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# Soil water effects of agroforestry in rainfed jujube (*Ziziphus jujube* Mill.) orchards on loess hillslopes in Northwest China

Qiang Ling[a,1], Xiaodong Gao[b,1], Xining Zhao[b,*], Jun Huang[c], Hongchen Li[a], Lusheng Li[a], Wenhao Sun[a], Pute Wu[b]

[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] Pearl River Water Resources Commission of the Ministry of Water Resources, Guangzhou 510000, Guangdong Province, PR China

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ABSTRACT

Soil water is the most critical factor influencing the growth and productivity of crops on the Loess Plateau of China. The popular clean-cultivation soil management practice in rainfed jujube orchards in this region causes a variety of environmental problems, including serious soil erosion and soil quality degradation. Agroforestry is a promising avenue to cope with this problem but its effect on soil water in the root zone is yet to be elucidated. In this study, two different agroforestry systems were established in jujube orchards on the hillslopes of the Loess Plateau, to test the effects on root-zone soil water. The *Hemerocallis fulva* and fodder *Brassica napus* were planted between jujube rows. The results showed that both agroforestry systems clearly improved soil water at depths of 0–20 cm and 20–60 cm under jujube trees, however, they apparently reduced the inter-row soil water at depths of 60–120 cm and 120–180 cm in different years compared to the control. A simple method, based on the difference of soil water content between inter-row crops and jujube trees (SWDR), was introduced to judge the possibility of water competition happening. The analyses based on this method showed that in the jujube- *H. fulva* intercropping system, *H. fulva* frequently competed soil water with jujube trees in the 0–120 cm depth primarily in the relatively dry period (May to July). However, there was almost no water competition occurred in the jujube-*B. napus* treatment. Overall, fodder *B. napus* may be more appropriate than *Hemerocallis fulva* for intercropping with jujube trees. The results here can provide insights into ground management practice of sloping orchards in water-limited areas.

## 1. Introduction

The hilly region of the Loess Plateau in China is a typical semiarid region with annual mean precipitation ranging from 400 to 600 mm. Rainfall is the sole water source for rainfed agriculture in the area because of deep groundwater (generally > 50 m; Gao et al., 2016). Access to moisture is a particularly severe problem in rainfed jujube orchards on sloping land on the Chinese Loess Plateau, where water resources are increasingly scarce (Zhao et al., 2009). Since the Chinese government implemented the "Grain for Green" project on the Loess Plateau in 1999, the planting of jujube trees which are considered to be drought-resistant and of great economic potential has been encouraged (Zhao et al., 2009; Wu et al., 2008). Currently, the area of jujube is around one million hectares on the hilly region of the Loess Plateau (Chen et al., 2014). Clean cultivation management is usually employed in jujube orchards in order to reduce competition for water and nutrients by eradicating any weeds. This traditional soil management in the region can create soils that are prone to erosion and nutrient loss, and thus decrease soil quality and productivity (Gao et al., 2014; Zhao et al., 2014). Therefore, it is necessary to seek a soil management regime that will support the sustainable development of jujube orchards.

Vegetation cover can reduce soil evaporation and soil erosion and facilitate soil water infiltration (Baptista et al., 2015; Yao et al., 2005). Crops between rows of trees can enhance the amount of soil water infiltration and reduce soil evaporation and thus increase soil water availability (Agus et al., 1997; Atucha et al., 2013; Baets et al., 2007; Gutierrez-Lopez et al., 2014; Huang, 2014; Kiepe, 1995; Young, 1997). Gómez et al. (2009) and Gómez et al. (2011) found that the use of cover crops in vineyards and olive groves could dramatically improve soil water and decrease runoff and sediment yield to tolerable levels. Schwab et al. (2015) suggested that a mature, fully developed agroforestry system had the potential to enhance soil quality and long-term

* Corresponding author.
*E-mail addresses:* zxn@nwafu.edu.cn, xiningz@aliyun.com (X. Zhao).
[1] These authors contributed equally to this work, and therefore they share the first author.

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soil productivity significantly, with positive effects appearing shortly after the conversion from conventional monocropping systems. Huang et al. (2014) studied six soil management treatments − strip cocksfoot (*Dactylis glomerata* L.); strip crown vetch (*Coronilla varia* L.); strip birdsfoot trefloil (*Lotus corniculatus* L.); strip white clover (*Trifolium repens* L.); full white clover; and clean cultivation − in a jujube orchard using a soil bin (a simulated study), and found that the vegetation cover enhanced rainfall infiltration and reduced the runoff volume and sediment yield. Ultimately, they recommended strip cocksfoot cover as the best ground management in a jujube orchard.

However, the different components within an agroforestry system may compete for water and nutrients, especially in water-limited environments. Many studies have shown that water competition is the primary factor affecting crop yield in arid and semi- arid areas (Singh et al., 1989; Bremen and Kessler, 1995; Gao et al., 2013). Soil water plays a key role in plant transpiration, photosynthesis, nutrient transport and root water uptake (Schulze, 1991). Generally, soil water monitoring provides a simple and effective way to examine water competition between trees and crops (Wang et al., 2010; Yang et al., 2009; Chen et al., 2014). Zhang et al. (2010) found that *Trifolium repens* L. in an apple orchard could alleviate soil aridity and promote soil water storage, but may compete for soil water to some degree. Gao et al. (2013) reported that in apple–soybean and apple–peanut intercropping systems, soil water was the primary factor affecting the crop yields; the second most important factor was light. Jose et al. (2000) found that maize (*Zea mays* L.) cover beneath black walnut (*Juglans nigra* L.) and red oak (*Quercus rubra* L.) increased the soil water available for trees when 'barriers' and 'trenches' were constructed between the maize and the trees. Hernández et al. (2005) found that clover cover (*Trifolium subterraneum* L.) in an olive orchard competed little or not at all with the trees during normal or high rainfall years. In fact, the soil water effects of agroforestry and the water competition between different components are highly dependent on the intercropping species (Freyman, 1989; Crandall 1980; Huang et al., 2014). In order to establish stable and sustainable agroforestry systems, research on soil water effects for specific crops on the semiarid Loess Plateau is required.

At present, most of the existing studies focus on soil water variations in clean-cultivation jujube orchards on the Loess Plateau (Xiao et al., 2012; Gao et al., 2011). Although a few studies have examined the soil water effects of a jujube–grass intercropping system (Huang et al., 2014; Wang et al., 2014), the study plots were mini artificial pans (e.g., 0.8 m × 0.2 m in the two studies cited above) and subjected to simulated rainfall, which is not entirely representative of real field conditions. The soil water effect of agroforestry in jujube orchards under field conditions has rarely been reported. To this end, a typical jujube orchard was selected in a hilly area of the Loess Plateau in which to establish an agroforestry system, by introducing two economic crops (fodder *Brassica napus* and *Hemerocallis fulva*) between the jujube rows. The primary objectives of our research were (1) to understand each crop's regulatory role with respect to soil water in the jujube orchard; and (2) to analyze interspecies soil water competition between trees and crops.

## 2. Materials and methods

### 2.1. Study site

The field experiment was conducted in Qingjian County, Shaanxi Province, located in the north of the Loess Plateau; the site has typical loess hill and gully terrain (37°15′ N, 118°18′ E) (Fig. 1) and a temperate continental monsoon climate. The annual mean temperature is 8.6 °C, with the lowest mean monthly temperature −6.5 °C (January) and the highest 22.8 °C (July). Annual mean precipitation is 505 mm, of which 70% occurs generally between July and September, the soil type at this site is loess soil, which is a silt loam soil. Field capacity is about 25% (volumetric water content), wilting percentage is about 7% (volumetric water content). The primary soil hydraulic properties and soil nutrients were given in Table 1.

The study area has various types of land (orchard, farmland, grassland, etc.). Jujube orchard is one of the main economic forest systems in the area, planted on hillslopes with slope gradients of 15–24°, and containing 2, 6 and 10-year-old jujube trees. A 6-year-old pear-jujube orchard (cv. Lizao on *Ziziphus* rootstock) was chosen in the experiment. The jujube trees were planted in an East-West orientation in 2008. With the exception of watering when the jujube seedlings are first planted, all the orchards are rainfed. The jujube orchard was located on narrow terraces (~60 cm in width) constructed along the contour, the trees were planted in rows along each terrace and the distance between two trees located in adjacent terraces was 6 m (Fig. 2).

The *Hemerocallis fulva* is an indigenous perennial species. It was not killed at the end of the growing seasons, instead it was allowed to wither and die back naturally. The litter formed by the dead vegetation was retained on the soil surface, and the plants regenerated from roots in the next growing season. Fodder *Brassica napus* is an exotic annual species introduced to the Loess Plateau in recent years. It was planted in May, and was harvested at the end of October. After harvesting, it was used to provide livestock (e.g., cattle and sheep) with fresh fodder.

### 2.2. Experimental plot layout

Two typical intercropping systems of jujube–fodder *Brassica napus* and jujube–*Hemerocallis fulva* were chosen for the study, which was conducted during the jujube growing seasons in 2014 and 2015. There were three treatments in this study: jujube–*Brassica napus* (JB), jujube–*Hemerocallis fulva* (JH) and jujube monoculture (CC), which served as the control. For each treatment, three plots having an area of 45 $m^2$ (5 m × 9 m) for each of them were established as three replicates with the spacing interval of 5 m between neighboring plots. Therefore, a total of nine plots were established on hillslopes with similar slope gradients (15−18°), slope aspects (326−349°) and slope positions (upper slope). And each plot included three rows with 2.5 m between trees and 6 m between rows. The growth data of jujube trees and inter-row crops under different treatments were given in Tables 2 and 3, respectively.

### 2.3. Data collection

A portable Time Domain Reflectometry (TDR) system (TRIME-PICO IPH/T3; IMKO, Germany) was used to take volumetric measurements. Tubes for measurements were installed under trees and crops. Each tube was 30 cm away from the west side of the trunks, and a total of 54 soil water monitoring tubes were installed. The TDR tube depth was 180 cm, with 20 cm increments. Soil water was measured from mid-May–mid-October, every 2 weeks, with additional monitoring after rain. Measurements were taken a total of 34 times, with each sampling session being completed in 2 h. Jujube physiological and growth characteristics were observed and classified in four stages during the growing season:

(I) Leaf emergence (Early-May–Mid-June), when the jujube begin to sprout, to produce branches, and when there is leaf expansion and bud differentiation;
(II) Blossom and young fruit (Mid-June–Mid-July), when tree physiological functions increase, there is rapid growth of the canopy, flowering, and fruit set;
(III) Fruit swelling (Mid-July–Mid-September), when in all respects tree growth is at its maximum (including shoot growth, leaf area, etc.);
(IV) Fruit maturation (Mid-September–Mid-October), when all growth indices (including shoot growth, leaf area, etc.) have reached a steady state.