Agricultural Water Management 136 (2014) 23–33

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Response of relative sap flow to meteorological factors under different soil moisture conditions in rainfed jujube (*Ziziphus jujuba* Mill.) plantations in semiarid Northwest China

Dianyu Chen [a], Youke Wang [a,b,*], Shouyang Liu [a], Xinguang Wei [a], Xing Wang [c]

[a] College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling 712100, China
[b] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling 712100, China
[c] College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, China

ARTICLE INFO

Article history:
Received 11 September 2013
Accepted 6 January 2014
Available online 1 February 2014

Keywords:
Relative sap flow
Meteorological factor
Soil moisture
Rainfed jujube plantation
Semiarid region

ABSTRACT

As a drought tolerant plant, jujube (*Ziziphus jujuba* Mill.) is commonly planted in semiarid Northwest China under rainfed conditions. To clarify the response of water use to climatic conditions, sap flow (*SF*) in 8 non-irrigated jujube trees was monitored using thermal dissipation probes. Also meteorological variables, soil water content, crown projection area and leaf area index were measured during the 2012 growth season. Based on relative extractable water (θ_e), soil moisture conditions were classified into water stress ($\theta_e < 0.4$) and non-water stress ($\theta_e > 0.4$) conditions. Since leaf area (*LA*) significantly influences SF, relative sap flow (defined as $SF_R = SF/LA$) was used to analyze its relationships with selected meteorological factors. Obvious differences were noted between responses of SF_R and its sensitivity to meteorological factors under the two different soil moisture conditions. Daily SF_R was linearly related with solar radiation (R_s) but logarithmically related with vapor pressure deficit (*VPD*), variable of transpiration (*VT*) and reference crop evapotranspiration under both soil moisture conditions. Hourly SF_R was linearly related with R_s, *VPD* and *VT* at $\theta_e > 0.4$, while, at $\theta_e < 0.4$, it was lineary related with these variables to a threshold value, but it tracked a horizontal curve thereafter. On the average, the change in SF_R with meteorological factors was classified into two on the basis of the time of day. The first characteristic change was during 00:00–15:00 h and the second during the rest of the day. There were significant differences in SF_R dynamics between the two periods of the day under every soil moisture conditions, while, significant differences in the first periods but few differences in the second periods of SF_R dynamics between two soil moisture conditions. The results of the study could be used to fine-tune transpiration modeling for efficient soil water management in rainfed jujube plantations in semiarid regions.

1. Introduction

In semiarid northwest China where climatic conditions are dry with severe water shortage, agricultural development is limited by water availability. Also because of water scarcity in the region, most crops are cultivated under rainfed conditions (there is no source of available water except rainfall for crops growth). Jujube which is among the commonly cultivated crops in the region, now covers more than one million hectares of land and its planted area continues to expand due to its high drought tolerance and considerable economic benefits. Chen et al. (2008) noted that high water consumption rate of several forest tree varieties causes drying up of soils and ecological degradation in arid/semiarid regions. In order to avoid the same phenomenon in vast jujube plantations, efficient water and soil management are essential because of the prevailing fragile ecological environment in Northwest China. Hence, a proper understanding of how water use limits and controls this crop is particularly important.

Like all other trees, rainfed jujube mainly uses soil water for physiological development and reproductive processes. It is therefore important to maintain sufficient soil water in arid/semiarid regions through sustainable cultivation strategies. For jujube, there was little relevant information, particularly about its water use strategy. Ma et al. (2007) conducted a limited study on the effect of water deficit on sap flow in jujube under greenhouse conditions. Also Zhao et al. (2009) studied transpiration and canopy conductance of jujube under full irrigation conditions in the semiarid Northwest China. In the North China Plain, Sun et al. (2012) investigated evapotranspiration and water-saving potential in jujube under different agricultural measures. Irrespectively, water consumption mechanism varies considerably with climatic conditions, plant type, irrigation scheme and management methods. This

* Corresponding author at: College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling 712100, China. Tel.: +86 13359180956; fax: +86 2987012210.
E-mail address: wangyouke2013@gmail.com (Y. Wang).

0378-3774/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2014.01.001

necessitates further studies on water use mechanism of jujube under rainfed conditions.

In soil–plant–atmosphere continuum, plant growth influences not only soil chemical properties but also soil moisture distribution (Bai and Wang, 2011; Gao et al., 2011, 2012). Soil moisture in turn characteristically influences plant transpiration and root distribution in soils (Ma and Wang, 2012). In water-scarce regions, soil water conditions could even restrict plant physiological processes. Furthermore, sap flow characteristics are driven not only by soil moisture conditions but also by leaf area index (*LAI*), especially in the early periods of plant growth. Also meteorological factors such as temperature (T_a), vapor pressure deficit (*VPD*) and solar radiation (R_s) variously influence sap flow. This suggests that plants respond relatively differently to different meteorological factors and soil water conditions (Baert et al., 2013; Bovard et al., 2005; Gea-Izquierdo et al., 2012; Köhler et al., 2010; Liu et al., 2012; Nasr et al., 2011).

The exploration of tree water use strategy is not only important in investigations of ecosystem function and of catchment hydrology (Zeppel and Eamus, 2008), but also necessary for developing viable water-saving management strategies that support high water use efficiency and economic benefit in regions subjected to water scarcity. In addition, to encourage proper reforestation practices, common species need to be investigated to understand their water use strategies under different weather conditions and to determine if they are suitable for developing stable forest ecosystems (Du et al., 2011).

This study focused on the water-use strategy of jujube tree plants under rainfed conditions characterized by water stress and dry climate. To achieve this, sap flow (*SF*) was monitored (using the Granier-type thermal dissipation probes) along with meteorological factors, soil water content (θ), crown projection area and leaf area index (*LAI*). The soil moisture condition was divided into water stress and non-water stress conditions. The study aimed to: (1) compare the difference in the responses of relative sap flow (SF_R) to variations in atmospheric and soil moisture conditions; (2) lay the basis for soil water management in jujube plantations in semiarid regions; and (3) develop relevant guidelines for accurate modeling of jujube plant transpiration.

2. Materials and methods

2.1. Study site

The field study was conducted from May 10 through October 9 in 2012 at the Mizhi Experimental Station of Northwest A&F University. The station is located at 38°11′ N–109°28′ E at an elevation of 1049 m in Yulin City of Shaanxi Province, Northwest China. The period from May to October is jujube growth season in the semiarid Northwest China region. The study area belongs to the Loess Plateau, where topographical characteristics are typical of loess hills/gullies with a semiarid temperate climate (Ma and Wang, 2012). Mean annual precipitation in the study area is 393 mm (mostly occurring in July to September), that of temperature is 8.5 °C, solar radiation is 161.46 W m^{-2} and frost-free period is 160 days (Zhang et al., 2010; Bai and Wang, 2011).

The average depth to water table is over 50 m and the typical loess soil has a uniform texture and moderate permeability (Ma and Wang, 2012). Mean bulk density of the soil is 1.29 kg dm^{-3} in the upper 1.0 m soil profile, field capacity is 17.10% (mass percentage) and wilting moisture content is 5.16% (mass percentage) (Han et al., 2012; Zhang et al., 2010).

The experimental plot was 37.7 ha in area with row and stand spacings of the 9-year-old jujube trees of 3 m and 2 m, respectively. The jujube plants were cultivated on 25° east-facing slope terrace under rainfed conditions. To facilitate the management and control of crop water consumption, the jujube trees were pruned every year to maintain a canopy height of about 1.5 m. The growth season of the jujube plants in 2012 lasted for 153 days—from DOY (day of year) 131 (which was May 10) to DOY 283 (which was October 9) of the year.

Table 1
Details of selected jujube tree variables, including tree height (*TH*), sapwood area (*SA*), trunk diameter at 20 cm above ground (*TD*), crown projection area (*CPA*) and leaf area index (*LAI*).

No.	*TH* (m)	*SA* (cm^2)	*TD* (cm)	*CPA* (m^2)	*LAI* (m^2 m^{-2})
1	1.55	61.21	9.87	1.17	2.89
2	1.39	46.43	8.60	1.24	3.19
3	1.46	57.32	9.55	1.10	2.19
4	1.54	65.22	10.19	2.12	1.93
5	1.63	43.06	11.46	1.15	2.29
6	1.47	33.69	10.19	1.17	2.65
7	1.52	53.57	8.28	2.98	2.19
8	1.60	39.81	6.69	1.58	2.17

Note that the data of crown projection area and *LAI* were the measurements in stable stage. Sapwood area data were interpolated from the relationship between trunk diameter at 20 cm above ground and sapwood area obtained from fell trees.

2.2. Leaf area and leaf area index

The Winscanopy canopy analysis equipment (Winscanopy 2005a, Regent Instruments Inc., Canada) was used to take hemispherical photography following procedures described by Zhang et al. (2005). The photography was taken every 10 days on sunny days during the period from germination to the stable state of fruit ripening stage. Then, leaf area index (*LAI*) was obtained after the photography analysis using the Winscanopy 2005a software. Also crown dimensions of jujube plants were concurrently measured in four cardinal directions. Leaf area (*LA*) was obtained by multiplying leaf area index with crown projection area—the area summation of four quarter ellipses connection points (Dierick and Hölscher, 2009).

Then the time series of leaf area and leaf area index were fitted with growth function. Next, leaf area was interpolated using the fitted equation between leaf area and DOY as:

$$LA = \frac{3.97}{1 + EXP(-0.05(DOY - 156.47))} \tag{1}$$

where *LA* is leaf area (m^2). The correlation coefficient from the above relation in Eq. (1) was $R^2 = 0.96$.

2.3. Sap flow

Using the thermal dissipation method (Granier, 1985, 1987), sap flux was monitored in 8 jujube trees randomly selected from the jujube plantation. The characteristics of the selected jujube trees are summarized in Table 1. Because the jujube trees needed to be preserved from destruction for future studies, only single thermal dissipation probes (TDP, Dynamax Co., USA) of two needle probes (length: 20, diameter: 2 mm) were installed on the trunks of the selected plants to minimize tree injury (O'brien et al., 2004). Only the upper probe was continually heated while the lower probe was kept unheated.

As noted by Jiménez et al. (2000), TDP probe placement could induce considerable variations in sap flux. To minimize sap flux variation, the probes were uniformly horizontally inserted at the 0–20 mm depth of sapwood and installed on the north side of the trunks at about 20 cm above the land surface (Lu et al., 2004). Prior to the installation of the probes, about two layers of the tree trunk bark were peeled off. To limit external disturbances, the probes were carefully packaged in silver membranes (Wilson et al., 2001;