



Soil moisture dynamics in a hedgerow olive orchard under well-watered and deficit irrigation regimes: Assessment, prediction and scenario analysis



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ABSTRACT

A study was conducted in a hedgerow olive orchard (SW Spain) to assess the capability of the HYDRUS 2D/3D model in predicting seasonal soil water dynamics in a well-watered (full irrigation, FI) and two regulated deficit irrigated plots (60RDI and 30RDI) differing in the timing and level of water stress imposed. The simulated soil water balance components were used to assess the suitability of the irrigation management accomplished in the experimental orchard and that of the irrigation treatments for different soil types and management scenarios. Soil water content (θ) was measured in all four plots per irrigation treatment with two access tubes per plot installed at 0.1 m and 0.4 m away from the dripper. Comparison of simulated against observed θ showed mean absolute errors ranging from 0.03 to 0.045 cm³ cm⁻³, root mean square errors from 0.035 cm³ cm⁻³ to 0.056 cm³ cm⁻³ and Nash–Sutcliffe efficiency coefficients from 0.438 to 0.834 across all treatments and probe locations. The modelled soil water balance components showed that drainage water losses represented 9–12% only of the applied irrigation water across all irrigation treatments. Scenario analysis revealed that daytime irrigation led to higher drainage water losses in FI than nighttime irrigation. For the same irrigation volumes, rootzone soil pressure head decreased (i.e. became more negative) when the irrigation frequency of the RDI treatments increased, thus supporting the lower irrigation frequencies scheduled in RDI as compared to FI in the experimental orchard. Scenario analysis also revealed the importance of adjusting irrigation schedules to soil type, irrespective of whether FI or RDI treatments were to be implemented.

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1. Introduction

Water resources are under increasing pressure from rapidly growing demands and climate change (WWAP, 2012). Globally, agriculture is the largest user of water, with nearly 70% of withdrawals worldwide (FAO, 2014). In many areas, irrigation efficiency has been increased by adopting advanced and more efficient irrigation techniques, such as localized irrigation. In Spain, 48% of the irrigated land is under drip irrigation, although in some regions (e.g. Andalusia) this percentage may reach 74% (ESYRCE, 2014).

However, the mere adoption by growers of this irrigation technology does not always guarantee high irrigation efficiencies, as

there are many design and management factors that may affect drip irrigation performance. In a recent study conducted in a mandarin orchard with a high precision drip irrigation system, Phogat et al. (2014) showed that around 34% of the applied water drained out of the rootzone despite the fact that irrigation needs were based on estimated crop evapotranspiration. These authors argued that more appropriate management could have reduced these water losses, but also highlighted the importance of combining strategic soil water monitoring with numerical modelling to fine-tune irrigation schedules. Moreover, identifying the best practices for irrigation management is crucial to maintain and to improve the sustainable development of agriculture (Provenzano et al., 2013).

Maintaining high irrigation efficiencies, i.e. optimizing the match between water applied and water actually available to plants, is important because water resources are limited, but also arises from the need to mitigate the negative environmental impacts of irrigated horticulture, such as the potential threats to groundwater caused by leaching of nitrates (Dahan et al., 2014) or other potential contaminants (Huseth and Groves, 2014).

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With the aim of efficiently designing and managing drip irrigation systems (either surface or subsurface), numerous models have been developed over the last decades to analyse water flow under drip irrigation (Arbat et al., 2013; Cook et al., 2003; Communar and Friedman, 2010; Revol et al., 1997; Singh et al., 2006; Skaggs et al., 2004; Warrick, 1985). However, their take-up by technicians in drip irrigation design and management is low, probably due to the lack of user-friendly interfaces and of gaps in the required expertise (Arbat et al., 2013). Moreover, although these models are fairly reliable, they are difficult to apply in practice due to the high number of variables and the complex computational analysis. For these reasons, simplified agro-hydrological models have been extensively used for irrigation management of horticultural crops (Allen et al., 1998; Rallo et al., 2012, 2014).

One of the most complete software packages to simulate soil water distribution, including under micro-irrigation is HYDRUS 2D/3D (Šimůnek et al., 2006), which has been widely used in the scientific literature for design optimization and management assessment of micro-irrigation systems under different soil, water and crop conditions (e.g. Arbat et al., 2008; Cote et al., 2003; Deb et al., 2013; Gardenas et al., 2005; Kandelous et al., 2012; Mguidiche et al., 2015; Patel and Rajput, 2008; Phogat et al., 2014; Provenzano, 2007; Skaggs et al., 2004; Yao et al., 2011). These works have highlighted the potential of HYDRUS 2D/3D to simulate spatio-temporal soil water dynamics in drip-irrigated crops, but have also stressed the need to accurately define key factors such as soil hydraulic properties, boundary conditions, crop water uptake or root distribution patterns. Once validated for a specific crop system, these simulation tools provide valuable decision-support information for irrigation management under contrasting environmental conditions, with the advantages of being less time-consuming and costly than field trials.

Olive groves cover about 21% of the irrigated land in Spain (ESYRCE, 2014), being irrigated primarily with drip irrigation systems. Among the various olive orchard designs, numbers of hedgerow orchards with high planting densities, also called super high density (SHD) olive orchards (1500–2000 trees ha⁻¹), have increased exponentially in Spain since they were introduced in the early 1990s. Presently, it is estimated that the area devoted to SHD olive orchards worldwide is over 100,000 ha, of which around half are found in Spain (Rius and Lacarte, 2010).

SHD olive orchards require irrigation water supplies to hasten canopy development at the first stages and to obtain profitable yields over their productive life. As compared to low-density olive orchards, SHD orchards have some particularities that may magnify the negative consequences of errors in either irrigation design or management (Fernández et al., 2013). Particularly, the root system of SHD trees usually explores small soil volumes, compared to traditional orchards (Díaz-Espejo et al., 2012), which results in low buffer capacities of the soil and the subsequent risk of significant fractions of the supplied water not being taken up by roots if irrigation supply is not accurately designed and managed. Additionally, current evidence suggests that common problems derived from excessive tree vigour in SHD orchards can be minimized via a range of deficit irrigation strategies, such as a regulated deficit irrigation (RDI) adapted to the crop growing cycle (Fernández et al., 2013). The success of these RDI strategies will depend, in part, on the level of agreement among scheduled and actually available water supplies.

Accurate knowledge of soil water dynamics in drip-irrigated SHD olive orchards under limiting and non-limiting water supplies may therefore contribute to optimize irrigation performance in SHD olive orchards. There are a limited number of studies in the literature in which HYDRUS 2D/3D has been validated for well watered and deficit irrigated crop systems (Li et al., 2015; Patel and Rajput, 2008, 2011; Phogat et al., 2013; Zhao et al., 2009) and none of them performed for olive tree orchards.

Hence, this study aims to assess the performance of the parameterized HYDRUS 2D/3D model to predict soil water dynamics throughout the whole irrigation season in a SHD olive orchard grown in SW Spain, under a full irrigation (i.e. full crop water needs are met by irrigation supply) and a RDI strategy with two levels of imposed water stress. Once validated against soil moisture measurements, the model was used (i) to assess the correctness of the irrigation design and management accomplished in the experimental orchard through analysis of the simulated soil water balance components, and (ii) to assess the performance of the irrigation treatments evaluated under different environmental and management scenarios.

2. Materials and methods

2.1. Experimental conditions

The field experiment was conducted in 2012 at the Sanabria orchard, a commercial SHD olive orchard near Seville, southwestern Spain (37°15'N, 5°48'W). The trees were 6-year-old olive trees (*Olea europaea* L., cv. Arbequina) planted at the top of 0.4 m high and 1.1 m wide ridges. The spacing was 4 m × 1.5 m (1667 trees ha⁻¹) and tree rows were oriented N–NE to S–SW. Irrigation water was supplied automatically by a drip irrigation system consisting of one drip line per tree row (16 mm low density polyethylene) and three 2 L h⁻¹ pressure compensating drippers (0.5 m apart) per tree. One flow meter per irrigation treatment recorded the amount of water applied in each irrigation event. An irrigation controller (Agronic 2000, Sistemas Electrònics PROGRÉS, S.A., Lleida, Spain) was used for irrigation scheduling. The Leaf Area Index, measured at bloom (day of year - DOY - ca. 130) with a LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA), varied within 1.0–1.3 m² m⁻². Trees were fertigated following current commercial practices. Herbicides were applied below the trees and weed growth in the inter row spacing was controlled mechanically over the spring-summer seasons.

Climate of the study area is Mediterranean, characterized by mild rainy winters and hot, dry summers. Rainfall occurs normally from late September to May. Average annual data of reference evapotranspiration (ET₀) and precipitation recorded over the period 2002–2012 were 1541.5 mm and 534.0 mm, respectively. These records were collected from a standard weather station located near the orchard, belonging to the Agroclimatic Information Network of the Junta of Andalusia. Table 1 shows the weather data (monthly averages) recorded over the experimental year. The warmest months were July and August which registered monthly-averaged mean temperatures of 26.0 °C and 27.2 °C and maximum temperatures of 35.3 °C and 36.6 °C, respectively. The coldest months were January and February which registered monthly-averaged mean temperatures of 8.2 °C and 7.1 °C and minimum temperatures of 1.4 °C and -2.2 °C, respectively. Annual precipitation was 457.1 mm with no rainfall events occurring over the June–August period.

The orchard soil (Arenic Albaqualf, USDA 2010) had a sandy loam top layer (0.0–0.4 m) and a sandy clay layer underneath (0.4–1.0 m). The electrical conductivity of the saturated soil-paste (EC_e) determined for the top soil layer (0.0–0.4 m) was 2.5 dS m⁻¹. This value is lower than the EC_e threshold of salinity tolerance determined by Aragües et al., (2005) for the olive tree cultivar used in this study, indicating that trees were not salt-stressed and that transpiration reductions due to soil salinity were unlikely. The soil pH was 6.34 and the organic matter content 0.28%.

2.2. Irrigation treatments

Three irrigation treatments were imposed in the orchard, as described in Fernández et al. (2013); a full irrigation treatment

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