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Subsurface drip irrigation affects trunk diameter fluctuations in lemon trees, in comparison with surface drip irrigation

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ABSTRACT

The aim of this work was to assess the suitability of using trunk diameter fluctuations for irrigation scheduling in a subsurface drip irrigation system in adult lemon trees. The experiment was carried out over two consecutive years in an experimental orchard located in Torre Pacheco (Murcia, Spain) in 18-year-old 'Fino 49' lemon trees (*Citrus limon* (L.) Burm. fil.) grafted on *Citrus macrophylla* Wester. Well-watered trees were maintained with surface (SUR) and subsurface (SUB) drip irrigation systems by applying irrigation water independently, maintaining in both systems the soil water content of the root zone at ≈80% of the amount of water available and the midday stem water potential (Ψ_{stem}) > −1.3 MPa. Following these criterias for irrigation scheduling, the use of the SUB system increased the water use efficiency in lemon trees, due to an irrigation water saving of 19% without the yield being affected. However, the SUB system induced different trunk growth dynamics, which produced different reference equations for the maximum daily trunk shrinkage (MDS) and Ψ_{stem}. In spite of this, the prediction power of MDS was similar for both systems. In both cases, the environmental variable that best correlated with Ψ_{stem} and MDS was the daily mean air temperature. Thus, based on these results, MDS measurements can be suitable for adjusting the irrigation scheduling of lemon trees, but differences found between irrigation systems in the MDS reference baselines highlight the necessity of determining the baselines for each irrigation system.

1. Introduction

The availability of freshwater sources for irrigation is diminishing in all parts of the world, and the conflicts between urban and agricultural interests for this water are continuing to increase. This situation is exacerbated in the Mediterranean regions, characterised by a semi-arid climate with scarce rainfall and high evapotranspiration.

Spain is the world's leading exporter of fresh lemon fruit. The main growing area of lemon (*Citrus limon* Burm. fil.) is the southeast of the Iberian Peninsula (provinces of Murcia and Alicante), where more than 80% of production is concentrated (www.magrama.gob.es). In these regions, the availability of water represents the most important limiting factor of the production. Thus, increasing water use efficiency by using improved irrigation techniques is a priority for the citrus growers, to maintain market competitiveness, levels of production and fruit quality.

Since the 1980s, subsurface drip irrigation (SUB) has become popular as the most efficient irrigation system (Camp, 1998). The SUB is an irrigation system whereby water is supplied under low pressure directly to the plant roots, inducing many potential advantages. If a SUB system is well-managed, the advantages can include minimisation of soil water evaporation and nutrient leaching; maintenance of a uniform water distribution, resulting in greater control of the irrigation water and nutrients; increased adaptability of livestock waste disposal; reduction of deep percolation losses, that can decrease ground water pollution; and increased flexibility to match various soil types and plant rooting depth (Camp et al., 2000; Trooien et al., 2000; Hillel, 2004; Palacios-Díaz et al., 2009). A number of studies have shown that SUB can increase crop water use efficiency because it consumes less water and produces similar or better crop yields compared to other irrigation methods (Camp et al., 2000; Ayars et al., 2015).

A recent review of SUB carried out by Lamm et al. (2012) showed that the use of surface drip irrigation (SUR) has been much more widespread than that of SUB, because growers may have an erroneous perception that SUB presents a greater economic risk than SUR—because of the lack of easily observed indicators of the SUB system operation and performance. They also indicated that pro-

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ducers managing large irrigated areas usually have very limited time available for various management aspects of their operations; therefore, they must rely heavily on visual clues concerning plant and soil water status. Even in cases where a systematic irrigation management strategy has been implemented, such as the reference evapotranspiration (ET_0)—crop coefficient (K_c) approach, over-irrigation may still occur and result in deep percolation, poor soil aeration and reduced crop yields (Colaizzi et al., 2004). It is quite conceivable that advantages in soil water and plant water stress sensors coupled with irrigation flowmeter measurements might lead to a level of redundancy of the SUB system performance information, that would be considered acceptable to those subscribing to the 'no visibility' perception. Such redundancy may also serve to reduce the management time required, an essential prerequisite for the adoption of any new technology. Better management tools and guidelines and redundancy in providing real-time system performance parameters might help reduce this perception.

In order to implement efficient irrigation practices, especially in SUB systems, more-precise irrigation scheduling is required. To this end, the use of plant-based water-status measurements represents a promising approach, since they measure the plant stress response directly while integrating environmental effects (Jones, 2004). To monitor the physiological response to deficit irrigation of citrus orchards, many authors have used plant water-stress indicators, such as the midday stem water potential (Ψ_{stem}) (Pérez-Pérez et al., 2014), stomatal conductance (García-Tejero et al., 2010), sap flow (Ortuño et al., 2005) or trunk diameter fluctuations (TDF) and related functions such as the trunk maximum daily shrinkage (MDS) and trunk daily growth (TDG) (Fernández and Cuevas, 2010). Although Ψ_{stem} is the standard parameter used for monitoring the plant water status (Shackel et al., 1997), monitoring Ψ_{stem} requires a significant input of labour since frequent determinations are required (Ortuño et al., 2009). On the other hand, measurements of MDS, which provide continuous and automated registers of the changes in tree water status, have demonstrated its sensitivity to changes in tree water supply in different citrus species such as sweet orange (García-Tejero et al., 2012), mandarin (Vélez et al., 2007) and lemon (Ortuño et al., 2009). But, MDS depends on both the soil water available to plants and the evaporative demand of the atmosphere, so, reference values are required for plant-based irrigation scheduling and to detect water stress (Fereres and Goldhamer, 2003). In this sense, several authors showed that it was possible to predict MDS reference values in citrus trees when meteorological variables measured on a whole-day basis were used (Vélez et al., 2007; Ortuño et al., 2009).

Since MDS is an indicator derived from TDF, there are other factors, independent of environmental conditions, which can affect MDS. A recent review by Fernández and Cuevas (2010) indicated that TDF does not depend solely on water stress, and factors such as seasonal trunk growth patterns, crop load, plant age and crop management can complicate the interpretation of TDF records. Among the crop management factors, there is no information about the influence of the irrigation system on TDF. In this sense, the only reference to it was made by Intrigliolo and Castel (2004). These authors observed that their MDS signal values were lower than those found by Goldhamer and Fereres (2001) and suggested that these differences could have been due to differences in the irrigation system.

All studies of TDF-based irrigation scheduling in citrus to date have been carried out under surface drip irrigation systems, but there is no information about how the suitability of TDF reference lines may be affected when subsurface drip irrigation is used. Thus, the aim of this work was to evaluate the importance of the irrigation system (surface and subsurface) in the suitability of TDF baselines for irrigation scheduling in adult 'Fino 49' lemon trees grafted on *Citrus macrophylla* Wester. Since with subsurface drip irrigation systems it is difficult to achieve the correct management, due to the lack of reliable indicators, the establishment of suitable Ψ_{stem} and TDF-derived reference baselines through the use of meteorological variables will permit optimisation of the irrigation scheduling in subsurface drip-irrigated trees.

2. Material and methods

2.1. Orchard characteristics

The study was carried out in 2011 and 2012 at the experimental station of the IMIDA in Torre Pacheco, Murcia (south-eastern Spain). The soil is an aridisol, with 27.9% clay, 33.5% loam and 38.6% sand, an organic matter content of 0.71% (dry soil), an electrical conductivity of a 1:5 soil water extract (EC_{1-5}) of 0.30 dS m^{-1}, 17.5% active $CaCO_3$ and a pH of 7.6. The climate is Mediterranean semi-arid, with a mean daily solar radiation greater than 170 W m^{-2} (>9 solar hours), a mean annual air temperature of around 17 °C, scarce annual rainfall (370 mm) and a total annual reference evapotranspiration (ET_0), calculated via the Penman–Monteith method, of 1313 mm, averaged over the years 2006–2010. The climatic parameters were obtained daily from a weather station located at the experimental orchard.

The experiment was performed in a 1-ha orchard, on 18-year-old 'Fino 49' lemon trees (*C. limon* (L.) Burm. fil.) grafted on *C. macrophylla* rootstock with a tree-spacing of 8 m × 3 m. The irrigation was applied through two drip irrigation systems: surface and subsurface. In both cases, two drip-lines (UniRam^{TM}, specially designed for subsurface systems, Netafim, Tel Aviv, Israel) were used in each tree row, separated by 1 m from each side of the trunk, with six self-compensated, anti-siphon and anti-drainnant drippers (3.5 L h^{-1}) per tree, 1 m apart. In the subsurface drip irrigation system, the drip lines were buried at 40 cm depth.

The amount of irrigation water for well-watered trees was determined, independently for each irrigation system, by weekly estimation of the crop evapotranspiration (ET_c), using the following equation: $ET_c = ET_0 \times K_c \times K_r$, where ET_c is in mm, K_c is the crop coefficient and K_r is the coefficient factor as a function of the shaded area for the crop (Fereres et al., 1981). The K_c values applied during the experimental period were obtained from the "Servicio de Información Agraria de Murcia (SIAM-IMIDA)" for early-harvested 'Fino' lemon trees grafted on *C. macrophylla*. The final irrigation doses applied were adjusted to maintain, in both systems, the soil moisture of the active water uptake root zone (10–50 cm depth in the surface system and 20–60 cm depth in the subsurface system) at ≈80% of the amount of water available (AWA) and the midday stem water potential (Ψ_{stem}) > −1.3 MPa (Pérez-Pérez et al., 2012). The annual amount of fertiliser applied in both irrigation systems was 270 kg N, 90 kg P_2O_5, 162 kg K_2O and 5 kg MgO per ha plus 80 g of Fe chelate per tree, supplied through the irrigation system. The irrigation was controlled automatically by a head-unit program (mod. Xilema NX300, Novedades Agrícolas, Torre Pacheco, Spain) and electro-hydraulic valves (mod. uPVC, Regaber, Parets del Vallès, Spain). The frequency of irrigation differed along the season: from two days per week in winter to daily in summer. The amounts of water applied for each irrigation treatment were measured with flowmeters. The pest control practices and pruning were those commonly used by growers in the area.

The lay-out of the experiment consisted of two rows, oriented in a southeast–northwest direction, which were subdivided into three plots. In every plot there was one row per treatment with three trees. One tree per row and treatment was excluded from the study to eliminate potential edge effects.