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Effect of plant cover type on soil water budget and tree photosynthesis in jujube orchards

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ABSTRACT

The traditional soil management practice used in rainfed orchards in the Chinese Loess Plateau is clear cultivation (bare soil). This system leads to severe water erosion and considerable loss of water as runoff during heavy rainfall, especially on steep slopes. Plant cover systems represent a controversial alternative to the clear cultivation system. Although cover plants strongly promote water infiltration during rainfall, they may also compete with the trees for limited soil water. In this study, water regimes and inhibition of jujube (*Ziziphus jujube Mill.*) tree photosynthesis by water stress were compared across two types of soil management strategy: 1) a traditional clear cultivation system (CC); and 2) three plant cover systems (PCS) using different species, namely birdsfoot trefoil (*Lotus corniculatus* L.), cocksfoot (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.), in constructed soil macrocosms ($0.8 \times 0.8 \times 2.0$ m) under simulated rainfall regimes. The PCS resulted in the infiltration of significantly more water during a rainfall event of about 60 mm (infiltration coefficients 86%–91% for PCS and 68% for CC). The superior infiltration achieved in the PCS treatments was then gradually offset by their extra water consumption compared with that of CC. During a light rainfall event (rainfall amount: 30 mm), runoff became negligible (less than 1.5% of the total rainfall amount) and the plant cover systems had mainly negative effects, including faster development of drought and water-mediated photosynthesis inhibition in jujube leaves. The white clover cover treatment showed the lowest runoff (runoff coefficient: 15% for the heavy rainfall and 3% for the light rainfall), the most conservative water consumption and the weakest inhibitory effects on jujube photosynthesis (net assimilation rate: >8 μmol CO_2 m^{-2} s^{-1}) among the three plant cover treatments. The white clover cover treatment is thus recommended as the most suitable choice for jujube orchards in the Loess Plateau area.

1. Introduction

Appropriate soil management practices improve the availability of soil water, which is vital for the production of fruit in rainfed orchards. The soil management practice used in orchards situated on steep slopes has traditionally been a clear cultivation system (CC, bare soil). Severe soil erosion accompanied by considerable water loss in the form of excessive runoff (Cerdà et al., 2016) are the main soil degradation problems in this system, especially in semi-arid areas such as the Loess Plateau of China (Wang et al., 2016). Several alternative soil management strategies to overcome those shortcomings have been widely tested; they include soil mulching (Prosdocimi et al., 2016; Wang et al., 2015) and vegetation cover systems (Wang et al., 2016). It is widely accepted that plant cover systems (PCS) offer productivity and ecological advantages, which include enhanced rainfall water capture efficiency (Palese et al., 2014), increased sediment-trapping capability (Alliaume et al., 2014; Li et al., 2014), improved soil nutrient cycling (Yu and Jia, 2014) and additional forage production (Feng et al., 2015). However, the plant cover species may compete with trees for soil water and lead to declines in fruit yield. The more widespread adoption of PCS has thus been constrained (Hernández et al., 2005). A comprehensive understanding of the compensatory and compet-

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itive influences of PCS would lay a foundation for the optimized design and adoption of plant covers in orchards (Everson et al., 2009; Huang et al., 2016).

Plant cover systems allow soil to absorb rainfall water more effectively due to improvements in infiltration and water holding capability (Taguas et al., 2010). PCS alter soil physical and hydraulic properties (Xu et al., 2012; Palese et al., 2014) via root growth (Ni et al., 2015), and they prevent surface crusts from forming (Lin and Chen, 2015). The performance of PCS with respect to reducing surface runoff and increasing infiltration capacity is species-specific (Huang et al., 2014). Careful choice of cover species is critical in the adoption of PCS in sloping orchards, and this subject has been widely studied, with comparisons being made on the catchment scale (Abazi et al., 2013), field scale (Cerdà and Jurgensen, 2011; Zuazo et al., 2009) and micro-plot scale (Huang et al., 2014; Palese et al., 2014). The efficacy of increasing infiltration varies across vegetation species used in PCS due to differences in both canopy cover protection (Correia et al., 2013; Zhao et al., 2016) and root growth characteristics (Zuazo et al., 2009).

In terms of soil water consumption, increased transpiration from plant covers in PCS offsets the higher soil water content (SWC) that results from the increase in water infiltration (Rodríguez-Carretero et al., 2013). Moreover, PCS using different ground cover species may lead to different water regimes (Volaire and Lelièvre, 2010; Huang et al., 2014) and orchard productivity (Monteiro and Lopes, 2007; Ramos et al., 2011). Several factors may be responsible for the differences in water consumption and drought-induced yield reduction that have been observed across PCS using different cover species; these factors may include root distribution (Garwood and Sinclair, 1979), water use strategy (Hernández et al., 2005), and drought tolerance mediated by means of altered morphology (Zegada-Lizarazu et al., 2006). Thus, the extent of water consumption and competition with orchard trees is another reason for the careful selection of cover species in PCS. When the SWC in a rainfed orchard is low, tree photosynthesis will be restricted by water stress and thus reduce the primary productivity of the orchard. The cause of photosynthesis reduction can be stomatal or non-stomatal, depending on the severity of the soil water shortage (Berry and Downton, 1982; Campos et al., 2014). Leaf photosynthesis dynamics have frequently been used to evaluate the reductions in production that result from competition for water in orchards (Correia et al., 2013; Hua et al., 2005; Parvizi et al., 2016).

The amount and intensity of rainfall play significant roles in water infiltration and thus in SWC dynamics after rainfall events (Everson et al., 2009; Hernández et al., 2005). Generally, the difference in rainfall-event infiltration between PCS and CC is more apparent under conditions of high rainfall intensity (Lieskovský and Kenderessy, 2014; Zhao et al., 2013), and this may be attributed to the difference between rainfall intensity and the infiltration capacity of soil surface. Water regimes in PCS and CC are thus dependent on the amount and intensity of rainfall (February et al., 2013; Pereira et al., 2015). Infiltration is related to both antecedent SWC and soil properties and these factors are highly unstable and impossible to compare across PCS and CC in field trials (Cerdà, 1996, 1997, 1998; Rodrigo Comino et al., 2016; Seeger, 2007). For this study, simulation experiments were therefore carried out in soil bins in order to standardize the variables not of direct interest here.

Over one million hectares of rainfed pear-jujube (*Ziziphus jujube Mill.*) orchards are situated on steep slopes in the Loess Plateau, China (Chen et al., 2014), where they are a key source of income for local farmers. The predominant soil management practice used in this region is CC, which leads to considerable water loss and drought (Zhang et al., 2016). Although some studies on the adoption of PCS in local orchards have been reported (Huang et al., 2014; Wang et al., 2016), research on the comprehensive effects of adopting PCS in these jujube orchards is scarce. In this study, the hydrological

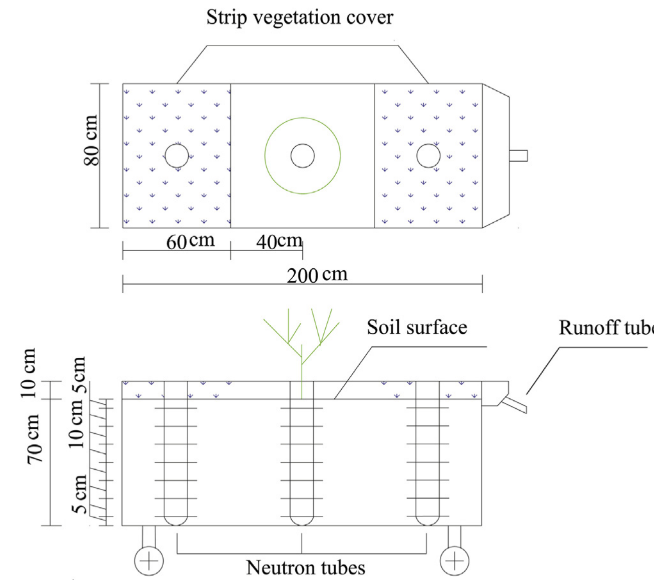

Fig 1. Plan view and cross-section of the vegetation cover and the jujube tree in a soil bin, and the apparatus used for measuring soil moisture. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

effects (water proportioning and sediment yield) and physiological effects (net assimilation, jujube yield) of adopting PCS were investigated during a simulated heavy or light rainfall and the subsequent drying stage. The performances of three types of PCS were compared with that of CC and with a jujube orchard in the field. The goals of this study are: (i) evaluating the overall effects of different PCS on water regime and jujube physiology; (ii) determining how manipulation of rainfall characteristics impacts on the performance of PCS and CC at the rainfall-event scale using simulated rainfalls.

2. Material and methods

2.1. Study area and materials

To establish the experimental mesocosms, soil samples were collected from the top layer (0–80 cm) of a local farmland in the year 2010. The soil was then passed through a sieve with 10 mm square openings to filter out the stones, and air-dried to a volumetric soil water content of 6–10%. The sieved soil was thoroughly mixed to minimize variability within and across all the treatments and then packed into soil bins of size 200 cm × 80 cm × 80 cm, as shown in Fig. 1. The soil was packed in eight 10-cm-deep layers to achieve a bulk density of 1.35 g cm^{-3}, in accordance with the typical value in traditional local jujube orchards (Ye et al., 2013). The soil contained 18% sand (2–0.02 mm), 64% silt (0.02–0.002 mm) and 18% clay (<0.002 mm) and was classified as Calcaric Cambisol on the basis of the FAO WRB soil taxonomy (IUSS Working Group WRB, 2014). According to Gao et al. (2011) and Ma et al. (2012), over 90% of the roots of 3-year-old pear–jujube trees are distributed at a depth of 0–60 cm. It is therefore unlikely that our soil bins constrained the vertical root growth of the jujube trees. The four vertical sides and the bottom of each soil bin were covered with insulating foam and silver paper to reduce heat flux. No drainage was allowed from the soil bins. Each bin was mounted on four wheels to facilitate transportation. After the soil bins had been established, a three-year-old pear-jujube (Ziziphus jujube Mill.) tree (blue in Fig. 1) was transplanted into the center of each bin on November 20th, 2010. The cover plants (green in Fig. 1) were planted at both ends of the soil bins at a seeding rate of 15 g m^{-2}