Effect of deficit irrigation during oil synthesis period on carbohydrates content in olive hedgerows (cv. Arbequina)

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Abstract

During fruit oil synthesis and accumulation period, fruits are the main carbohydrate sink and water stress may modify the reserve availability for next season development. The objective of this study was to evaluate the effect of deficit irrigation during fruit oil synthesis period on next season carbohydrates content. Experiment was carried out in a super high density olive orchard (*Olea europaea* cv Arbequina) located in La Puebla de Montalbán, Toledo, Spain (39º 48'N, 04º27'W, 516 msnm). Two irrigation level were applied from the middle August until harvest (First November), when most of the 80% of the oil accumulated on fruits occurs. The control treatment (Non stressed) was irrigated until harvest, trying to maintain the root zone close to field capacity. The Stressed treatment was irrigated with water dosage being reduced to 12% of Non stress treatment. Carbohydrates (soluble sugars and starch) were measured on roots, leaves and stems at the end of winter. Differences on carbohydrate concentration were observed on leaves but not in the reserve organs as roots or stems. Leaves of the Stressed trees presented higher carbohydrates content. These results show the important role of carbohydrates on water stress adaptation by osmotic regulation.

Keywords: irrigation, sugars, starch, reserves, super high density orchard

INTRODUCTION

In the middle 90's super-high density orchard were developed on hedgerow in order to facilitate mechanical harvesting. Worldwide, olive hedgerows are now planted over 100.000 ha. Arbequina is the cultivar most widely used in hedgerow orchards due to precocity in production, high yields, low alternate bearing, and low vegetative growth. Olive (*Olea europaea* L.) is considered resistant to scarce water conditions, however, irrigation is necessary when high-density orchard are planted in areas with low rainfall. Grattan *et al.* (2006) observed that maximum production of olive hedgerow orchards was not achieved with maximum irrigation, and that regulated deficit irrigation strategies (RDI) could be applied to reduce vegetative growth without detrimental effect on yield (Chalmers *et al.*, 1981; Ruiz-Sánchez *et al*., 2010).

The responses of a mature olive orchard to water deficits are highly dependent on the phonological stage. Goldhamer (1999) suggested that is possible to reduce irrigation rates during the summer, after pit hardening, without negative effects on olive fruit and oil yield. In early summer (i.e. July), deficit irrigation with stem water potential at midday near to -2.9 MPa, did not impact on oil production in 'Arbequina' hedgerow orchards (Gómez-del-Campo, 2013a; b) and polyphenol content in oil was increased (Gómez-del-Campo and García, 2013). Spring is the most sensitive period to water stress because flower structures are developed. During late summer-autumn (end August until harvest) oil is synthesized and is consider a medium water sensitive period (Pastor, 2005) and mild stress (-2.3 MPa) can be applied in 'Arbequina' with no effect on production (data not published).

Oil production will depend on the carbohydrates supplied for fruit development and oil synthesis. Olive leaves are photosynthetically when climatic conditions are optimum for photoshynthesis; this is radiation PAR higher than 800-1000 µmol m^{-2} s^{-1} and temperature of 28 ºC (Connor and Fereres, 2005) and remain active during autumn and winter producing and accumulating sugars. Spring growth and flower development are supported by photosynthesis and carbohydrates accumulated. During summer and autumn, fruits are the main carbohydrates sink in the tree, while shoot growth has stopped and depend on photosynthesis activity. At the same time that oil is synthesized, bud flower induction occurs for next year production (Rallo and Cuevas, 2004). Flower induction becomes more intense as the sugar concentration in buds increases (Tombesi, 2003). In this sense water deficit affect flower induction because it reduces stomata gas exchange and consequently photosynthesis and carbohydrates production.

The aim of this study was to determine the effect of deficit irrigation during the late summer-autumn period on next season carbohydrates concentration in an olive high-density plantation.

MATERIALS AND METHODS

The experiment was conducted in 2011 in a 45 ha commercial olive (*Olea europaea* L. 'Arbequina') orchard located in La Puebla de Montalbán, Toledo, Spain (39º 48'N, 04º27'W, 516 m altitude). The orchard was planted in 1997, at a spacing of 4 x 2 m (1,250 olive ha^{-1}) with rows oriented 20 °N of E-W. Soil was clay loam (Haploxeralf typic) with an effective rooting depth of 0.60 m, comprising three layers each of 20 cm depth. For the three horizons in sequence, texture was clay loam, clay loam and sandy clay loam. At the time of the experiment, hedgerows were 2.3 m high and 1.1 m wide.

The area is characterized by low rainfall (average annual rainfall of 395 mm), high evaporative demand (average annual ET_0 of 1,180 mm) and a long frost period (November to March). Weeds were controlled using a non-residual herbicide, and fertilizer was applied according to leaf analyses carried out each year in July.

Two irrigation treatments (Non-stressed and stressed) were maintained during 2011 season in a completely randomized design with four blocks. Non-stressed trees were irrigated according to continuous readings of 6 Watermark™ sensors connected to a data logger (Irrometer, CA, USA). The sensors were located in pairs at 0.3 m depth and 0.3 m from emitters adjacent to trunks of 3 representative trees. Stressed trees were irrigated similar than Non-stressed treatment, except from late summer (23 August) until harvest (31

October) that received 12% of water applied to Non-Stressed trees. Irrigation was applied by one drip with emitters of 3 L h^{-1} spaced 0.50 m apart. Non-Stressed treatment was applied modifying the irrigation time. Irrigation and climatic conditions are presented in Table 1.

Table 1. Rain fall, ET_0 and applied water at the experiment olive orchard in La Puebla de Montalbán, Toledo, Spain.

	Rain (mm)	ETo (mm)	Non stressed irrigation (mm)	Stressed irrigation (mm)
01/10 - 18/05/11	340	402	-	-
19/05 - 22/08/11	14	520	263	263
23/08 - 21/10/11	2	252	167	20
22/10 - 31/10/11	15	17	-	-
Total	371	1191	430	283

In winter (1st February 2012) one branch and roots were removed in 3 trees of 3 blocks. The mean characteristics of the different organs were: shoots of 100 cm with 144 leaves, one-year old stem of 14 cm with 50 leaves, 6 leaves of three-years old and samples of 10 cm of structural roots (>4mm). They were frozen to -40°C during 5 days to stop enzyme activity, and were dried during 2 weeks in oven at 60°C. Samples were washed and dried at 50 °C to constant mass. The dried root samples were ground with a hand mill (M20, IKA-WERKE, Staufen, Germany). Root starch was then hydrolyzed by acid and enzyme hydrolysis, followed by spectrophotometric determination as described by Boehringer (1984) for powdered samples. Carbohydrates were determined by Nelson-Somogyi method.

Data were subjected to analysis of variance using MSTAT-C (University of Michigan, USA). LSD's multiple range test at $p < 0.05$ was used to separate means of parameters evaluated between irrigation treatments.

RESULTS AND DISCUSSION

The oil synthesis and accumulation in fruits mainly occurred two months before harvest date, as have been previously observed by Gómez-del-Campo (2013a) in the same experimental site. The oil synthesis period of 2011 was dry with 2 mm of rain and high water demand (252 mm). During this period Stressed trees received 20 mm of irrigation (Table 1), that represented 12% of the Non-stress trees, suffering strong water stress conditions.

Water stress applied before harvest can reduce the oil production (Pastor, 2005) but also next year production could be affected in two ways: flower induction and carbohydrate reserves. Flower induction occurs on summer-autumn-winter (Rallo and Cuevas, 2004) and depends on bud carbohydrates concentration during this period (Tombesi, 2003). Reserves accumulated during autumn support spring vegetative growth and flower differentiation. In this experiment, soluble carbohydrates four months after deficit period (February) varied between 4 to 10% and starch content was lower, ranged from 3.5 to 5.5%. These values were within range previously reported in olive (Drossopoulos and Niavis, 1988).

Irrigation treatment did not significantly affect soluble carbohydrates and starch content on reserve organs (roots and stems) (Table 2). Photosynthesis activity of perennial leaves during autumn and winter may have compensated the lower activity of stress trees during oil synthesis period. This could explain the lack of differences in next year flowering and shoot growth observed in this experiment (Marrero-Rodríguez *et al.*, 2015).

In contrast, carbohydrates in three years old leaves were significantly higher in Stressed than Non-stressed trees (Table 2). Higher carbohydrates concentrations (glucose and mannitol) in olive leaves and wood under stress conditions during summer were also observed by Chehab *et al.* (2009). The mannitol acts as an important osmolyte and our results support the important role of carbohydrates on water stress adaptation by osmotic regulation (Chimenti *et al.*, 2006).

Table 2. Soluble carbohydrates and starch content in February 2012 on organs of olives hedgerow 'Arbequina'. Non water stressed and Stressed treatments were applied during 2011 oil synthesis period.

		Non stressed	Stressed	
Roots >4 mm	Sol. carbohydrates (%)	6.24	7.21	
	Starch (%)	5.49	5.62	ns
Shoot	Sol. carbohydrates (%)	5.49	5.58	ns
	Starch (%)	3.51	3.41	ns
Two years stem	Sol. carbohydrates (%)	3.90	3.00	ns
	Starch (%)	3.50	3.60	ns
One year leaves	Sol. carbohydrates (%)	10.07	10.40	ns
	Starch (%)	4.09	3.89	ns
Two years leaves	Sol. carbohydrates (%)	9.88	10.14	ns
	Starch (%)	4.43	4.10	ns
Three years leaves	Sol. carbohydrates (%)	9.08	10.58	**
	Starch (%)	4.77	4.80	ns

ns and * = not significant and significant difference between irrigation treatment by LSD test at P ≤ 0.05.

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