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Effects of permanent ground cover on soil moisture in jujube orchards under sloping ground: A simulation study

Jun Huang[a,b,c,1], Juan Wang[a,b,c,1], Xining Zhao[a,b,c,d,*], Pute Wu[a,b,c,d], Zhiming Qi[e], Hongbing Li[a,b,c]

[a] College of Water Resources and Architecture Engineering, Northwest A&F University, Yangling 712100, Shaanxi, China
[b] Institute of Water Saving Agriculture in Arid regions of China, Northwest A&F University, Yangling 712100, Shaanxi, China
[c] National Engineering Research Center for Water Saving Irrigation at Yangling, Yangling 712100, Shaanxi, China
[d] Institute of Soil and Water Conservation, Chinese Academy of Sciences & Ministry of Water Resources, Yangling 712100, Shaanxi, China
[e] Department of Bioresource Engineering, Macdonald Campus, McGill University, Ste-Anne-de-Bellevue, QC H9X 3V9, Canada

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ABSTRACT

A simulated study including 6 soil management treatments was conducted in 2011 and 2012 to evaluate impacts of ground cover on soil moisture and slope runoff in a pear-jujube (*Ziziphus* jujube Mill.) orchard. Treatments were (1) strip cocksfoot (*Dactylis glomerata* L.) cover (SCF), (2) strip crown vetch (*Coronilla varia* L.) cover (SCV), (3) strip birdsfoot trefoil (*Lotus corniculatus* L.) cover (SBF), (4) strip white clover (*Trifolium repens* L.) cover (SWC), (5) full white clover cover (WCC) and (6) control (clean cultivation) (CC). Results showed that, the 2-year mean infiltration water amount after rain was significantly higher under vegetation cover treatments than under CC ($P < 0.05$), and significantly greater under WCC than under strip vegetation cover treatments ($P < 0.05$, except for SCF). The runoff volume and sediment yield were significantly larger under CC than under other treatments ($P < 0.05$). The daily water consumption under WCC and CC was larger than other treatments. The mean soil moisture was significantly higher under SCF than under others ($P < 0.05$). Significant differences were found between the grass and legume covers ($P < 0.05$). The cocksfoot was considered as the best choice as a ground cover in pear-jujube orchards on dry slopes.

1. Introduction

Root-zone soil moisture is the major factor affecting crop production and vegetation reconstruction in arid and semiarid regions (Kang et al., 2002; Porporato et al., 2001). However, water resources are becoming increasingly scarce, and this is a particularly severe problem in sloped dry-farming jujube orchards on the Chinese loess plateau (Yang and Zehnder, 2001; Zhao et al., 2009) because of its limited annual precipitation of 400–500 mm, but mean evaporative demand of over 1000 mm (Cheng and Wan, 2002).

Many field and simulation experiments have been conducted to study soil moisture in Chinese loess plateau croplands (Huang et al., 2002; Zhang et al., 2008), abandoned land (Du et al., 2005; Huang et al., 2005), grassland (Chen et al., 2008; Huang et al., 2012; Zhao et al., 2013), and watersheds with various land use types (Bi et al., 2009; Cheng and Liu, 2011; Liu et al., 2010). Soil moisture variations relate to land use patterns. Fu et al. (2003) concluded that soil water content in shrubland differed from that in cropland, orchards, and intercropped land (a land contains more than one crop cultivated simultaneously). Wang et al. (2010) concluded that the formation rate and thickness of dry soil layers were dependent on the vegetation type. Chen et al. (2010) reported that the shrub vegetation land retained more soil water than other land cover types, and the water storage in the 0–100 cm layer decreased at both the beginning and the end of growing seasons regardless of land cover type, using long-term field measurements from 1986 to 1999. Zhao et al. (2011) found that moisture in the 30–50 cm layer in grazed grassland was lower than that in ungrazed grassland in Inner Mongolia. In general, soil moisture used during the growing season was not fully replenished by precipitation during wet season. Chen et al. (2007) and Bi et al. (2009) confirmed this conclusion based on the field experiments on the Chinese Loess Plateau, and noted that soil moisture distribution showed high spatial and temporal variations. Cheng et al. (2003) came to the conclusion based

* Corresponding author. Tel.: +86 2987011354.
E-mail addresses: hjnwsuaf@gmail.com (J. Huang), blesswangj@hotmail.com (J. Wang), zhaoxining_2014@sohu.com (X. Zhao).
1 These authors contributed equally to this work.

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on field observations that natural vegetation could be used to control surface runoff on slopes, reduce evaporation and improve soil water storage, and surface runoff is very closely associated with the infiltration water for individual rainfall event (McLeod et al., 2006; Huang et al., 2012).

The Grain for Green project was implemented in 1999 on the Chinese loess plateau to convert steep cultivated land to forest/grassland, to reduce soil erosion and enhance environmental protection. Because of the project, the area of commercial forests and orchards has rapidly increased and become the main income source for local farms (Wu et al., 2009); of particular importance is the cultivation of jujube trees on sloping land (Wu et al., 2008a). However, the traditional soil management regime of such orchards in this region was clean cultivation, which has caused many problems (Zhao et al., 2000), including severe soil loss (in particular in the wet season), high levels of evaporation (especially in the dry season) and soil degradation. Although some researchers have investigated root-zone soil moisture and its spatial pattern (Gao et al., 2011a,b; Xiao et al., 2012) in jujube orchards on dry slopes where conventional soil management is employed, limited information is available about soil moisture in such orchards with ground cover vegetation. It is widely accepted that vegetation cover has many advantages (Dabney, 1998; Yao et al., 2005), such as reducing evaporation by altering net radiation, wind speed and surface temperatures (Unger, 1976; Unger and Parker, 1976), improving soil structure by root growth (Danso and Curbelo, 1991; De Baets et al., 2007; Lipecki and Berbec, 1997), promoting soil permeability by preventing surface sealing and improving available water storage capacity (Anderson et al., 1992; Rachman et al., 2004; Walsh et al., 1996), and decreasing runoff and soil loss by increasing hydraulic roughness as well as both canopy and surface detention storage (Atucha et al., 2012; Francia Martínez et al., 2006; Hernández et al., 2005). Vegetation cover on soil surface can absorb raindrop kinetic energy to reduce slope soil and water loss by the mean of diminishing soil crust formation and maintaining high soil penetrating quality (Greene and Hairsine, 2004; Gyssels et al., 2005). Nieto et al. (2013) revealed that cover crops in Mediterranean olive (Canavium album Raeuseh) groves can increase the carbon storage into the soil and decrease the CO_2 concentration in the atmosphere. Latimer and Percival (1947) suggested that hay mulch placed under McIntosh apple trees could enhance soil moisture conditions and increase soil organic matter content. Vegetation in orchards can also significantly increase infiltration and decrease soil and water losses (Angermann et al., 2002). Francia Martínez et al. (2006) studied the environmental effects of various soil-management systems in olive groves in SE Spain, and found that a no-till system with strips of barley (*Hordeum vulgare* L.) could effectively reduce soil and water losses. Results presented by Gómez et al. (2009) and Gómez et al. (2011) indicated that the use of cover crops in vineyards and olive groves could efficiently decrease runoff and sediment yield to tolerable levels, and dramatically improve soil moisture conditions. Dabney (1998) reported that cover crops could enhance water infiltration and reduce both runoff rates and soil erosion. However, grass cover in orchards also has several disadvantages: (1) competition for water (Anderson, 1989; Anderson et al., 1992; Giulivo, 1989), especially during the dry summer months; and (2) some species may depress the vigor and yield of fruit trees (Bowen and Freyman, 1995; Merwin and Stiles, 1994; Neilsen and Hogue, 1992; Paris et al., 1995). Lan and Jun (2000) observed such water competition in the field of an orchard on the Chinese loess plateau, and Alcántara et al. (2011) killed the ground cover (*Sinapis alba* L. subsp. *mairei* (H. Lindb. Fil.) Maire, *Eruca vesicaria* (L.) Cav., *Raphanus sativus* L. and *Brassica carinata* A. Braun) to avoid these undesirable effects in Mediterranean olive groves. Unger and Vigil (1998) reported that growing cover crops (*Secale cereale* L., *Trifolium incarnatum* L., *Poa compressa* L., *Stellaria media* L., and *Bromus tectorum* L.) may have either no or negative effects on soil water supply for the next crop in regions with limited rain. Zhang et al. (2010) found that vegetation cover (*Trifolium repens* L.) in apple orchards could alleviate soil aridity and promote soil water storage, but may compete for soil water to some degree. However, Hernández et al. (2005) found that clover cover (*Trifolium subterraneum* L.) in an olive grove competed little or not at all with olive trees during normal or high rainfall years. Song et al. (2006) suggested that straw mulching and white clover (*Trifolium repens* L.) intercropping could improve soil water content for the key 0–20 cm soil layer and the key growth stage (April to June) of tea trees (*Camellia sinensis* (L.) Kuntze) based on four years of continuous field observations. Freyman (1989) and Crandall (1980) found that perennial ryegrass (*Lolium perenne* L.) could depress the yield of fruit trees, while white clover appeared to promote the yield. Thus, overall, there is little consensus in the literature regarding the effects of ground cover vegetation in fruit orchards on soil moisture and fruit yields.

While many studies have examined soil moisture conditions in jujube orchards on sloping dry land under conventional soil management regimes (Gao et al., 2011a,b; Xiao et al., 2012), more detailed investigations of the effects of living ground cover on soil moisture in such orchards are required. To date, the soil management in most orchards on the Chinese loess plateau has involved clean cultivation. Because it is impossible to control the conditions in field trials, and robust data are very difficult to obtain from them (Qu et al., 2008), we conducted a simulation experiment to quantitatively study effects of various types of vegetation cover on soil moisture conditions, surface runoff and soil erosion.

2. Material and methods

2.1. Soil properties

The experimental soil was loessal soil collected from farmland in Qingjian County (E109°52′, N37°03′, 1060 m above Sea Level), Yulin city in Shaanxi Province, China. The soil was passed through a sieve with 10 mm × 10 mm grid, and then air-dried until it had an initial water content of 6–10%. Finally, it was thoroughly mixed to minimize variability, then packed into soil bins in seven 10 cm deep layers to achieve a natural bulk density of around 1.35 g cm^{-3}. Each layer of soil was lightly raked before packing the next layer to minimize discontinuities between layers. Particle sizing experiments were conducted by Mastersizer 2000 (Malvern, UK), which can supply the clay, silt and sand content (w/w). The saturated hydraulic conductivity was measured by infiltration method under constant water head (5 cm). The saturated moisture content, field capacity and wilting coefficient was calculated by the soil water characteristic curve, using a centrifuge method (CR21G, Hitachi, Japan). Selected physical properties of the final experimental soil are presented in Table 1.

2.2. Rainfall simulator and soil bins

All experiments were performed using a needle-type rainfall simulator as shown in Fig. 1. The rainfall simulator was composed of three main components. (1) A raindrop producer, consisting of (A) a water tank and (B) a needle plate. (2) A rainfall intensity adjustment/control apparatus, including (C) a water level monitoring device with (D) a water level sensor, (E) a water level regulator, (F) communicating vessels and a pump with (G) a frequency converter control. (3) The water supply device, comprising (H) a water storage tank, and (I) a resin adsorption column.

The red line in Fig. 1 indicates the system water table level. Firstly, the water flows into the water storage tank (H) through