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Effects of timing and intensity of deficit irrigation on vegetative and fruit growth of apricot trees

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ABSTRACT

The effect of different deficit irrigation strategies were studied over a four year period in mature apricot trees (*Prunus armeniaca* L., cv. Búlida) to ascertain how the intensity and duration of water deficit affects the growth of the root and aerial (shoot, trunk and fruit) parts of the tree, and hence future tree productivity. The irrigation treatments consisted of: a control, irrigated at 100% of seasonal crop evapotranspiration (ETc); continuous deficit irrigation (CDI) at 50% of ETc; two regulated deficit irrigation (RDI), at 100% of ETc only during the critical periods, and reduced to various percentages of ETc during the rest of the season. Soil and plant water status, yield, vegetative and fruit growth were measured in the different treatments. Vegetative growth decreased according to the intensity and duration of the water deficit applied, and depending on the phenological period when the water deficit occurred. Deficit irrigation promoted a decrease in trunk and shoot growth by a 33% on average, although root length density increased nearly double in the 0–0.25 m drip-line band compared with the Control trees. In the RDI treatments, trunk growth and pruning were significantly reduced only under severe water deficit conditions. While CDI proved to be detrimental for maintaining fruit yield due to the significant reduction in vegetative growth, which led to a decrease in the number of fruits per tree, the RDI treatments only led to reduced yields when the water deficits during the non-critical periods were severe, tree trunk growth being significantly reduced as a consequence. Also, fruit size and total yield decreased when deficit irrigation relief was delayed until after the onset of stage III. Overall, water saving up to 22% affected negatively to the total yield and the number of fruits per tree, by reducing the tree growth.

1. Introduction

Southeastern Spain produces 65% of the total Spanish apricot crop and 16% of the European Union's, reaching 62,209 t in 2009 (MARM, 2012). In the province of Murcia almost all the cultivated area (≈10,000 ha in 2009) is irrigated, although the climate in this region is characterized by medium levels of air relative humidity and winters that are enough to cover the chilling requirements of apricot (Ruiz et al., 2006), the high temperatures during the rest of the season and low rainfall require that irrigation be applied to attain profitable yields. Low precipitation, of around 380 mm year^{-1} on average during the last 70 years (MARM, 2012), coupled with a high evaporative demand that exceeds 1200 mm year^{-1}, characterize the Segura River Basin and the province of Murcia, an area suffering one of the greatest water scarcity in the European Union.

In the past 10 years the area dedicated to apricot tree cultivation in Spain has decreased by about 6000 ha, representing a decrease in production of about 50,000 t. On the other hand there has been an increase of about 17,000 t in the amount of apricot exported, which represents 45% of the total fruit Spanish production (MARM, 2012). This illustrates the sector's increasing focus on production intended for fresh consumption as opposed to fruit for the processing industry, which implies the quality of the harvested fruits needs to be ensured.

Climatic forecasts predict a major reduction in rainfall, which may lead to a decline in water resources available for irrigation. This means that the agricultural sector must become more efficient in its use of water for irrigation (Morison et al., 2008). To this end, different deficit irrigation strategies have been proposed, including

Abbreviations: ETc, crop evapotranspiration; CDI, continuous deficit irrigation; RDIm, moderate regulated deficit irrigation; RDI, regulated deficit irrigation; RDIs, severe regulated deficit irrigation; ET_0, reference crop evapotranspiration; θ_v, volumetric soil water content; Ψ_{pd}, predawn leaf water potential; Ψ_{md}, midday leaf water potential; S_Ψ, water stress integral; $\bar{\psi}_{md_{i,i+1}}$, mean Ψ_{md} for any interval i, $i+1$; C, maximum Ψ_{md}; DPI, dots per inch; RLD, root length density; TCSA, trunk cross-sectional área; LAI, leaf área index; AS, área shaded by the canopy.

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Table 1
Class A pan evaporation (E_{pan}), rainfall and irrigation water application in the different irrigation treatments during the four-year experimental period.

	1st year	2nd year	3rd year	4th year	Average
E_{pan} (mm)	1527	1428	1425	1501	1470
Rainfall (mm)	208	368	355	134	266
		Irrigation (m^3 ha^{-1})			
Control	6559	6488	7218	7800	7016
CDI	3218 (51)*	3127 (52)	4002 (45)	3802 (51)	3537 (50)
RDIm	4005 (39)	4574 (30)	6200 (15)	6450 (17)	5307 (25)
RDIs	3575 (46)	3955 (39)	5700 (21)	6075 (22)	4826 (32)

* Water saving with respect to control (%).

sustained and regulated deficit irrigation. The first of these strategies implies a continuous reduction in water inputs to below the full requirements throughout the growing season (Fereres and Soriano, 2007), and the second a reduction during certain phenological periods, in that the reduction in water does not affect yield or fruit quality (Chalmers et al., 1981).

There has been much research on plant responses to deficit irrigation, with special reference to water savings and yield in woody trees (Fereres and Soriano, 2007; Ruiz-Sánchez et al., 2010), and the sensitivity of vegetative growth (Bradford and Hsiao, 1982). Some questions remain as to how reductions should be implemented, particularly in apricot trees, to improve the fruit quality without jeopardizing future yields. Pérez-Pastor et al. (2007) noted that deficit irrigation strategies improved apricot fruit quality at harvest and also during the subsequent cold fruit conservation period, which guarantees the proper transfer of the product to markets distant from the plantation site. Pérez-Pastor et al. (2009) also quantified the effect of deficit irrigation strategies on apricot yield during a four year study. This companion paper aims to study the long-term effects of different deficit irrigation strategies on the growth of mature apricot trees in an attempt to ascertain how the intensity and duration of water deficit affects both the root and aerial (shoot, trunk and fruit) parts of tree growth.

2. Materials and methods

2.1. Plant material and experimental site

The experiment was performed over four years in a 2 ha plot of a commercial orchard, located in the Mula Valley, Murcia (SE Spain) (37°52′N and 1°25′W, altitude 350 m). The soil is loam-textured (27.21% clay, 42.92% silt, and 29.85% sand) and classified as a Xeric Torriorthent. The volumetric water content at field capacity was 26% and 11% at wilting point as determined in undisturbed soil samples by Richards (1965) pressure plate technique. The plant material consisted of 10-year-old apricot trees (*Prunus armeniaca* L., cv. Búlida, on Real Fino apricot rootstock), spaced 8 m × 8 m, with an average height of 4.1 m and ground cover of 52%. Trees were drip irrigated using one drip irrigation line for each row, with seven emitters per tree, each with a flow rate of 4 L h^{-1}.

During the experimental period, the weather was typically Mediterranean, with mild winters and dry summers. The mean daily air temperature presented a similar trend throughout the four years with values of about 12.6 °C in winter and 22.6 °C in summer. The seasonal pattern of mean daily relative humidity oscillated between 82.1% and 74.1%, for RH and solar radiation varied between 125.7 and 254.6 W m^{-2}. The mean daily evaporation rate from a U.S. Weather Bureau class A pan (on bare soil and located at a weather station in the orchard) ranged from 1.4 mm day^{-1} in January to 7.5 mm day^{-1} in July. Annual evaporation for the experimental period averaged 1470 mm, with only minor year-to-year deviations from these values. Annual rainfall averaged 320 mm (Table 1). The rainy period was as usual in this area, occurring during spring and autumn.

Trees were fertilized with 158 kg N, 769 kg P_2O_5 and 110 kg K_2O, per ha and year, which were supplied through the irrigation system. A routine pesticide programme was maintained. No weeds were allowed to develop within the orchard, resulting in a clean orchard floor for the duration of the experiment.

2.2. Experimental design and irrigation treatments

Four irrigation treatments were applied: (i) a control treatment, irrigated at 100% of seasonal ETc, (ii) a continuous deficit irrigation treatment (CDI) irrigated at 50% of control treatment all year, and two regulated deficit irrigation (RDI) treatments: (iii) moderate regulated deficit irrigation (RDIm) irrigated at 100% of ETc during the critical periods (second rapid fruit growth period and 2 months after harvest), and at 40% of ETc during the rest of the non-critical periods for the two first years and 60% for the two last years, and (iv) severe regulated deficit irrigation treatment (RDIs), irrigated at 100% of ETc during the critical periods and at 25% of ETc during the rest of the non-critical periods for first two years and at 40% for the third and fourth. The dates of full bloom, initiation and end of the critical periods (irrigation at 100% of ETc for RDI treatments), and first harvest during the four years for the experimental period have been described elsewhere (Pérez-Pastor et al., 2009).

Irrigation amounts were scheduled weekly based on local crop coefficients (Abrisqueta et al., 2001), reference crop evapotranspiration (ET_0), determined from data collected the previous week in a US Weather Bureau class A pan (on bare soil from a nearby weather station) (Doorenbos and Pruitt, 1977) and estimated application efficiency (95%). Irrigation amounts were adjusted according to canopy size (Fereres and Goldhamer, 1990). Irrigation was automatically controlled by a timer-irrigation programmer and electro-hydraulic valves. Irrigation frequency varied from one to two times per day, 7 days a week in spring–summer and one time per day, 1–3 days a week in winter–autumn. The amounts of water applied for each irrigation treatment were measured with in-line flow meters. The amount of water applied in the control treatment averaged 702 mm $year^{-1}$, increasing yearly according to tree size (Table 1). Rainfall efficiency was around 50% due to the compacted soil resulting from successive mechanical weeding and the slope of the soil (Abrisqueta et al., 2007).

The irrigation water savings with respect to the control treatment were 50% in the CDI treatment while in the RDI treatments varied from a maximum of 46% (RDIs in the first year) to a minimum of 15% (RDIm in the third year) (Table 1). The mean irrigation volumes applied during the four-year trial were 700, 354, 528 and 483 mm $year^{-1}$ for Control, CDI, RDIm and RDIs, respectively. The RDI treatments showed two distinct trends, where lower total amounts of water (427 and 377 mm) were applied in the first two years as compared with 628 and 589 mm applied in the last two years for RDIm and RDIs, respectively.

Each irrigation treatment had four replications each consisting of two rows of seven trees distributed in a randomized complete block design. The central five trees of the first row were used for experimental measurements, and the others served as guard trees.