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Carry-over effects of deficit irrigation applied over seven seasons in a developing Japanese plum orchard

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ABSTRACT

Deficit irrigation is a strategy that in the short term often allows increasing water use efficiency with minimal impacts on tree performance. However, the long-term and carry-over effects of this practice have not been sufficiently investigated. Here, we report a research that was conducted over eight years in a young Japanese plum orchard planted with cv. Black-Gold in Valencia, Spain. Different deficit irrigation and crop load regimes were applied in the first seven seasons. In the last experimental season, however, all trees were well irrigated in order to explore the possible carry-over effects of the water restrictions applied previously. The results obtained indicate that under the experimental conditions of the current research (low irrigation water salinity, and Mediterranean climate with some intense rainfall events during fall and spring), deficit irrigation applied for seven consecutive seasons did not lead to accumulation of salts in the soil, a concern when deficit irrigation is applied in the long-term. Nonetheless, water restrictions impaired the fruit bearing capacity quantified as the number of fruit per unit branch length before thinning application. This effect was partly explained by a decrease in the concentration of starch reserves in the root system in one of the deficit irrigated treatments. A decrease in the fruit bearing capacity itself did not impair yield as the cultivar employed in this study required intense thinning that offset the initial differences in the number of fruit per branch length. However, deficit irrigation led to smaller trees (31% in tree shaded area in the most stressed treatment against 47% in control trees). This effect was the ultimate cause of the 29% yield reduction observed in the eighth season, when the previous deficit irrigated trees were fully watered. It is then concluded that deficit irrigation strategies in developing orchards should be used with caution. Only slight restrictions can be imposed in order to avoid the long-term carry-over effects of deficit irrigation on tree performance.

1. Introduction

Water is a scarce resource in the Mediterranean countries. With irrigated agriculture accounting for up to 74% of global water consumption (Eurostat, 2010), one of the main objectives demanded to the growers is to increase crop water use efficiency, e.g. marketable yield divided by water use. This may be achieved with genetics, and though new advances in biotechnology offer some promising perspectives in the long-term, currently, improvements in practices like irrigation water management remain more feasible (Fereres and Gonzalez-Dugo, 2009).

Regulated deficit irrigation (RDI) was developed in the 1980s as a strategy to reduce tree growth of vigorous trees and to save water (Chalmers et al., 1981; Behboudian and Mills, 1997). In RDI programs, water restrictions are applied in those phenological periods when yield is less sensitive to soil water deficit, while during the rest of the season, full tree water requirements are normally applied. Particularly in stone fruit trees, RDI has very often been effective on saving water with no yield loss or any agronomical penalty (see revisions by Naor, 2006; Ruiz Sánchez et al., 2010). When deficit irrigation is applied over a two-three year period, stone fruit trees seem to cope well with the mild water stress (Girona et al., 2004; Intrigliolo and Castel, 2005). On the other hand, there is some evidence that in the medium-term, when deficit irrigation is applied over more than three years, there might be some negative effects on yield as shown by some long-term research conducted in almond (Girona et al., 2005) and olive trees (Melgar et al., 2009). However, very little information is available on the carry-over effects of deficit irrigation applied on a longer term.

There are some concerns that growers might face when they consider applying deficit irrigation in an orchard over several years. One of them is related with soil salt accumulation. When trees are irrigated at a rate below its water needs there is a feasible threat in the long-term of salt accumulation in the root-zone. While this has been well recognized in conditions of high irrigation water salinity

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Table 1
Average reference evapotranspiration (ETo) and rainfall registered during fruit growth, post-harvest and yearly periods for the long-term deficit irrigation seasons (2000–2006) and for the recovery season (2007).

	2000–2006 (deficit irrigation trial)			2007 (recovery trial)		
	Fruit growth	Post-harvest	Year	Fruit growth	Post-harvest	Year
ETo (mm)	571	396	1095	602	358	1070
Rainfall (mm)	164	174	390	165	200	445

(Mounzer et al., 2013; Pedrero et al., 2013), it is not clear whether this can occur when trees are irrigated with good quality water. Another concern is related with tree size reduction due to the detrimental effects of water stress on vegetative growth. While one of the advantages of an RDI strategy is the restriction of plant tree growth, increasing carbon allocation to reproductive structure; it is also certain that particularly in young developing trees, a reduction in tree growth when canopy is not still complete might be detrimental to the future tree productivity.

The objectives of this work were to assess the long-term effects of different irrigation and crop level regimes carried out during seven consecutive seasons on plum, and to determine the carry-over effects when the deficit irrigation strategies ended and trees were irrigated at full crop evapotranspiration.

2. Materials and methods

2.1. Experimental plot and treatments

The experiment was performed during eight consecutive seasons (2000–2007) in a commercial Japanese plum orchard (*Prunus salicina*, 'Black Gold') grafted on 'Mariana GF81' rootstock at Líria, Valencia, Spain (40° N, elevation 300 m). The orchard was planted in 1997, and at the beginning of the experiment (year 2000) trees had an average trunk circumference of 0.23 m with a canopy ground cover of 12%.

The climate of this area is Mediterranean with warm and dry summers and rainfalls occurring mainly during winter and spring. As an average for the seven seasons in which RDI was applied, reference evapotranspiration and precipitation during the growing season (March–November) were 982 and 324 mm, respectively (Table 1). Average yearly rainfall was 390 mm.

The soil was a sandy loam with 32% by weight stones and an effective depth of 80 cm. The irrigation water had an average EC of 1.1 dS m^{-1} and an average Cl concentration of 122 mg L^{-1}. Trees were planted in 1997 at a spacing of 5 × 3.5 m and were drip irrigated. *P. salicina*, 'Black-Diamond' and 'Black-Amber', were planted in guard rows as pollinizers.

Agricultural practices followed were those common for the area. 'Black-Gold' flowers on late February with 300–400 flowers per meter of branch and has typically a 15–20% fruit set. Thus, 85% of the fruit are generally removed as a commercial practice in order to obtain good fruit size. For our experiment, fruit were hand thinned during April when the different crop load levels were established.

During seasons 2000–2003, six different irrigation regimes during phenological stages II and III of fruit growth and post-harvest were applied as described in Intrigliolo and Castel (2005), where the main findings related with the short and mid-term effects of deficit irrigation are also reported. During seasons 2004–2006, deficit irrigation treatments were carried out during phase II of fruit growth and post-harvest in combination with different crop level regimes (commercial and low crop load level). A detailed description of the treatments carried out and the main results obtained are summarized in Intrigliolo and Castel (2010) and Bonet et al. (2010).

In both experiments (Bonet et al., 2010; Intrigliolo and Castel, 2005, 2010) there was always a control treatment, T1, irrigated at 100% of the estimated crop evapotranspiration (ETc) and maintained to a medium commercial crop level (5.1 fruit per cm^2 of trunk cross sectional area). Table 2 summarizes the amount of water applied and crop level regimes imposed to the trees in the different treatments for these seven experimental seasons.

In 2007, the control treatment (T1) continued being irrigated at 100% of ETc while treatments T3 and T5 were watered at 100% and 133% of ETc, respectively, in order to asses the long-term carry-over effects of the deficit irrigation applied once trees were watered at full crop evapotranspiration or even over-irrigated (Table 2). During the growing season of 2007, ETo and rainfall were 966 and 342 mm, respectively (Table 1).

Crop evapotranspiration was estimated as the product of reference evapotranspiration (ETo), calculated according to Allen et al. (1998), and crop coefficient (Kc) adjusted for tree size (Fereres and Goldhamer, 1990). Weather was recorded at an automated weather station near the orchard.

Crop level treatments were based on thinning at different intensities, with fruit thinning performed manually in April. For the purposes of the present experiment we compared the T1, T3 and T5 treatments that had similar crop levels among them during the last experimental season, 2007 (Table 2).

The experimental layout was a randomized complete block design with three replicates per treatment. Each plot had three rows, with eight trees per row. The six central trees of the middle row were used for data collection of yield and growth determinations, while the two central trees were used for water relations.

2.2. Determinations

In all seasons and treatments, midday stem water potential (Ψ_{stem}) was measured with a Scholander pressure chamber (Model 600 Pressure Chamber, PMS Instrument Company, Albany, USA), following procedures described by Turner (1981). Two mature leaves per tree, from the north face near the trunk, were enclosed in plastic bags covered with silver foil at least two hours prior to the measurements, which were carried out between 12:00 and 13:00 h solar time. Determinations were made every ten days in 4–6 trees per treatment.

Trunk perimeter was measured at the beginning and at the end of each experimental season. Relative trunk growth was then calculated as Δtrunk perimeter/initial trunk perimeter.

Tree shaded area was measured at the end of season 2006 (when the deficit irrigation-crop level trials had finished) on each tree just after harvest using a point grid method (Wünsche et al., 1995). A plastic sheet with grid points spaced at 50 × 50 cm was laid under the canopy, and percentage of shaded area of each grid point estimated. Total tree shaded area was calculated and corrected for solar elevation.

By the end of 2006, once deficit irrigation and crop level regimes had finished, soil salt concentration was determined at the emitters' location at different depths in saturated paste extracts from soil cores obtained up to 60 cm depth. Two samples per experimental plot were obtained in the T1 (control) and in other two previously deficit irrigated treatments (T5 and T6).

During the winter of the 2006 season, root starch concentration levels were determined in all treatments in two samples per experimental plot (six samples per treatment). Root starch