Financial assessment of adopting irrigation technology for plant-based regulated deficit irrigation scheduling in super high-density olive orchards

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A B S T R A C T

Hedgerow orchards with high plant densities, or super high-density (SHD) orchards, are considered to be amongst the most profitable management systems for most fruit-tree species. Regulated deficit irrigation (RDI) strategies are recommended for SHD olive orchards, especially when scheduled from automatic and continuous measurements of plant water stress. There is a lack of information, however, on the profitability of this approach. In this work we analysed the financial feasibility of using three different systems for monitoring water stress in an 'Arbequina' SHD olive orchard under a RDI strategy recommended for the experimental area (SW Spain). The systems were based on sap flow (SF), trunk diameter variation (TDV) and leaf turgor pressure (TP) related measurements. We first compared their equivalent annual cost (EAC), resulting the TP based technology as that with the greatest potential to be adopted by farmers. We then used Discounted Cash Flow Analysis (DCFA) to compare the financial feasibility of an RDI treatment scheduled from TP related measurements and providing 45% of the crop water needs (45RDITP) with both a similar treatment but scheduled with the crop coefficient approach (45RDIC) and a fully irrigated (FI) treatment. Our results from two irrigation seasons demonstrated that the 45RDITP strategy guarantees the profitability of SHD olive orchards in the long-term, with both 45RDIC and 45RDITP showing positive Net Present Value and Internal Rate of Return above the interest on capital. All the financial indicators suggested higher financial performance of 45RDITP as compared to 45RDIC, but differences were not significant, likely because of the high variability among replications. The financial impact of Common Agricultural Policy payments as well as varying olive oil and irrigation water prices on the irrigation treatments was discussed.

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1. Introduction

Water is becoming increasingly scarce around the world, being the sustainable use of water resources a major water policy challenge. In water-scarce areas, such as the Mediterranean region where most of the water resources available are allocated to agriculture, the challenge is even greater as limited water resources must be allocated to the various productive uses of water while preserving the environment and ecosystems (Falkenmark, 2000). To accomplish this, policy initiatives oriented towards the sustainable use of water from both the supply and demand perspectives should be promoted (Alcon et al., 2014a). While supply initiatives have been focused on increasing water resources availability (i.e. water regulation, alternative water resources), the demand alternatives aim to fostering better resource management practices through, for instance, the adoption of technologies or techniques to reduce water use.

In agriculture, water saving approaches such as drip irrigation, have been widely adopted in arid and drought-prone areas (Alcon et al., 2011), with the resulting water use efficiency enhancement and irrigation input reduction while maintaining production levels (Skaggs, 2001). Drip irrigation systems have been extensively adopted in water-scarce regions because they reduce water losses by deep percolation, soil evaporation and runoff, as compared to
other irrigation systems, and because their ease to control irrigation doses and frequencies. In addition to these advantages, research has demonstrated that the combination of drip irrigation systems with appropriate irrigation strategies and efficient irrigation scheduling methods substantially reduce irrigation supply while achieving the production target (Fereres and Soriano, 2007; Ruiz-Sanchez et al., 2010). Common irrigation strategies include full irrigation and a variety of deficit irrigation (DI) strategies, with regulated deficit irrigation, sustained deficit irrigation and supplemental irrigation among the most widely used (English, 1990). All those DI strategies have received much attention by researchers as a measure to reduce agricultural water use in regions with limited water availability (Centritto et al., 2005; Egea et al., 2009; Fernández et al., 2013; Girona et al., 2004; Marra et al., 2016; Marsal et al., 2002). Regulated deficit irrigation (RDI), in fact, has a high potential for woody species. With RDI, irrigation amounts close to the crop water needs are applied on the phenological stages most sensitive to the lack of water, while irrigation is reduced, or even interrupted, for the rest of the growing season (Concejero et al., 2011; Díchío et al., 2007; Fernández et al., 2013; Goldhammer et al., 2002; Marsal et al., 2000). With sustained deficit irrigation (SDI), a fixed fraction of the crop water needs is supplied all throughout the whole irrigation season (Fereres and Soriano, 2007; Laribi et al., 2013; Moriana et al., 2003; Peña et al., 2013). In addition to saving water, there are other advantages that can be attained with DI, such as increased crop quality (Buendía et al., 2008), earlier harvests (Fernández et al., 2010) and the control of excessive vegetative vigour (Fernández et al., 2013).

For hedgerow olive orchards with high plant density, also called super-high-density (SHD) orchards, RDI has been reported to be one of the best irrigation strategies in terms of orchard productivity under semi-arid conditions (Fernández et al., 2013; Gómez del Campo, 2013). However, achieving the expected agronomic targets in SHD olive orchards under RDI is challenging, since the targeted water savings must be achieved at the same time that episodes of excessive water stress are avoided when the crop is most sensitive to drought (Chalmers et al., 1981). Thus, the success of the RDI strategy in SHD olive orchards depends largely on proper monitoring of crop water status throughout the irrigation season. With that purpose, efforts have focused on the use of plant-based sensors for collecting records on physiological variables related to plant water status (Fernández, 2014a). In this sense, measurements related to sap flow (Fernández et al., 2008b; Rousseaux et al., 2009), trunk diameter (Cuevas et al., 2010; Moriana et al., 2010) and leaf turgor (Fernández et al., 2011; Padilla-Díaz et al., 2016) have been successfully used to monitor water stress in a variety of species. Systems have been developed for the continuous and automatic monitoring of those variables, robust enough for working under field conditions for long periods of time, and a number of user-friendly water stress indices have been derived and tested (Fernández, 2014a).

There is little information, however, on to what extent the use of new DI strategies and new irrigation technologies for plant-based regulated deficit irrigation scheduling is profitable in commercial fruit-tree orchards.

When water is the limiting factor for cropping, implementation of DI strategies is usually more profitable than full irrigation (Alcon et al., 2014b; García et al., 2004; Pérez-Pérez et al., 2010; Romero et al., 2006). Moreover, when DI is correctly scheduled, yields and farm incomes are stabilized, which help farmers and orchardists on planning economic decisions (Geerts and Raes, 2009). In addition, the adoption of DI becomes more interesting when other water saving technologies are in place, at conveyance and farm level, and becomes compulsory when water is scarce (Alcon et al., 2014b). Still, and for the case of RDI adoption in SHD orchards, there is no evidence on its financial suitability. The financial feasibility of SHD olive orchards has been previously evaluated (AEMO, 2010; Ait Hmida, 2010; Arbonés Florensa et al., 2014; Freixa et al., 2011; IOC, 2015), but without considering the impact of different irrigation management strategies. Therefore, studies aiming to assess the profitability of implementing RDI together with water stress monitoring tools in SHD orchards are needed to ease the process of adoption by farmers.

In this context, this study aims to evaluate the financial feasibility of a super-high-density (SHD) olive orchard grown for olive oil production in a water-scarcity context that has been managed following the recommended RDI strategy for this production system and supported by emerging water stress monitoring technologies. We considered three different stress monitoring technologies with potential for scheduling irrigation based on measurements related to sap flow (SF), trunk diameter variation (TDV) and leaf turgor pressure (TP), respectively. They were firstly analysed through their equivalent annual cost (EAC) to select the decision support technology for RDI scheduling most likely to be adopted by farmers. The selected technology was then implemented in a commercial SHD olive orchard, to schedule the RDI strategy recommend by Fernández (2014b) for this type of orchards, and compared through Discounted Cash Flow Analysis (DCFA) to conventional RDI (i.e. without plant-based water stress monitoring) and full irrigation strategies. The main contributions of this work are, therefore, to increase existing financial evidences on the adoption of RDI by farmers in the SHD management system for olive, and to evaluate the financial impact of adopting farm-level technology (i.e. plant-based sensors) to support RDI scheduling in this type of orchards.

2. Materials and methods

2.1. Orchard description and irrigation treatments

The experiment was conducted at a commercial SHD olive orchard near Seville, Spain (37.248979, −5.796538) representative of those in the area. The olive trees (Olea europaea L., cv. Arbequina) were planted in 2007 at 4 m × 1.5 m tree spacing (1667 trees ha−1). The trees were drip irrigated with one drip line per tree row and three 2 l·h−1 pressure compensating drippers per tree. One flow meter was installed in each irrigation treatment to record the irrigation supply. Trees were fertilized to cover the crop needs and no weeds were allowed to grow in the inter-row spacing over the spring-summer season. The climate of the region is Mediterranean, characterized by a mean annual reference evapotranspiration (ET0) and precipitation of 1528 mm and 540 mm, respectively (period 2002–2014). The soil has a sandy loam layer in the top 0.4 m and a sandy clay layer underneath. The electrical conductivity of the saturated soil-paste, pH and organic matter content determined in the top soil layer (0–0.4 m) were 2.5 dS m−1, 6.34 and 0.28%, respectively.

Three irrigation treatments were established in the orchard during the growing cycles of 2014 and 2015: (i) full irrigation (FI) that supplied the irrigation needs (IN), calculated as ETc–Pc (ETc = crop evapotranspiration; Pc = effective precipitaiton), for the whole irrigation season; (ii) regulated deficit irrigation aimed to replace 45% of IN, scheduled on the basis of the crop coefficient approach (45RDIC); (iii) regulated deficit irrigation aimed to replace 45% of IN, scheduled on the basis of leaf turgor related measurements (45RDITP) made with TP probes (Zimmermann et al., 2008). The 45RDIC trees were irrigated with enough water to replace IN in three periods of the year when olive is most sensitive to water stress (Fernández, 2014b). For the rest of the year just one or two irrigation events per week were applied. The crop coefficient method was applied for scheduling irrigation in both the FI and 45RDICC treatments, with crop coefficients adjusted for the orchard conditions by Fernández et al. (Fernández et al., 2013). For the 45RDITP treatment, irrigation scheduling for the three periods mentioned
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