of h in cm^3 m^{-3}, and h_1 and h_2 are the depths of adjacent sensors in cm.

Because the ground water depth is far beyond the maximum rooting depth in our site. Changes in soil water content are assumed to be driven only by precipitation and root water uptake. The increment (ΔSWS) of the soil water storage every 10 min was determined using the following equation:

$$\Delta SWS = SWS_{t+10} - SWS_t \tag{2}$$

where ΔSWS is the increment of the soil water storage every 10 min, cm, SWS_t is the value of SWS at t, cm, and SWS_{t+10} is the value at t + 10 min, cm.

The ΔSWS is primarily influenced by rainfall events and evapotranspiration in this study region where have no irrigation and negligible deep percolation (Zhang et al., 2007). Rainfall is the only source of replenishing soil water storage. Therefore, as ΔSWS>0, it means soil water storage is replenished by precipitation and the sum of ΔSWS is assumed to equal to infiltration from precipitation (Fig. 3). During rainfall events, soil evaporation and canopy transpiration are usually ignored because of low air temperature, high relatively humidity, and thus low vapor pressure deficit (VPD) (Cai et al., 2007). On the other hand, as ΔSWS < 0, it means soil water loss happens, which is primarily from soil evaporation in surface layer and from root water uptake in root zone layer, and the sum of absolute ΔSWS is assumed to equal to water consumption (Fig. 3).

2.5. Evaporation measurement

Measurements of evaporation from soil were made at 8:00 every day, using small lysimeters containing undisturbed samples

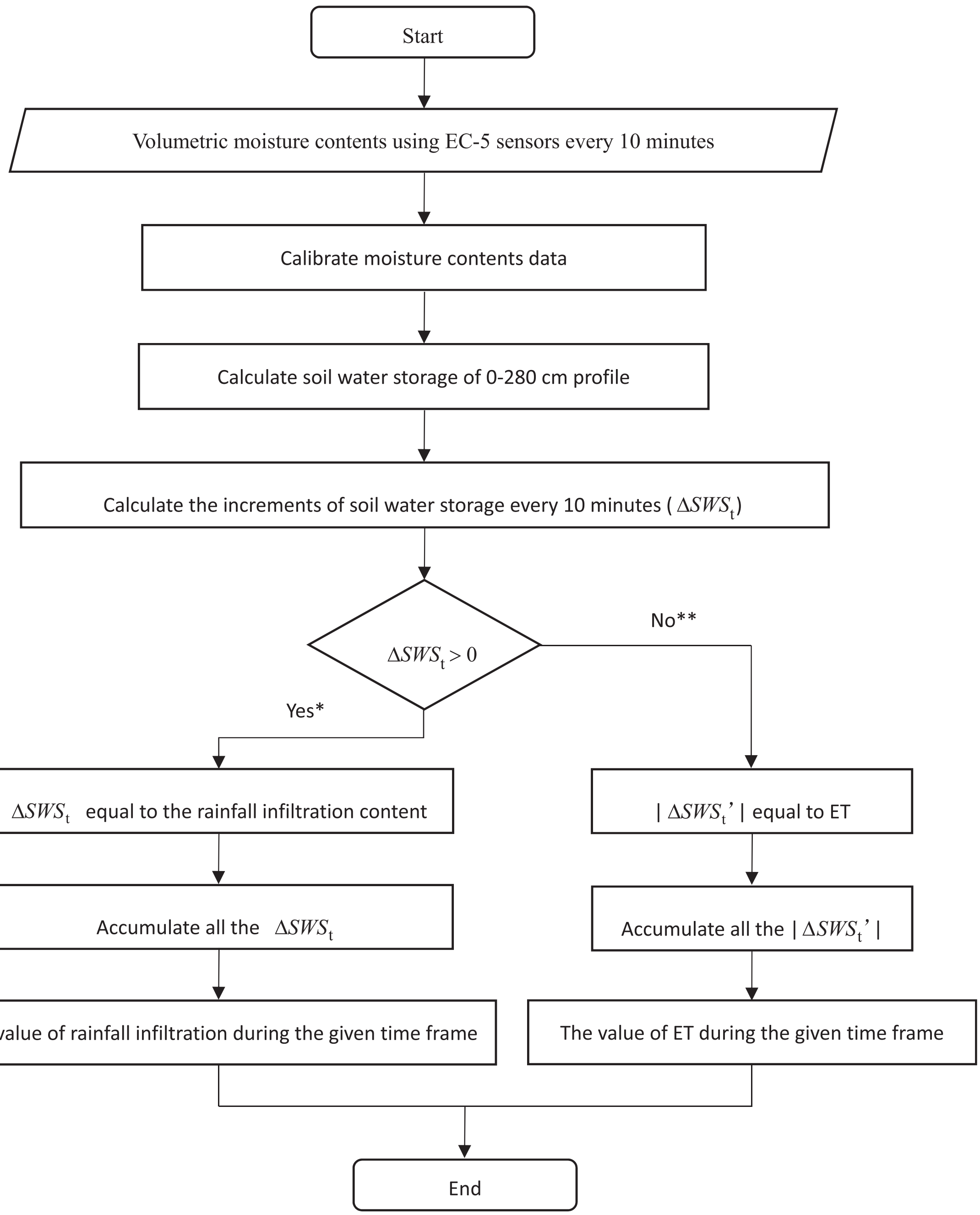

Fig. 3. A flow chart of methodology which is calculating rainfall infiltration and water consumption using automatic water monitoring devices methods. * There is an assumption that water consuming via evapotranspiration is ignored during rainfall process. ** There is an assumption that no rainfall events present within this time interval.

of soil (Daamen, et al., 1993; Marin et al., 2010). Lysimeters were composed of inner and outer PVC pipes. The inner one had a diameter of 10 cm and a depth of 20 cm, the outer one had a depth as long as the inner one and a slightly bigger diameter than the inner one, so that the inner one would fit into the outer one tightly. First, the inner pipe was filled with undisturbed soil, and then it was packed with gauze at the bottom. Then it was put into the outer pipe and weighed. In addition, for mulched plots, the top of the lysimeter was mulched with branch or straw. Finally, lysimeters were put into the pit from where undisturbed soil had been removed. The lysimeters were installed in each plot. They were re-weighed after 24 h to determine the water lost by evaporation and renewed with undisturbed soil every week or after rain events. The determination was continuously carried out during the growing seasons of 2014 and 2015.

2.6. Sap flow measurements

The daily transpiration rate of the jujube orchard was monitored over the 2014 and 2015 growing seasons. Using the thermal dissipation method (Granier, 1985), sap flux was monitored in 12 jujube trees. The characteristics of the jujube trees are summarized in Table 2. As the jujube trees needed to be preserved for future studies, only single thermal dissipation probes (TDP, Dynamax Co., USA) with two needle probes (length: 30 mm, diameter: 2 mm) were installed on the trunks of the selected plants to minimize tree damage (O'Brien et al., 2004). The upper probe was heated continually while the lower probe was kept unheated.

TDP probe placement can result in considerable variations in sap flux. To minimize sap flux variation, the probes were uniformly and horizontally inserted at 0–30 mm depth in the sapwood and

Table 2
Details of the selected jujube tree variables tree height (TH), trunk diameter at 20 cm above ground (TD), crown projection area (CPA), leaf area index (LAI), and sapwood area (SA).

Treatments	TH (m)	TD (cm)	CPA (m^2)	LAI (m^2 m^{-2})	SA (cm^2)
FB	1.62 ± 0.24	11.43 ± 0.67	1.54 ± 0.34	2.51 ± 0.42	73.43 ± 3.21
FS	1.66 ± 0.18	9.56 ± 0.45	1.43 ± 0.04	2.41 ± 0.11	65.21 ± 2.31
F	1.60 ± 0.04	11.21 ± 0.44	1.62 ± 0.09	2.68 ± 0.07	71.76 ± 2.64
CK	1.74 ± 0.15	10.53 ± 0.74	1.57 ± 0.14	2.12 ± 0.14	66.58 ± 3.64

FB: fish-scale pit with branch mulching; FS: fish-scale pit with maize straw mulching; F: fish-scale pit without mulching; CK: bare land treatment.
The data are the means ± SD of three replicate samples.
Sample date: 1st September 2014.

installed on the north side of the trunks at about 20 cm above the ground. Prior to the installation of the probes, two layers of the tree trunk bark were peeled off. To limit external interference, the probes were carefully packaged in silver membranes (Wilson et al., 2001; Wullschleger et al., 2001). The CR1000 data logger (Campbell, Co., USA) was used to record sap flow every 10 min during the jujube growth seasons in 2014 and 2015.

Standard non-calibrated sap flux density was calculated using the equation developed by Granier (1987) and proved by Clearwater et al. (1999):

$$J_s = 119 \times \left(\frac{\Delta T_m - \Delta T}{\Delta T}\right)^{1.231} \quad (3)$$

where J_s is sap flux density, g m^{-2} s^{-1}, ΔT is the temperature difference between the heated and unheated probe, and ΔT_m is the temperature difference with no sap flow.

Assuming that J_s is constant across the sapwood profile, then sap flow can be calculated as (Santiago et al., 2000; Oren and Pataki, 2001):

$$SF = K \times J_S \times A_S \quad (4)$$

where SF is sap flow, kg d^{-1}, K is unit conversion coefficient equal to 0.00864, and A_S is sapwood area, cm^2. A_s was estimated from the relationship between sapwood area and tree diameter determined by randomly cutting down 17 jujube trees at 20 cm above the ground (Fig. 4). A significantly linear correlation was observed, with the sapwood area increasing as the trunk diameter increased.

2.7. Statistical analysis

Statistical analysis was carried out using Microsoft Excel 2010 (Microsoft, Redmond, USA) and SPSS16.0 (SPSS, Chicago, USA) software. Differences between the treatments were examined using ANOVA, followed, when appropriate, by multiple comparisons based on the least significant difference (LSD), and results were considered significant when P-value is less than 0.05.

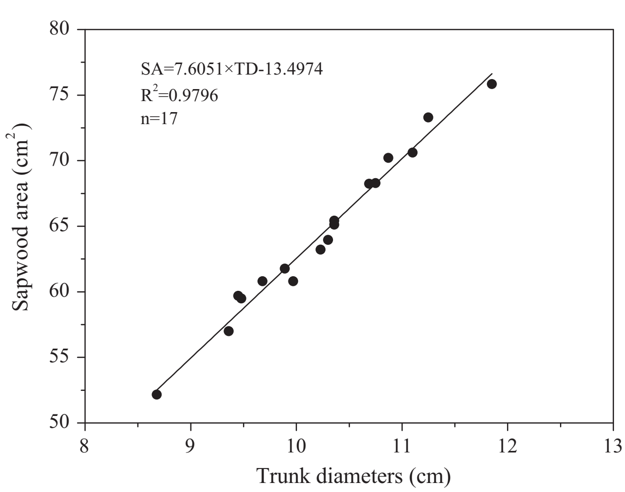

Fig. 4. Relationship between sapwood area and trunk diameter at 20 cm above the ground.

3. Results

3.1. Changes of meteorological condition

As shown in Fig. 5, for the 2014 and 2015 growing seasons, the average values of the diurnal temperature, wind speed, solar radiation and vapor pressure deficit were 19.38 °C, 1.08 m s^{-1} 197.44 W m^{-2} and 1.19 kPa, respectively. The rainfall in the growth stages during 2014 was 367.02 mm, which is 7.52% lower than the long-term average (396.88 mm). During the growing season of 2014, the rainfall was concentrated in July and the monthly rainfall was also almost equal to the long-term average, except that August 2014 was relatively dry, with rainfall amounts 45.10% less than the long-term average (106.73 mm). During the growing season of 2015, the rainfall was 251.84 mm, only 63.45% of the long-term average (396.88 mm). July was particularly dry with the rainfall only 9.12% (10.40 mm) of the long-term average (114.00 mm).

3.2. Soil water infiltration

The fitting equation by linear regression between volumetric moisture content by gravimetric value and dry soil bulk density and the measured volumetric values using soil moisture sensors were given in Eq. (5) as follows.

$$\theta_V = 0.834 \times \theta_E + 7.963 \quad (5)$$

Where θ_V is the volumetric moisture content by gravimetric value and dry soil bulk density, cm^3 cm^{-3}, θ_E is the measured volumetric values using soil moisture sensors, cm^3 cm^{-3}. The coefficient of determination reached 0.804 and the root mean square error (RMSE) of the EC-5 values was 0.0396 cm^3 cm^{-3}. Overall, the EC-5 sensors produce reliable soil moisture values in our site.

As shown in Fig. 6, the month-mean rainfall infiltration under the fish-scale pit treatments (FB, FS, and F) increased by 65.62% on average compared to CK during the rainstorm periods (July to September 2014, August to September 2015), but showed no significant different among these fish-scale pit treatments. For the whole growing season in 2014, the rainfall infiltration content of FB, FS and F increased by 53.24% (290.93 mm), 51.73% (288.05 mm), 41.39% (268.43 mm), respectively, compared to CK (189.85 mm). For the 2015 growing season, the increments were 51.60% (175.14 mm), 57.73% (182.21 mm), 37.30% (158.61 mm), respectively, compared to CK (115.52 mm).

3.3. Soil water consumption

In this section, soil water consumption was estimated using two different methods, i.e., (1) the decrease of soil moisture observa-

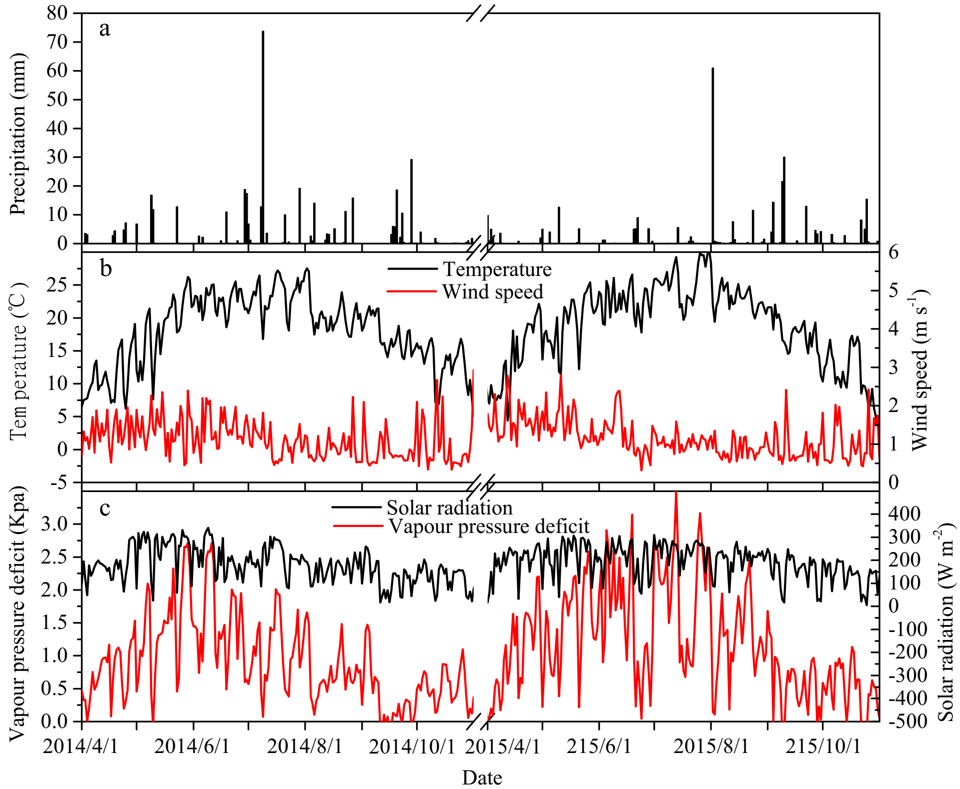

Fig. 5. Diurnal variation of (a) precipitation (mm); (b) temperatures (°C) and wind speed (m s^{-1}) and (c) vapor pressure deficit (kPa) and solar radiation (W m^{-2}) during the 2014 and 2015 jujube growing seasons.

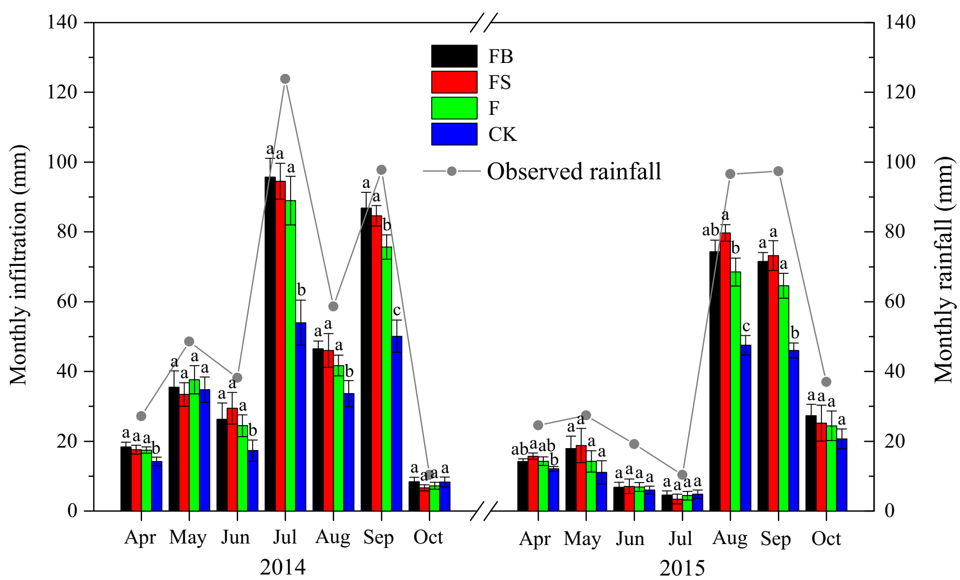

Fig. 6. Monthly rainfall and infiltration for all treatments during the 2014 and 2015 jujube growing seasons. Different letters denote significant differences between treatments at $P < 0.05$.

tions, and (2) soil evaporation and sap flow measurements. This study showed that there is considerable soil evaporation, especially during the rainy season, from F and CK in the experimental orchard (Fig. 7). No significant differences in evaporation each month was observed for FB and FS during the 2014 and 2015 growing seasons. During the rainy season (July at 2014 and from August to September at 2015), the evaporation from F was significantly higher than the other three treatments on a monthly basis. In the 2014 growing season, the evaporation from fish-scales pits without mulching increased by 42.28% on average compared to CK. When the fish-scale pits were mulched with branches and straw, the evaporation decreased by 44.53 and 42.47%, relative to CK, respectively. The values in 2015 were 65.59, 53.36 and 53.50%, respectively.

Fig. 8 shows the diurnal canopy transpiration (mm d^{-1}) calculated from daily whole tree cumulative sap flow and projected

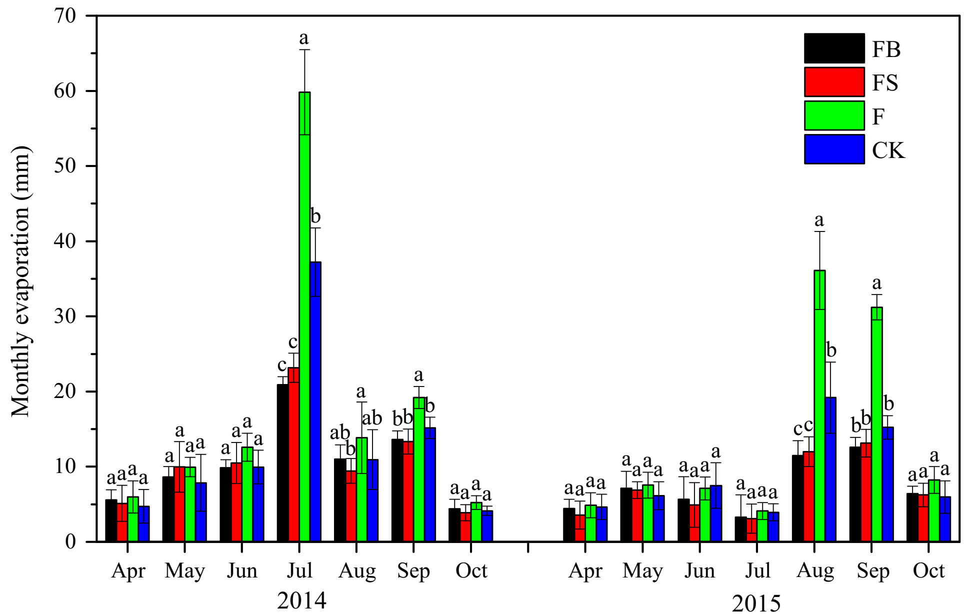

Fig. 7. Monthly soil evaporation for all treatments during the 2014 and 2015 jujube growing seasons. Different letters denote significant differences between treatments at $P < 0.05$.

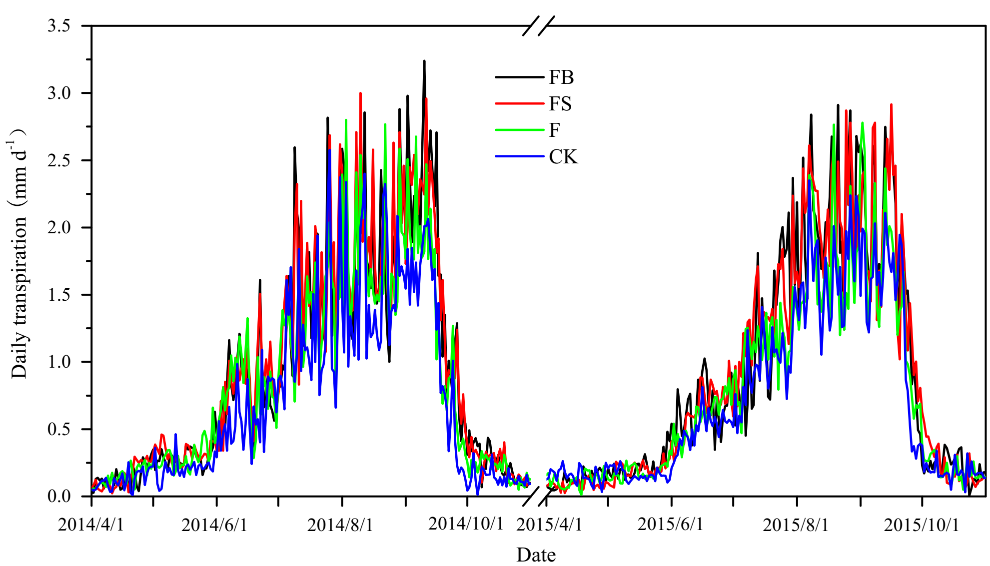

Fig. 8. Daily transpiration (mm d^{-1}) of the jujube trees for all treatments during the 2014 and 2015 jujube growing seasons.

crown area during the 2014 and 2015 growing seasons, respectively. The transpiration gradually increased from the end of April 2014, up to the highest value in mid-July. Jujube transpiration remained at a high level, and then rapidly reduced to zero in the end of September. On account of the low rainfall from April to July in 2015, the jujube transpiration was lower than 2014. With the advent of rain in August, jujube transpiration increased rapidly. Through the whole growing seasons, compared to CK, jujube transpiration for FB, FS and F increased by 49.83% (216.03 mm), 53.10% (220.76 mm), 21.22% (174.79 mm) at 2014 and 45.64% (180.46 mm), 47.91% (183.28 mm), 12.91% (139.91 mm) at 2015, respectively.

The soil water consumption estimated based on soil moisture observations was shown in Fig. 9. The water consumption of FB, FS and F increased by 28.61% (274.85 mm), 30.17% (278.17 mm), 27.30% (272.03 mm), respectively, compared to CK (213.70 mm) through the 2014 growing season. And the values of 2015 were 24.51% (207.04 mm), 28.53% (213.73 mm), 19.45% (198.63 mm), respectively. Overall, water consumption based on soil moisture observations was underestimated compared to the estimations based on evapotranspiration measurements, especially at July of 2014 and August and September of 2015.

4. Discussion

4.1. Water infiltration and consumption

Fish-scale pits could effectively increase rainfall utilization efficiency during the rainy seasons (Fig. 6). As reviewed by Fu et al. (2010), the relative reductions in runoff from the fish-scale plot for 20-year (160 mm), 10-year (120 mm), and 2-year (54 mm)

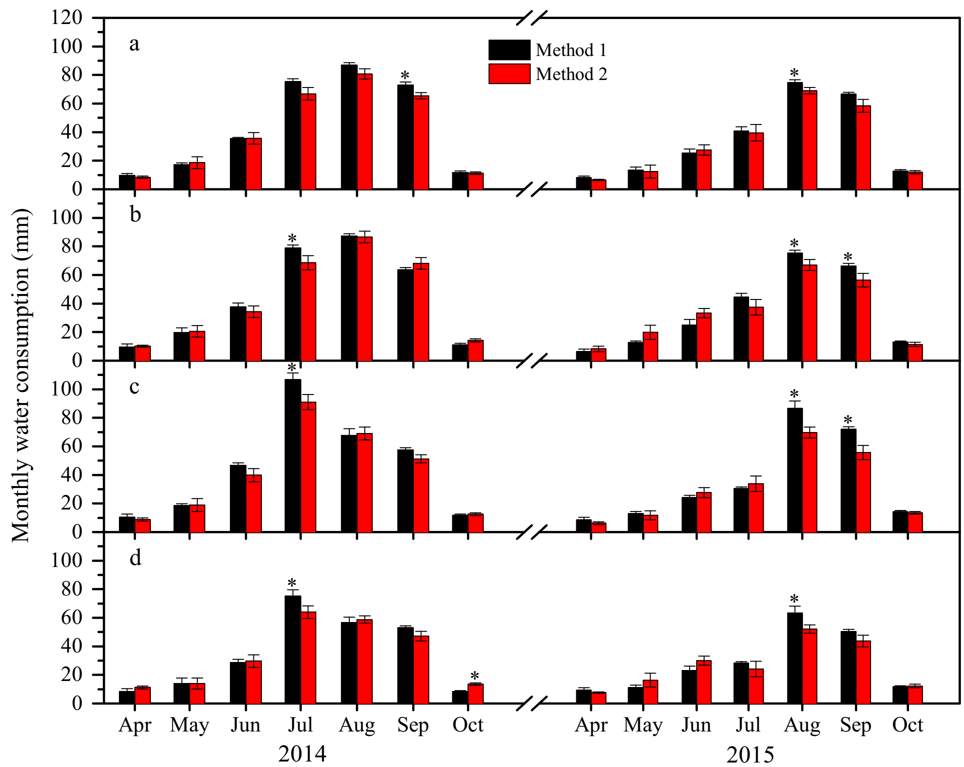

Fig. 9. Monthly consumption for (a) fish-scale pit with branch mulching, (b) fish-scale pit with straw mulching, (c) fish-scale pit without mulching, and (d) bare land treatment using (method 1) integration the micro-lysimeter and sap flow and (method 2) automatic water monitoring devices methods during the 2014 and 2015 growing seasons. Asterisks denote significant differences between two methods at $P < 0.05$.

return period daily rainfall were 18%, 28%, and 39%, respectively. Previati et al. (2010) reported that the water content values measured inside the fish-scale pits are generally higher than those monitored outside the micro-basins, but in spite of this general tendency, some noticeable effects due to soil type, time of the year, farm management and soil depth are observed. The fish-scale pits can effectively increase the rainfall infiltration by intercepting runoff at the wet seasons. But the soil water content will not necessarily increase because the fish-scale pits without mulching significantly increase the evaporation compared with control (Fig. 7), probably due to the increase in soil water content and enlarged contact area between soil and air. Furthermore, the rainfall interception of mulching material such as straw and jujube branches can result in the decrease of infiltration (Alliaume et al., 2017). Our results demonstrate that monthly infiltration between three treatments in fish-scale pits (FB, FS, F) generally showed no significant difference during the growing seasons of 2014 and 2015 in this experiment (Fig. 6), which indicated that combining fish-scale pits with mulching had little influence on soil water infiltration.

The mulching decreases soil water content loss by evaporation and the variation in soil temperature by insulating the surface (Davarzani et al. 2014; Jimenez et al., 2017). Furthermore, mulching can effectively reduce the formation of a physical soil crust by filtering soil particles during rainstorms, increasing water stable soil aggregates, and increasing soil water-holding capacity (Lin and Chen, 2015). Our results indicated that combining fish-scale pits with mulching increased soil water infiltration and canopy transpiration as well. This means that mulching increases soil water availability and carbon assimilation via photosynthesis and thus productivity of jujube trees. Hydraulic architecture has a large impact on the amount of water uptake in the root zone under sufficient water supply, but root water uptake was greatly restrained soil water availability under water stress (Lobet et al., 2014). Our study region located in the semiarid region of the Loess Plateau where soils are exposed to water stress for the majority of growing seasons; thus, the water uptake of jujube is mainly influenced by soil water content in our study site (Lobet et al., 2014). The mulching treatments increased root zone soil water content, which is expected to lead to higher root water uptake.

4.2. The methods of estimating soil water consumption

In this study, we tried to calculate the water consumption using two different methods based on soil moisture observations and evapotranspiration, respectively. At the rainy month, the soil moisture observations method generally underestimated the evapotranspiration (Fig. 9). The cause of the discrepancy was that the shallowest measuring point for an EC-5 sensor was only 5 cm below the soil surface. In the calculation of rainfall infiltration and consumption, soil water content in the 0–5 cm layer was replaced with the value measured at 5 cm (Eq. (1)). If the rainfall is small, water evaporates rapidly before reaching 5 cm depth. So, this computing method clearly underestimates the evaporation, especially over the wet season. Simultaneous monitoring of the surface soil water can eliminate this error. Furthermore, the hypothesis of linear variation of the soil water between two sensors and deep percolation may introduce other sources of uncertainty. There are also possible systematic errors in estimating transpiration using Granier method, for examples, the difference of the trunk's natural temperature gradient and the heated probes temperature, the distribution of sapwood area and the installation position of probes (Sun et al., 2012; Ren et al., 2017). In addition, some researchers found that soil moisture content had large variation in space at orchard scale and thus the selection of *in situ* monitoring location can impact the accuracy of soil moisture estimation by sensors (Villagra et al., 1995). Therefore, future studies should evaluate the uncertainty caused by single monitoring location by using statistical approaches such as time stability analysis (Hu et al., 2010; Gao et al., 2015).

4.3. Implications

By now, land engineering measures were alone used to establish on slope in arid and semiarid regions, which will increase evaporation. From our findings, combination of mulching and land engineering measures on hillslopes increased rainfall infiltration and decreased soil evaporation as well. In addition, the economics of using mulch material needs to be considered. Trimmed jujube branches and maize straw were selected as mulching material in this experiment. The rainfall interception process of these two materials was not clear enough to allow it to be ignored, for two reasons. First, the surface of these two materials was smooth, thus it was not very hygroscopic. Second, the rainfall could easily reach the soil surface through microvoids formed by these two materials. When choosing mulching materials, one should consider not only the effect on soil water conservation, improvement of physical soil properties, and the effect of regional local climate but also economic applicability. For instance, of the two materials used in this study, jujube branches are easier to obtain than maize straw following the reduction in cultivated land area. The jujube branches were mainly from the annually trimmed branches. In addition, the presence of straw increases the damage caused by pests and diseases. The use of trimmed branches as mulching materials reduced the cost of the processing and transportation of material. Using trimmed branches also helped with the two objectives of rainfall interception and storage, and soil water preservation, providing both an economic and ecological benefit to rainfed orchards in semiarid hillslopes.

5. Conclusion

In this study, we tried to calculate water consumption using automatic water monitoring devices and combined sap flow and micro-lysimeter methods in a semiarid rainfed orchard. The results obtained from the two methods were similar over monthly. During the 2014 and 2015 growing seasons, only about 50% rainfall infiltrated the soil. The fish-scale pit treatments without mulching significantly increased the rainfall infiltration by 41.38 and 27.30%, respectively, and also increased evaporation by 42.28 and 65.59%, respectively, compared to CK during the growing seasons of 2014 and 2015. The jujube transpiration significantly increased by 45.64–53.10%, and the evaporation decreased by 42.47–53.50% when fish-scale pits were mulched using branches or straw. Hence, farmers should be encouraged to apply the comprehensive agricultural measures to sustain agroecosystems on sloping field management of semiarid rainfed orchards.

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