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Almond tree response to a change in wetted soil volume under drip irrigation

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ABSTRACT

Under localized irrigation, even when applying non-limiting amounts of water, there could be transpiration (T) limitations due to a limited wetted soil volume. To study under field conditions how drip-irrigated almond trees responded to a change in wetted soil volume, two treatments were established in summer 2012 in a drip irrigated almond orchard in Cordoba, Spain. One treatment ("*Large volume*") was initially irrigated with micro-sprinklers (MS) to wet the entire ground surface, and then reverted to drip irrigation, while other was always kept under drip irrigation ("*Small volume*"). Continuous monitoring of T and measurements of soil moisture content, tree water status and trunk growth were carried out. Even though trees in both treatments were supplied with sufficient water, the MS application induced an increase in T and an improvement in water status in *"Large volume"* relative to *"Small volume"*. A reduction in the hydraulic resistance of the tree was also detected in "*Large volume*", as well as an enhancement in canopy conductance and tree growth. We concluded that there are situations in the field where almond tree transpiration is limited by an insufficient wetted soil volume, even when supplied with adequate water, due to a high hydraulic resistance during times of high evaporative demand.

1. Introduction

Localized irrigation has expanded substantially during the last decades, following the introduction of drip irrigation in the early 1960′s (Goldberg et al., 1976). At present, there are more than 14 million ha of agricultural land under localized irrigation worldwide (ICID, 2016). One primary difference between localized and full coverage irrigation is the partial wetting of the soil volume by the emitters. While full coverage systems wet nearly 100% of soil surface in localized irrigation this percentage is significantly reduced. The adoption of drip irrigation systems has been particularly successful in tree crops where the plants do not fully cover the ground and any system reducing the evaporation from soil will increase water use efficiency (Fereres and Soriano, 2007; Passioura, 1977).

The quantity of water applied determines the soil water potential and thus how easily water can be extracted by the root system (Gardner, 1960). The distribution in the soil of that quantity of water defines the surface of roots influenced by irrigation. If the volume wetted by irrigation does not enclose a surface area of roots sufficient to meet plant water demand, there will be a limitation of transpiration (T) no matter the amount of water applied. The catenary hypothesis (van den Honert, 1948) establishes that T is related to the difference between soil and leaf water potential and a set of resistances:

$$T = \frac{\Delta\Psi}{R_{soil} + R_{plant}} \quad (1)$$

Where, R_{soil} is the resistance to the movement of water from the bulk soil towards the root, R_{plant} is the resistance of the plant, that considers the movement of water from the root surface to the xylem vessels right before the substomatal cavities and $\Delta\Psi$ is the water potential gradient between the soil and the leaf. Variations in R_{soil} are inversely related to the root length density (length of roots per volume of soil; more roots density means a shorter pathway for water particles from their location to any root surface) or the soil water content, increasing when one or the two variables diminish. Let us assume that we provide with the same amount of water two identical trees, with the same leaf area, root length and anatomical features. In one of the trees, the entire volume occupied by the root system is wetted to field capacity by the irrigation system, while in the other tree, only half of this volume is wetted and the rest is dry. The gradient in water potential of the wetted roots and the R_{plant} will be the same in both trees. The only difference is that in one tree only half of the root system will be withdrawing water;

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therefore, in that tree the overall R_{soil} will be necessarily higher if the root surface area of the wetted zone is not sufficient to meet the T demand. Consequently, T in the half root volume wetted tree will be lower due to a greater total R_{soil}. This simple analogy can explain why in localized irrigation T might be limited even though the amount of water applied exceeds the maximum crop demand. The wetted soil volume limitations of localized irrigation were recognized early by the engineers that designed the first drip systems (Keller and Karmeli, 1974) who recommended wetting 30–50% of the ground in low rainfall areas for an appropriate development of the crop. However, due to the excellent results obtained with this irrigation method, that concern has generally been ignored since that time. Currently, it is common to find studies about plant responses to deficit irrigation treatments where it is uncertain whether the volume of soil wetted by emitters was large enough to avoid a T limitation in the crop even in the full irrigation treatment, regardless of the amount of water applied.

García-Tejera et al. (2017) tested the hypothesis of T limitation due to limited wetting volume under localized irrigation using a SPAC model that was able to capture horizontal heterogeneities in soil water content and root distribution present under such systems. A simulation was performed in which the same amount of water was distributed to a larger surface area. Simulations results showed that in a well-irrigated tree (irrigation was applied to maintain the wet bulb at field capacity) T increased as the wetted soil area was increased for the same volume of water applied (García-Tejera et al., 2017) under model assumptions. The authors also demonstrated that the degree of T limitation depends on the evaporative demand and on the root length density relations inside and outside the wet bulb. These results are in accordance with the hypothesis of T limitation by an hydraulic effect (Kramer 1988, Kramer and Boyer 1995). An alternative hypothesis argues that T is limited by stomata closure induced by chemical signals from roots exploring dry soil (Davies and Zhang, 1991).

In the field, the relation between the spatial distribution of water and crop T appeared in different crops. The general approach to study this relationship has been to use and compare different irrigation systems such as micro-sprinkler, surface and subsurface drip systems with a changing number of emitters (Bielorai 1982; Bryla et al., 2003, 2005; Edstrom and Schwankl 2002; Gispert et al., 2012; Moreshet et al., 1983; Pastor et al., 1997; Porras et al., 1988; Schwankl et al., 1999). However, in those studies it is not clear whether the water applied was sufficient to meet the maximum crop water requirements. Then, although the general conclusion was that growth and production is favoured by a large percentage of the surface wetted by irrigation, it was not possible to clearly separate the effects of larger soil volumes wetted from higher amounts of water, because larger wetted areas were always obtained by increasing the volume of water applied. Hutmacher et al. (1994), for instance, found a strong relationship between almond tree growth and amount of water applied under drip, and attributed the increase in growth not only to the increased water volumes but also to the increased volume of soil wetted as the applied water volumes increased. In a French prunes deficit irrigation experiment Lampinen et al. (2001) found that well drip-irrigated trees showed a worse water status than the expected according to the relationship between VPD and stem water potential obtained by McCutchan and Shackel, (1992) for prunes. They pointed out as a possible explanation that in their experiments the amount of wetted soil was limited whereas the relationship found by McCutchan and Shackel, (1992) was obtained from orchards where the entire soil surface was wetted.

The confusion between the effects on crop production of variable water amounts and of changing soil wetting patterns could also explain why in almond, some studies conclude that applying more water than the estimated as full requirements promotes vegetative growth (Shackel et al., 1998; Torrecillas et al., 1989) while Girona et al. (2005) applying 130% of estimated crop water requirements, did not observe greater yields that when applying 100%. Note that Girona et al. (2005) used a micro-sprinkler irrigation system, and thus wetted a significant fraction of the soil surface regardless of the irrigation treatment, while in the other experiments a drip irrigation system was used and presumable, the volume of wetted soil increased with the irrigation level. Then T of low, and even in high, irrigation treatments could have been limited by small volume of soil wetted.

If the volume of wetted soil has an influence on tree response even when trees are supplied with adequate water, the implications for the design and operation of drip and other microirrigation systems would be highly relevant. In this study, we attempted to: a) determine if the volume of wetted soil actually limits transpiration under drip irrigation in almond trees that were receiving adequate amounts of water; and, b) describe the response of almond trees to a sudden change in wetted soil volume under field conditions.

2. Materials and methods

The experiments were performed in the summer of 2012 on four-year-old almond trees (*Prunus dulcis* Mill., cv. Guara) growing in the experimental orchard “Alameda del Obispo” of IFAPA in Córdoba, Spain. Tree spacing was 6 × 7 m; average canopy volume was 31 m^3 and approximately 34% of the ground was covered by the trees. The climate is semi-arid Mediterranean: average annual rainfall is 615 mm concentrated from autumn to spring, and annual reference evapotranspiration (ET_o) is 1350 mm with 920 mm occurring from June to September. The irrigation system was a single drip line per tree row with emitters spaced 1 m apart, discharging 2.4 l/h (a total of six emitters per tree). Irrigation frequency was daily. No rainfall occurred throughout the course of the experiment. Irrigation requirements were calculated using the crop coefficients recommended by Allen et al. (1998) and corrected by a reduction coefficient to adjust for incomplete cover relative to the ET_c of a mature crop (Fereres et al., 2012). The K_c used for the experimental period was 0.96 and the reduction coefficient $K_{r,t}$ was 0.63 for a shaded area by trees of 34%. A tree placed in a weighing lysimeter in the orchard (Lorite et al., 2012) which had 20 emitters in the 9 m^2 of the lysimeter surface provided actual consumptive use records which were used to adjust the calculated applied water.

The soil of sandy loam texture is deep, of alluvial origin, and is lighter below the 150-cm depth; the upper and lower limits of soil water storage are 0.23 and 0,08 cm^3/cm3, respectively.

The soil profile in 2012 was partially dry at the start of the irrigation season, as the rainfall between 21 December and 1 April was 54 mm while ET_o was 215 mm. As no irrigation to refill the soil profile was applied, the soil water reservoir was partially depleted at the start of the experiments. The experiment was carried out between 11 July and 10 August. Two different wetted soil volume situations were recreated in the field corresponding to the two treatments:

- A control treatment (“*Large volume*”) to represent a situation where the volume of soil wetted by irrigation is large and where it is not expected that transpiration would be limited. This was done by the application of a micro-sprinkler irrigation at the beginning of the measurement period to substantially increase the soil volume previously wetted by the drip system. The micro-sprinklers were run for 50 h spread over three days to apply 100 mm starting in July 12th. Applications were scheduled as follows: July 12th (18 h), July 13rd (16 h), July 17th (16 h). During the micro-sprinkler irrigation there was no irrigation applications through the drip system. From then on, irrigation was applied via drip as in the “*Small volume*” treatment and the rest of the orchard.
- A treatment where irrigation is applied in a small volume of soil (“*Small volume*”). This was the situation in the whole field irrigated by the drip system. Irrigation was applied daily. To ensure that in the case that T was lower in the “*Small volume*” than in the “*Large volume*” treatment the differences were due to a smaller volume of soil wetted and not due to insufficient applied water, a slight excess