Agriculture, Ecosystems and Environment 265 (2018) 392–401

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Seasonal water use patterns of rainfed jujube trees in stands of different ages under semiarid Plantations in China

Gaopeng Huo[a,b], Xining Zhao[b,c,*], Xiaodong Gao[b,c], Shaofei Wang[a,b], Yanhui Pan[b,c]

[a] College of Water Resources and Architectural Engineering, Northwest A & F University, Yangling, 712100, Shaanxi Province, PR China
[b] Institute of Soil and Water Conservation, Northwest A & F University, Yangling, 712100, Shaanxi Province, PR China
[c] Key Laboratory of Western China's Environmental Systems, Lanzhou University, Lanzhou, 730000, Gansu Province, PR China

ARTICLE INFO

Keywords:
Plant water use
Stable isotopes
Low precipitation period
Plantation
Loess Plateau

ABSTRACT

Flexible water use patterns are of great importance for planted trees if they are to acclimate to more uncertain future conditions in water-limited regions. This study aims to understand seasonal water use patterns of rainfed jujube trees in stands of various ages. A two-year experiment was conducted at four plantations of different ages (4-, 8-, 15-, and 22-years-old), in which the stable isotope technique was combined with three analytical methods. Soil moisture in the shallow (0–20 cm), middle (20–60 cm), and deep (60–200 cm) layers served as potential water sources for the jujube trees. The results showed that the 4-year-old trees mainly used soil moisture from shallow and middle layers. The 8-year-old trees shifted flexibly their water source between the three layers. However, the 15- and 22-year-old trees often ignored moisture in shallow layers and primarily used water from subsurface layers, obtaining more soil moisture from the middle layer in periods with more rainfall while more soil moisture from the deep layer when the precipitation was low. Compared with the 4- and 8-year-old trees, the two low precipitation periods during the study period clearly resulted in more water use from deep layers for the 15- and 22-year-old trees. Overall, older jujube trees were more dependent on soil water from deeper layers compared to younger trees, resulting in extensive use of soil water from deeper layers which was difficult to be replenished by precipitation. This indicates that older trees are more vulnerable to future prolonged and extremely low precipitation, and measures are needed to improve water status, especially for deeper layers under older trees.

1. Introduction

Revegetation is one of the primary means to improve ecosystem services in degraded landscapes, and is especially important in developing regions (Zhao et al., 2015). In addition, water availability is one of the most important factors affecting the sustainability of revegetation in water-limited regions, where high evaporation and limited rainfall often lead to water shortages (Jia et al., 2012). Furthermore, significant future changes in climate have been forecasted, which would lead to more intense and frequent drought (Stocker et al., 2007). As for fruit trees, the persistence and their productivity can be greatly impacted by water shortages (Drake and Franks, 2003; Xu et al., 2016). Thus, flexible water use patterns are of great importance for trees used in revegetation in order to survive climate change in arid and semiarid regions (Eggemeyer et al., 2009; Song et al., 2016).

An analysis of stable isotope composition (δD and δ^{18}O) provides a powerful, reliable and nondestructive method to study plant water source use (Dawson and Ehleringer, 1991). In general, no fractionation occurs during water transport between the roots and shoots except in some halophytic and xerophytic plants (Ellsworth and Williams, 2007; Lin et al., 1993); therefore, the isotope compositions of water in the xylem reflect the mean isotope values of the water extracted by roots from different soil layers (Dawson and Ehleringer, 1991). This technique has been widely applied in agricultural, ecological and hydrological research to understand ecohydrological processes (Ceccon et al., 2011; Dawson and Ehleringer, 1991; Schwinning et al., 2002, 2005). In general, water use patterns of trees are influenced by different physiological and physical characteristics (Volkmann et al., 2016) as follows. (1) Distribution and functioning of fine roots; deep-rooted species can use more deep soil water and groundwater than shallow-rooted species under water stress (Dai et al., 2015; Nie et al., 2010; Wu et al., 2017). (2) Soil water availability; trees growing in arid and semiarid regions absorb most of their water from shallow soil layers in wet seasons but shift to absorb more water from deep soil layers (or groundwater) in dry seasons (Dai et al., 2015; Nie et al., 2010). (3) Water demands of trees, which relate to leaf area index, biomass, vapor

* Corresponding author at: No. 26, Xinong Road, Yangling, Shaanxi, Post code: 712100, PR China.
E-mail addresses: zxn@nwafu.edu.cn, xiningz@aliyun.com (X. Zhao).

https://doi.org/10.1016/j.agee.2018.06.028
Received 2 February 2018; Received in revised form 23 June 2018; Accepted 26 June 2018
0167-8809/

Table 1
Site characteristics of the different-aged jujube stands.

Stand age (year)	Average DBH(mm)	Mean height (m)	Plant spacing (m × m)	Crown Width (m)	Percent of cover area (%)
4	32.78 ± 5.4 d	1.23 ± 0.20 c	2 × 6	1.22 ± 0.14 d	9.82 ± 2.24 cd
8	65.58 ± 7.3 c	2.23 ± 0.36 bd	2.5 × 6	1.83 ± 0.25 c	17.74 ± 4.79 c
15	91.52 ± 10.1 b	2.89 ± 0.42 ad	3 × 4	2.38 ± 0.27 b	37.37 ± 8.41 b
22	119.12 ± 10.2 a	3.55 ± 0.46 a	3 × 4	3.32 ± 0.24 a	72.36 ± 10.43 a

The data for average DBH, mean height, crown width and percent cover area are the means ± standard deviation of three replicate samples. The different letters indicate significant differences between the samples ($P < 0.05$).

pressure deficit, etc.; mature trees may need more water to meet their transpiration needs than young trees (Kerhoulas et al., 2013; Song et al., 2016). Simultaneously, interactions among these factors exist (Drake and Franks, 2003; Ehleringer and Dawson, 1992; Xu et al., 2016): the water availability for plants is controlled by the balance between the plant's demand and the water source exploited by roots (Dardanelli et al., 1997; Thompson et al., 2010). Meanwhile, variable use of resources and different root distributions of trees can regulate the dynamics of soil water content continually (Song et al., 2016; Thompson et al., 2010). Thus, the distribution of dynamic functional roots, soil moisture availability, and the water demands of trees in stands of different ages may have profound impacts on water use patterns; however, the majority of the existing literature relates to the water use patterns of trees at a specific stand age and the differences in water use between stands of different ages are rarely considered.

Jujube is a perennial fruit tree that grows in arid and semi-arid regions in central and Eastern Asia. They possess features of convenience of management; they have high survival rate, need little irrigation, and are easy to be trained and pruned (Ren, 1998). However, the water deficit at the critical stages of blossom and young fruit and fruit swelling would seriously affect the yield, fruit volume or eating quality (Galindo et al., 2016). Meanwhile, great attentions have been paid to the fruits for its important culinary use and medicinal use (Jiang et al., 2007). For all these reasons, since the initiation of the "Grain for Green" project in western China in 1999 (Feng et al., 2005), jujube (*Ziziphus jujuba*) trees have been planted extensively in the semiarid region of China's Loess Plateau (Li et al., 2017), both to reduce soil erosion and to enhance farmers' incomes. To date, the total area of jujube plantations has reached more than 2.0×10^5 hm^2 (Wei et al., 2015). Because of the high cost of irrigation in this hilly area, rainfed plantations dominate in the region. Water availability is the primary environmental factor affecting the persistence and productivity (Wei et al., 2015), so, the primary objective of this study was to characterize seasonal patterns of the water source use by jujube trees at stands of different ages, and provide a theoretical basis for the sustainable development of an economic orchard. The stable isotopes of hydrogen and oxygen (δD and δ^{18}O) in the water of twig xylems, different soil depths and the precipitation, combined with the soil water content (SWC) were analyzed in 4-, 8-, 15- and 22-year-old jujube plantations over two consecutive years (2015 and 2016) with significantly different rainfall regimes. We hypothesized that older jujube trees would be more dependent on soil water from deeper layers and hence be more resilient to drought than younger trees. However, greater water use from deeper layers would result in low soil water availability and high water stress because infiltration from precipitation as far down as the subsurface layers is very limited in the semiarid region.

2. Materials and methods

2.1. Study area and experimental site

This study was conducted at the Heping modern agricultural demonstration base which is located in the middle of the Loess Plateau (37°15′N, 118°18′E) in Qingjian country, Shaanxi Province, and has a semiarid continental climate. According to Gao et al. (2016), the annual average air temperature is 8 °C with a minimum and maximum of -22.6 °C and 38.1 °C, respectively. Annual mean precipitation is 505 mm (based on meteorological data for 1956–2006), and more than 70% of the rainfall occurs from July to September. There are 2720 h of sunshine on average each year. The whole area is covered by loess soil (Inceptisols, USDA) with a silt loam texture (Soil Survey Staff, 2010), and the average soil bulk density, field capacity and permanent wilting point in the 0–1 m range are 1.28 g/cm^3, 0.25 $cm^3\,cm^{-3}$ and 0.06 $cm^3\,cm^{-3}$, respectively. The depth of groundwater exceeds 50 m, and the supply of soil moisture is mainly delivered through rainfall.

This experiment was conducted in 2015 in 4-, 8- and 15-year-old jujube plantations, located on east-facing upper slopes with a similar gradient (12-15°). A similar experiment was added in 2016, namely a 22-year-old jujube plantation. The distance between any two adjacent stands was less than 200 m, and the area of different jujube orchards ranged from 1 to 2.5 hm^2. A plot (20 m × 20 m) was selected in each jujube stand, in which the spatial distribution of trees was relatively uniform (Table 1). Eight jujube trees were chosen from each plot based on the aboveground function traits in terms of the height, diameter at breast height (DBH) and crown width for sampling (Table 1) and four replicates were randomly chosen from the eight labeled trees within each plot for statistical analysis, to minimize the influence of individual heterogeneity. Because the water table (> 50 m) is far beyond the maximum rooting depth of jujube trees, it was not considered to be a water source in this study.

2.2. Plant, soil and rainwater sampling

Plant and soil samples were collected during the four stages of the growing season: leaf emergence (LFE; May), blossom and young fruit (BYF; June-July), fruit swelling (FSW; August), and fruit maturation (FTM; September). The exact sampling dates were 24 May, 24 July, 8 August and 15 September during 2015 and 29 May, 29 July, 26 August and 25 September during 2016. However, samples in the 4-year-old stand were not collected on the last date in 2016, because of severe damages caused by goats. On each sampling date, four selected trees were chosen randomly in each stand, soil and twig xylem samples were simultaneously collected between 8:00 and 12:00 when the trees were actively transpiring (Wang et al., 2010). Two lignified twigs (diameter 0.1-0.3 cm) from near the limbs and the length of which exceeded 30 cm were cut from the sunny side (Yang et al., 2015) of each sampled tree. The bark, phloem, cambium and the two ends were removed to avoid the isotopic fractionation of xylem water (Dai et al., 2015). The length of the remaining part was all about 15 cm and they were then cut into 1–2 cm segments and immediately placed in vials and wrapped in parafilm, then placed in a freezer box with ice for transportation to the laboratory, where the samples were frozen and stored (-15 ~ -20°C); The total number of twig xylem samples was 216. One soil core of 0–200 cm (more than 80% of the roots were in this range) was collected using a hand auger at a distance of 30 cm away from the north side of the trunk. The soil core was collected every 10 cm in the 0–20 cm range, every 20 cm in the 20–80 cm range and every 40 cm in the 80–200 cm range. Every layer of soil was mixed well and separated into two parts, one