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Crop load regulation and irrigation strategies to accelerate the recovery of previously water-stressed Japanese plum trees

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ABSTRACT

Regulated deficit irrigation (RDI) has been proven as a useful irrigation strategy in a wide range of fruit crops to deal with water scarcity. However, long-term RDI techniques in developing orchards can reduce tree growth resulting in a loss of tree yield capacity. Strategies that could be used to quickly recover trees from the possible carry-over effects of long-term deficit irrigation are then of physiological and commercial interest. Tree crop load is a determinant factor of the carbohydrates partitioning between fruit and vegetative sinks, being fruit sink strength higher than that of vegetative organs. The working hypothesis of this study was that tree crop load reduction could be employed to alleviate the detrimental effects that long lasting RDI strategies have on tree growth. The recovery of a young plum Japanese orchard (*Prunus salicina*, cv. 'Black Gold') after seven seasons under RDI was studied by testing combinations of two crop load levels (medium and low), two drip irrigation regimes [100 and 133% of crop evapotranspiration (ETc)] and two different number of emitters per tree (six and eight). Results showed that treatments applied led former RDI treatment trees to significantly reduce their differences in tree shaded area and particularly in trunk perimeter with respect to the control treatment trees. After two seasons of treatments, differences in yield, economic return and number of fruit per tree were exclusively due to the crop load levels imposed and not to a smaller size of former RDI treatment trees. Trees watered at 133% ETc and thinned at low crop load, which underwent a very severe RDI strategy previous to this experiment, were the trees that showed the greatest recovery in tree size. In this treatment, the lower competition between fruit and vegetative growth and the increase in the soil wetting area by using a higher number of emitters per tree, probably favored root growth significantly increasing tree growth with respect to the other treatments. Overall, this work shows that crop load regulation is a useful tool to quickly recover plum trees from the detrimental effects of long-term deficit irrigation.

1. Introduction

There is a generalized concern about the foreseeable future in which the world population is expected to grow while water resources shrink (Fereres and Gonzalez-Dugo, 2009). This increasing concern has led the research community to boost the number of studies on irrigation water saving strategies, such as RDI, which could allow growers to reduce the amount of water used in irrigation with none or a minimum impact on yield and revenues.

RDI has been studied in a wide number of vegetables and fruit crop trees (see reviews of Geerts and Raes, 2009; Ruiz-Sánchez et al., 2010). The vast majority of these studies dealt with the effect of deficit irrigation on plants at short or medium term while only few of them assessed the effects of long-term (more than three years) deficit irrigation. Girona et al. (2005) evaluated the use of RDI in almond trees over four consecutive seasons. These authors observed that water restrictions applied during the kernel-filling phase for three years reduced the dry matter accumulation capacity the next year as a carry-over effect of the deficit irrigation applied. One of the main effects of plant water stress is a vegetative growth reduction (Hsiao, 1973). In developing plum trees, Intrigliolo and Castel (2010) observed that after seven years under RDI, tree size reduction was the main effect of deficit irrigation. This reduction in tree size experienced by the seven-year deficit irrigated trees led to lower yield and economic return the next season, when water restrictions were not imposed and trees were irrigated meeting their full water requirements (Intrigliolo et al., 2013).

Drought periods have a cyclic nature in the Mediterranean region where precipitation rates are very erratic and might considerably vary from year to year. In the Valencia region, where this experiment was performed, there is evidence of an increase in the drought patterns and areas affected by drought (Vicente-Serrano et al., 2004). In areas where water availability often depends on local water reservoirs and ground water instead of transfers from

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other places, the annual precipitation variability can lead to very different amounts of water available for irrigation among the years. A period of several seasons with low rainfall in which growers are forced to deficiently irrigate plants, can be followed by a heavy rainy season that could fill up the local water reservoirs and raise the ground water levels providing growers with enough water to irrigate plants at their full water requirements during the whole season. Thus, in cases of both long-term RDI strategies applied to increase water use efficiency or long periods of deficit irrigation due to limited water resources, it would be desirable to apply strategies that at short-term, it could recover trees from their possible loss in productivity caused by the previously deficit irrigation imposed.

To the best of our knowledge, there is no information in the literature about the orchard performance after a long-term period of drought stress. It would be important to answer questions such as the time span it takes for trees to recover from the effects of deficit irrigation or whether there might be a strategy that could be applied to accelerate compensation in growth of former deficit-irrigated plants. Hutmacher et al. (1994) found that almond trees irrigated above the plant water requirements had higher trunk growth rates than trees irrigated to simply fulfill the estimated water requirements. This might be explained considering that in drip-irrigated orchards, where the wetted soil volume is limited, plants can suffer temporal root drying even when they are irrigated at full water requirements. Water applications above tree water needs can then prevent trees from experiencing this temporal drought stress.

In stone fruit trees, there is a strong competition between reproductive and vegetative growth (Berman and DeJong, 2003). High crop loads have generally been related to decrease in tree growth (Intrigliolo and Castel, 2010) caused by an increase in carbohydrate partitioning to fruit (Palmer, 1992), particularly during the last stage of fruit growth (DeJong and Grossman, 1995). In a four-year study aimed to control the biennial alternating bearing of 'Honeycrisp' apple trees, Embree et al. (2007) observed that thinned treatments promoted a larger canopy and trunk cross sectional area (TCSA) than control trees in which thinning was not performed. The influence that crop load has on the resources available for growth could then be used in stone fruit trees in which deficit irrigation has reduced their productivity. The main working hypothesis of this research was that strategies combining low crop load levels and irrigation regimes above trees' water requirements could be used to accelerate the recovery of former deficit-irrigated trees. Two crop load levels (low and medium), two drip irrigation regimes (irrigation at 100 and 133% ETc) and two different number of emitters per tree (six and eight) were tested in a Japanese plum orchard that had been previously subjected to different regulated deficit irrigation strategies for seven consecutive seasons.

2. Materials and methods

2.1. Orchard characteristics and treatments

The experiment was conducted over two years (2007–2008) in a commercial Japanese plum orchard located in Liria, Valencia, Spain (39°42′ N, 0°38′ W, elevation 300 m), where the climate is Mediterranean with rainfall mainly occurring in spring and autumn. Trees (10 years old at the beginning of the experiment) had been planted at a spacing of 5 m × 3.5 m and grafted on 'Mariana GF81'. Trees were irrigated with two drip-lines (16 mm of diameter) per row equipped with non pressure-compensating drippers of 4 l h^{-1} (Azud-drip compact, AZUD, Alcantarilla (Murcia), Spain). Irrigation inputs were registered by means of volumetric flow meters installed in each experimental unit.

The soil (Calcareous Fluvisol) was a sandy loam with 32% by weight of stones and an effective depth of 80 cm. The irrigation water had an average $EC_{(25\,^\circ C)}$ of 1.1 dS m^{-1} and an average Cl concentration of 122 mg L^{-1}. *Prunus salicina*, 'Black-Diamond' and 'Black-Amber' were planted in guard rows as pollinizers. More details about the orchard can be found in Intrigliolo and Castel (2005).

During seven consecutive seasons (2000–2006), five RDI treatments with water restrictions of different intensities (slight, mild, moderate, severe and very severe) had been tested in this orchard in comparison to a control treatment irrigated at full water requirements (Intrigliolo and Castel, 2005, 2010). The treatments applied along with the mean water savings obtained in each treatment with respect to the control are shown in Table 1. The main effect of the long-term RDI applied to these trees was a reduction in tree size that impaired their production capacity when those trees were irrigated at full water requirements the next season (Intrigliolo et al., 2013). In the present experiment during 2007 and 2008, different treatments were tested which combined two levels of crop load [medium crop load (M) and low crop load (L)], two irrigation regimes (100 and 133% ETc) and two number of drippers per tree (6 and 8) to recover the former RDI treatment trees.

The treatments used during 2000–2006, which were control, slight, mild, moderate, severe and very severe water stress RDI treatments, were renamed as 100-6-M, 100-6-L, 100/133-6-M, 100/133-6-L, 133-8-M and 133-8-L respectively (Table 1). Trees used as control during the previous RDI trial were thinned to a medium crop load and continued to be irrigated at 100% ETc in both experimental seasons (Table 1). Previous mild and severe RDI treatments were also hand thinned in April to a medium crop load (5.5 and 2.0 fruit cm^{-2} TCSA) on average in 2007 and 2008, respectively) while previous slight, moderate and very severe water stress RDI treatments were thinned to a low crop load (3.1 and 1.1 fruit cm^{-2} TCSA on average in 2007 and 2008, respectively). The evident difference in crop load between both seasons was due to a pollination problem in the orchard that reduced fruit set during 2008. During the 2007 season, former slight, mild and moderate water stress RDI treatments were irrigated at 100% ETc using six emitters per tree, which is the normal practice in this area. Former severe and very severe water stress RDI trees, however, were irrigated at 133% ETc, using eight emitters per tree in order to increase the soil wetting area. During this first experimental season there were two repeated treatments. Former control and mild water stress RDI treatments were both irrigated at 100% ETc and thinned at medium crop load (100-6-M and 100/133-6-M treatments, respectively), while former slight and moderate RDI treatments were also irrigated at 100% ETc although thinned at a low crop level (100-6-L and 100/133-6-L treatments). This was so in order to assess if the previous reduction in tree size (as in the former mild and moderate water stress RDI treatments) affected tree growth recovery with respect to control or to slight water stress RDI treatments, where tree size was normal for a ten-year-old tree of this cultivar. Since in 2007 there were no differences in trunk diameter growth among trees irrigated at 100% ETc regardless the watering regime during the previous seven seasons, irrigation in this former mild and moderate water stress RDI treatments during 2008 was increased to 133% ETc as indicated by the name of the treatment (100/133-6-M and 100/133-6-L).

Crop evapotranspiration was estimated weekly as the product of reference evapotranspiration (ETo), calculated according to Allen et al. (1998), and crop coefficient (K_c) adjusted for tree size (Fereres and Goldhamer, 1990). Weather was recorded in an automated weather station located 3 km from the orchard. The K_c used for all treatments as the reference for obtaining ETc was based on the canopy ground cover of the 100-6-M treatment (previous control in the RDI experiment). Crop coefficients varied along the season from a minimum of 0.29 in March to a maximum of 0.57 in June. As an average for the whole season K_c was of 0.46. The water needs