Water requirements and irrigation management in olive: improving water use efficiency in semiarid regions with dry winter season

Pierluigi Pierantozzi,[a] Mariela Torres,[b] Damián Maestri[a]

[a] Instituto Multidisciplinario de Biología Vegetal (IMBIV, CONICET-UNC). Instituto de Ciencia y Tecnología de los Alimentos (ICTA). Facultad de Ciencias Exactas, Físicas y Naturales (FCEFyN-UNC). Av. Vélez Sarsfield 1611, X5016GCA Córdoba, Argentina.
[b] Estación Experimental Agropecuaria San Juan (EEA INTA San Juan). Consejo Nacional de Investigaciones Científicas y Técnicas. Ing. Marcos Zalazar (Calle 11) y Vidart. Villa Aberastain, Pocito, 5427 San Juan, Argentina.

Abstract
The improvement of water use efficiency in olive cultivation is an issue of vital importance, with environmental and economic implications. In Argentina, the climatic pattern of the olive production areas is characterized by a marked water deficit during winter and spring months. A scientific experiment was carried out in an olive orchard at Córdoba province, Argentina. Four regulated deficit irrigation (RDI) treatments were imposed to olive trees (*Olea europaea* var. Arbequina and Manzanilla) at 0, 25, 50 and 75 % of Etc (determined using previously established crop coefficients and real-time reference crop water use), plus a control treatment of 100 % of Etc during all production year. The results showed that water stress imposed to olives trees during winter and spring months has a clear negative impact on tree productivity. Water deficit applied at the end of vegetative shoot growth affect flowering timing, and results in weakening of flowering, shortening of the fruit maturation period and, ultimately, decreased fructification. A scheduled irrigation strategy tending to conserve soil water content is useful to maintain top yields of high quality fruit.

Keywords: Olive, irrigation management, productivity.

Introduction

Olive (*Olea europea* L.) has been traditionally cultivated in countries from the Mediterranean Basin, under dry-land conditions, with little or no rainfall during the critical phenological phases for yield formation. Although the olive has been regarded as a dry farmed crop, it responds favourably to small additional amounts of water besides the rain.

To meet the increasing demand for olive oil and table olives, olive cultivation has been expanded to many regions of the world where agro-ecological conditions are as favourable as those prevailing in the Mediterranean countries. Olive production in Argentina has increased rapidly in recent years especially in arid and semiarid regions that are considered marginal areas for conventional crops. Unlike climatic pattern prevailing in the Mediterranean countries, the climatic pattern of the olive production areas in Argentina is characterized by a marked water deficit during winter and spring months, which lead to higher average daily values of ETo (1.6–2.6 mm/day) (Rousseaux et al., 2008).

Water availability is a considerable constraint in oliviculture and the improvement of water use efficiency (units of product per unit of water) in this agricultural sector is an issue of vital importance, with environmental and economic implications. For these reasons, it is important both to determine the olive tree water requirements and to evaluate irrigation strategies tending to reduce water supplies without affecting production and quality.

One of the most significant changes that are currently occurring in olive tree cultivation is the expansion of irrigated orchards. In several countries from the Mediterranean Basin, strategies using regulated deficit irrigation (RDI) have been proposed to optimize water use in olive growing (Grattan et al., 2006; Pérez-López et al., 2007). The aim is to apply the optimum irrigation amount below the crop water needs but in a rational way, to keep the crop performance as close as possible to its maximum potential. In addition, many studies on RDI are aimed to better establish the phenological periods for irrigation reduction (Pérez-López et al., 2008; Rousseaux et al., 2008). On the other hand, some works have evaluated the effects of RDI on productivity and classical quality parameters of olive oil (Romero et al., 2002; Grattan et al., 2006; Lavee et al., 2007; Servili et al., 2007). However, very little is known about the influence of controlled water deficit on olive performance under the pedo-climatic conditions of the olive production areas in Argentina.

The main goal of our project is to optimize sustainable irrigation conditions for the oliviculture development in central Argentina. This work examines the effect of different water irrigation levels - applied between the end of the autumnal period of vegetative shoot growth and the end of the flowering period - on productivity and quality of olives and olive oil from two major Spanish cultivars.

Materials and methods

Plant material

The field experiment was conducted in a commercial olive orchard located at the Cruz del Eje locality, Córdoba province, Argentina. Cruz del Eje (30º 43' S, 64º 44' W) is located in the dry Chaco Forest phytogeographical area, at 450 m above sea level. The climate in this area represents a typical arid Chaco climate with rains mostly falling in summer and dry and short winter. Table 1 summarizes climatic conditions during 2009 crop year in which olive trees were sampled. The lowest monthly average minimum temperature was 3.8 ºC (July) and the highest monthly average maximum temperature was 32.3 ºC (January). The total value of annual rainfall was 472.5 mm, with a relative humidity of about 51.4 %. Meteorological data were monitored using a weather station placed within the experimental plot (Table 1). The soil of the experimental site (Table 2) corresponds to a typical Haplustoll type soil, with sandy loam texture at the superficial horizons and silt loam texture at the deepest horizons.

During 2008 and 2009 crop years, four irrigation treatments were applied to 70-years-old olive trees (*Olea europaea* L. cv. Arbequina and Manzanilla), with planting distances of 10 m x 10 m. Irrigation water was delivered using a drip line around each tree, with drip nozzles at 1 m from the trunk. The experimental design included a treatment irrigated at 100 % of Etc (estimated crop evapotranspiration) during all year, and three RDI treatments, at 25 %, 50 % and 75 % of Etc (RDI-25, RDI-50 and RDI-75 respectively), applied between the end of the autumnal period of vegetative shoot growth (middle June) and the end of the flowering period (final October). Furthermore, olives trees growing without irrigation between early June and final October (only under natural rainfall) were used as a control treatment. During the rest of the year, the control, RDI-25, RDI-50 and RDI-75 treatments were irrigated at 100 % of Etc. Table 3 shows the total water applied to each irrigation treatment. For each treatment, six olive trees were used. The first year of differential irrigation treatments (2008) was employed as a period of plant acclimation to drip irrigation; the data obtained were not included in evaluation of the results.

Water requirements and plant water relations

The standard equation for Etc was used (Allen et al., 1998):
$Etc = Eto \times K_c \times K_r$,
where Eto is the Penman-Monteith FAO reference evapotranspiration; K_c is the crop coefficient [0.4 from April to August (Rousseaux et al., 2008), 0.68 during the rest of the year (Girona et al., 2002)]; and K_r is the tree ground-cover coefficient (Fereres and Castel, 1981). Figure 1 shows rainfall, irrigation applied, Eto and Etc data during 2009 crop year.

Leaf water potential (LWP) was measured midday, every week from the beginning of the experimental treatments, using a Scholander-type pressure chamber.

Soil water content was measured every twenty days using a soil auger at 0 – 90 cm depth. Soil samples were placed in plastic bags and transported to the laboratory where initial and dried (72 h at 80 ºC) weights were recorded. Soil bulk density was approximately 1.45 g cm^{-3}. Field capacity and permanent wilting point values were estimated at the 0 – 90 cm depth (16.5 % and 9.73 %, respectively).

Growth measurements, fruit production and quality

From each tree, six branches selected from the entire canopy were tagged. For each branch, an average of eighty inflorescences was used to measure flower density (number of flowers/inflorescence) and fruit density (number of fruits/inflorescence). At harvest time, each individual tree was hand-harvested and fruit production was quantified. From each tree, three independent fruit samples (500 g each) were taken in order to determine the maturity index (Beltrán et al., 2008), oil yield and fatty acid composition, and total phenol content.

For maturity index (MI) determination, 100 fruits were randomly taken and classified into the following categories: 0 - olives with intense green or dark green epidermis; 1 - olives with yellow or yellowish green epidermis; 2 – olives with yellowish epidermis but with reddish spots or areas over less than half of the fruit; 3 - olives with reddish or light violet epidermis over more than half of the fruit; 4 – olives with black epidermis and totally white pulp; 5 – olives with black epidermis and less than 50 % purple pulp; 6 – olives with black epidermis and violet (more than 50 %) or purple pulp; 7 – olives with black epidermis and totally dark pulp. With *a* to *h* being the number of fruits in each category, the MI is:

$$MI = (a \times 0 + b \times 1 + c \times 2 + d \times 3 + e \times 4 + f \times 5 + g \times 6 + h \times 7) / 100$$

Olive fruit samples were then ground (knife mill) and lyophilised until complete dehydration. From each lyophilised sample, a 20-g aliquot was extracted with n-hexane using a Soxhlet apparatus following the IUPAC Standard Method (IUPAC, 1992). The solvent was removed using a rotary vacuum evaporator at 40 ºC. The oil content was gravimetrically determined and expressed as weight percent on dry basis (%, DB).
For fatty acid composition, samples of 0.5 g oil were subjected to alkaline saponification (1 N KOH in methanol). Unsaponificable matter was extracted with n-hexane. The fatty acid methyl esters of total lipids were obtained using 1 N H_2SO_4 in methanol and analyzed by gas chromatography. Separations were made on a Supelcowax 10 fused-silica capillary column (30 m x 0.25 mm i.d. x 0.25 µm film thickness). Peaks were identified by comparison of their retention times with those of authentic reference compounds (Torres et al. 2009).

Total phenol content was analysed from 1- g aliquots of lyophilised fruit samples. They were homogenised with 40 mL n-hexane for 10 min. The upper phase was separated and the extraction was repeated twice with the lower phase to allow removal of pigments and most of the lipid fraction. The lower phase was then shaken (10 min) with 80 % (v/v) methanol (20 ml x 3). After centrifugation (3000 g, 10 min), the hidromethanolic phases were combined and filtered through a 0.45 µm nylon syringe filter. To a suitable dilution of the filtrate, the Folin – Ciocalteau reagent was added and the absorbance value of the solution at 725 nm was measured. Total phenol contents are given as mg caffeic acid/g fruit.

Statistical analyses: Statistical differences among treatments were estimated from ANOVA test, at $P < 0.05$.

Findings and discussion

Measurements of stem water potential (Ψ_{stem}) have been widely used to monitor the response of the tree water status to irrigation. More precisely, Ψ_{stem} measurements at midday are recommended for the control of water supply in olive orchards, although there are uncertainties on the thresholds to be used. From measurements in central Spain, midday Ψ_{stem} values between -1.2 MPa and -1.4 MPa are recommended as thresholds for irrigating mature olive orchards (Moriana et al., 2003).

There are not reference values of optimal Ψ_{stem} values for the agroecological conditions of olive cultivation in central Argentina. During the course of the period of differential irrigation application, Ψ_{stem} evolution for both Arbequina and Manzanilla varieties showed a similar pattern (Figs. 2 and 3). For the RDI-75 treatment, Ψ_{stem} values were fairly constant. In control, RDI-25 and RDI-50 treatments the Ψ_{stem} decreased progressively throughout the course of the differential irrigation application. At the end of the experiment, the Ψ_{stem} decreased markedly (below -2.50 Mpa) in control and RDI-25 treatments, possibly indicating a moderate water stress.

Beyond the end of the differential irrigation application period, 11 days after water deprivation suppression, the different treatments: a) showed no significant differences in Ψ_{stem} values, and b) recovered the Ψ_{stem} measured before water deprivation. These observations indicate a rapid response to rewatering and suggest good hydraulic conductance characteristics, in spite of the big size (4 to 6 m in height) and age (70-years-old) of the olive plants employed. After rewatering, an increase in soil moisture rapidly increased the Ψ_{stem}; therefore, most of the Ψ_{stem} recovery may be due to a large increase in root flow.

The soil water content in the more irrigated treatments (100 % Etc and RDI-75) gradually decreased, remaining upper the estimated permanent wilting point (PWP, 9.73 %) throughout the course of the experiment. The less irrigated treatments notably diminished two months after deficit irrigation application remaining near the PWP value. Two weeks after the last deficit irrigation event (final October), soil water content was similar in all treatments (Figure 4).

Table 1: Average monthly temperatures (ºC), total rainfall (mm), wind speed (m/seconds), reference evapotranspiration (Eto, mm/day) and crop evapotranspiration (Etc, mm/day) measured at Cruz del Eje locality (Córdoba province, Argentina) from April 2009 to March 2010.

Month	Temperature	Rainfall	Wind speed	Eto	Etc
April	21.8	26.6	2.43	3.93	2.67
May	16.1	19.1	1.96	2.54	1.01
June	12.6	0	2.47	2.36	0.95
July	10.2	16	2.05	2.16	0.87
August	16.6	0	2.62	3.55	1.42
September	14.3	26	2.95	4.10	2.79
October	21.6	5.4	3.05	6.09	4.14
November	25.2	30	2.86	7.03	4.78
December	25.0	117	2.54	6.28	4.27
January	26.9	35.6	2.5	7.10	4.83
February	25.5	124.1	1.93	5.29	3.6
March	23.8	173.7	1.81	4.57	3.11

Table 2: Physical and chemical characteristics of the soil horizons from the olive growing area at Cruz del Eje locality (Córdoba province, Argentina).

	Horizons			
Soil properties	**A1 y A3**	**Bw**	**BC**	**C**
Depth (cm)	0-25	30-40	50-60	70-80
Organic matter (%)	2.65 ± 0.11	1.68 ± 0.21	1.02 ± 0.07	0.66 ± 0.05
Total N (%)	0.15 ± 0.02	0.11 ± 0.02	0.09 ± 0.01	0.07 ± 0.008
$N\text{-}NO_3$ (ppm)	12 ± 0.9	7.0 ± 1.0	5.7 ± 0.8	4.8 ± 0.9
Assimilable phosphorus (ppm)	22 ± 1.4	17 ± 0.8	6 ± 0.8	3 ± 0.4
Sand (1-2 mm)	7.45 ± 0.31	6.69 ± 0.22	----	4.05 ± 0.35
Sand (500 -1000µ)	8.21 ± 0.31	7.51 ± 0.31	----	5.02 ± 0.21
Sand (250-500µ)	15 ± 0.06	11.39 ± 0.28	----	13.49 ± 0.22
Sand (100-250µ)	18 ± 0.45	12.97 ± 0.22	----	12.83 ± 0.28
Sand (50-100µ)	15 ± 0.11	11.18 ± 0.35	----	12.70 ± 0.45
Silt (20-50µ)	18 ± 0.19	25.06 ± 0.55	----	43.65 ± 0.61
Silt (2-20µ)	9 ± 0.07	10.23 ± 0.41	----	6.45 ± 0.72
Clay (<2µ)	10 ± 0.85	15.51 ± 0.07	----	2.14 ± 0.15
pH	7.86 ± 0.32	7.93 ± 0.24	8.00 ± 0.22	8.55 ± 0.14
Electrical conductivity (dS/m)	1.50 ± 0.05	0.90 ± 0.02	0.8 ± 0.01	0.8 ± 0.03

Table 3: Irrigation, effective rainfall and total water values provided to the different irrigation treatments.

Treatment	Irrigation (mm)	Effective rainfall (mm)	Total (mm)
100% Etc	545	260	805
RDI-75	493	260	753
RDI-50	442	260	702
RDI-25	391	260	651
0% Etc	340	260	600

Figure 1: Effective rainfall (mm), irrigation applied (mm), reference evapotranspiration (Eto, mm/day) and crop evapotranspiration (Etc, mm/day) measured at Cruz del Eje locality (Córdoba province, Argentina).

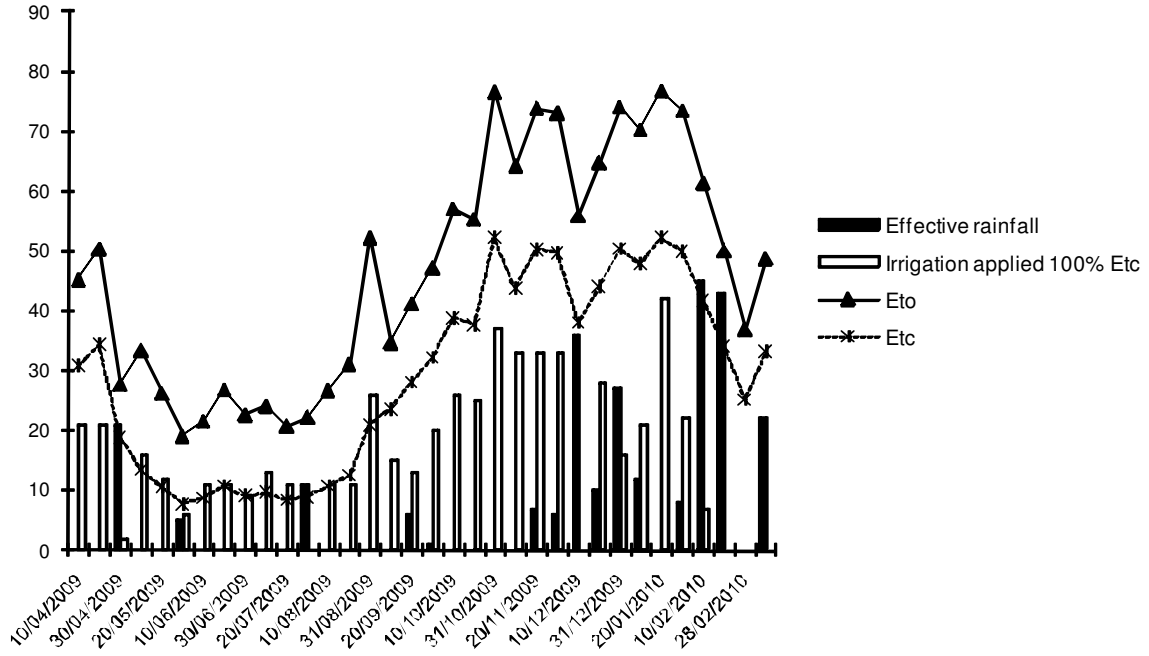


Figure 2: Midday stem water potentials obtained from Arbequina variety growing under different water irrigation levels. Each point represents the average value (with standard deviation bar) of 6 measurements. Vertical bars indicate the period of differential irrigation treatments application (middle June – final October).

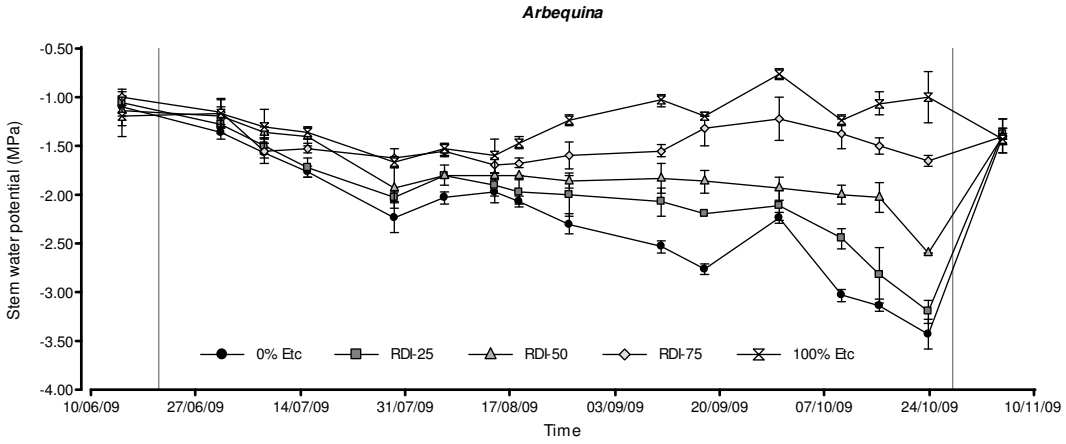


Figure 3: Midday stem water potentials obtained from Manzanilla variety growing under different water irrigation levels. Each point represents the average value (with standard deviation bar) of 6 measurements. Vertical bars indicate the period of differential irrigation treatments application (middle June – final October).

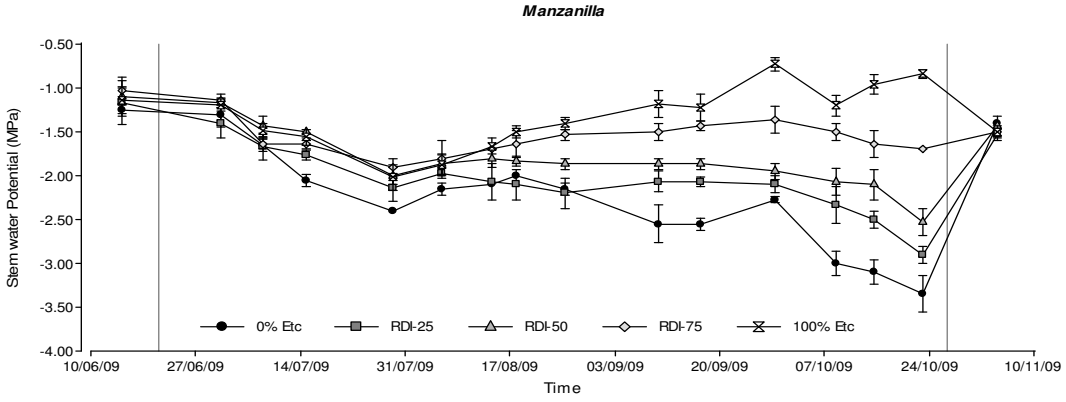
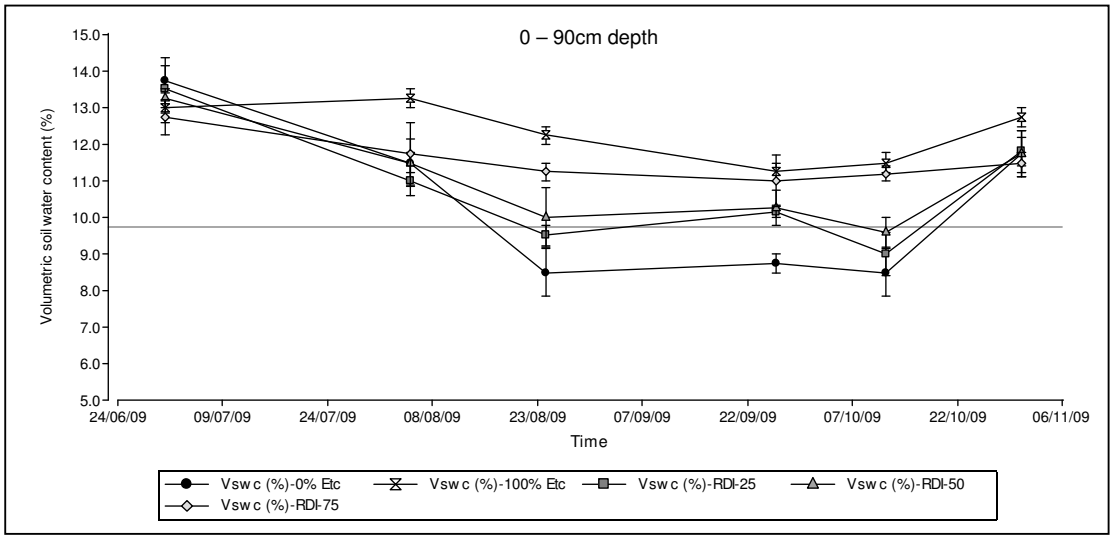


Figure 4: Volumetric soil water content (%) at one soil depth (0 – 90 cm) during the period of differential irrigation treatments application (middle June – final October). Horizontal bar indicate the permanent wilting point value.



Different water-application levels affected growth and productive parameters (Tables 4 and 5). Regarding inflorescence length, flower and fruit density, the general pattern of variation was as follow: treatments 0% Etc and RDI-25 (group A) without significant differences among them but differing significantly (lower values) from the other treatments; treatments RDI-75 and 100% Etc (group B) without significant differences among them but differing significantly (upper values) from the other treatments; treatment RDI-50 significantly different from both A and B groups.

Water deprivation delayed the beginning of the flowering time and shortened the flowering period (Fig. 5) with respect to treatments with higher irrigation rates. On the other hand, maturity index decreased with increased irrigation rates: fruits from treatments with minor water application began to mature sooner than those from higher water-application treatments.

Fruit yield increased dramatically with increased water application (Table 5, Fig. 6). The olive varieties studied were affected differently by the irrigation levels employed. In Arbequina, the 100% Etc irrigated treatment had an average of 90 kg/tree, almost 10 times higher than the average yield obtained from the control treatment. At the fully irrigated condition (100% Etc) the fruit yield had not significant difference with that of the RDI-75 treatment; it seems to reach the plateau indicating that, for the agro-ecological conditions of olive growing in central Argentina, full-irrigated Arbequina trees could reach the maximum yield potential. Fruit yield from Manzanilla trees increased linearly with the water irrigation level, but the rate of increment was lower than that observed for Arbequina variety.

Figure 5: Flowering time from Arbequina and Manzanilla varieties growing under different water irrigation levels.

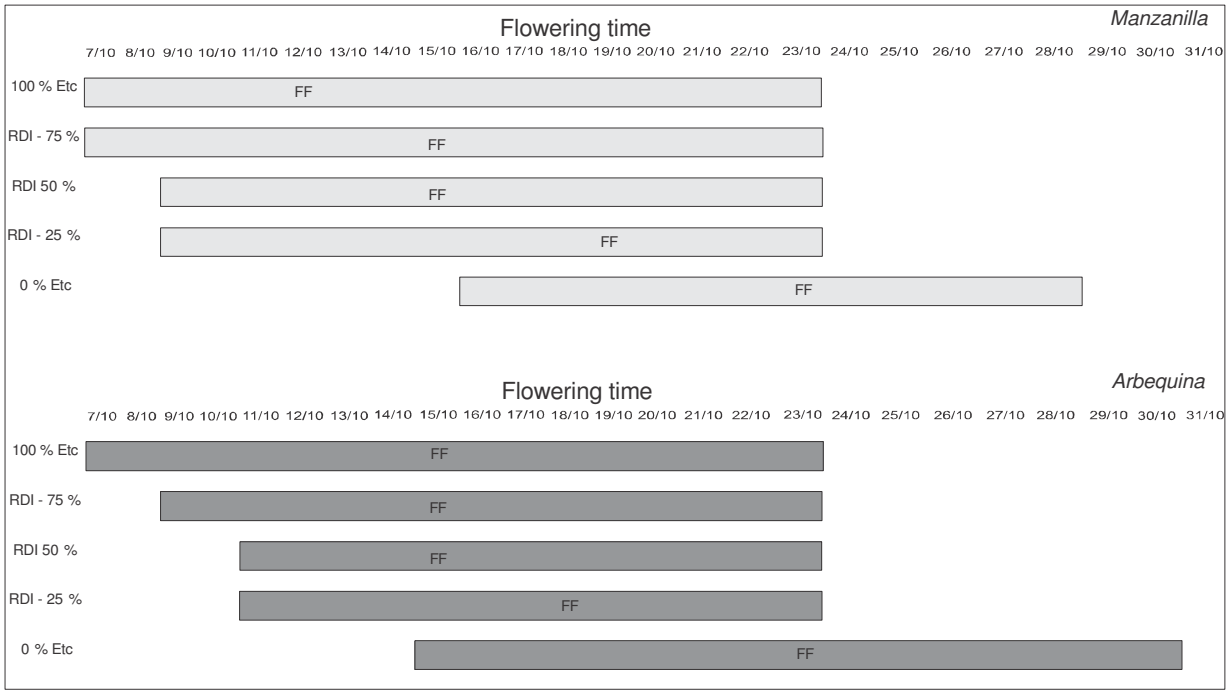


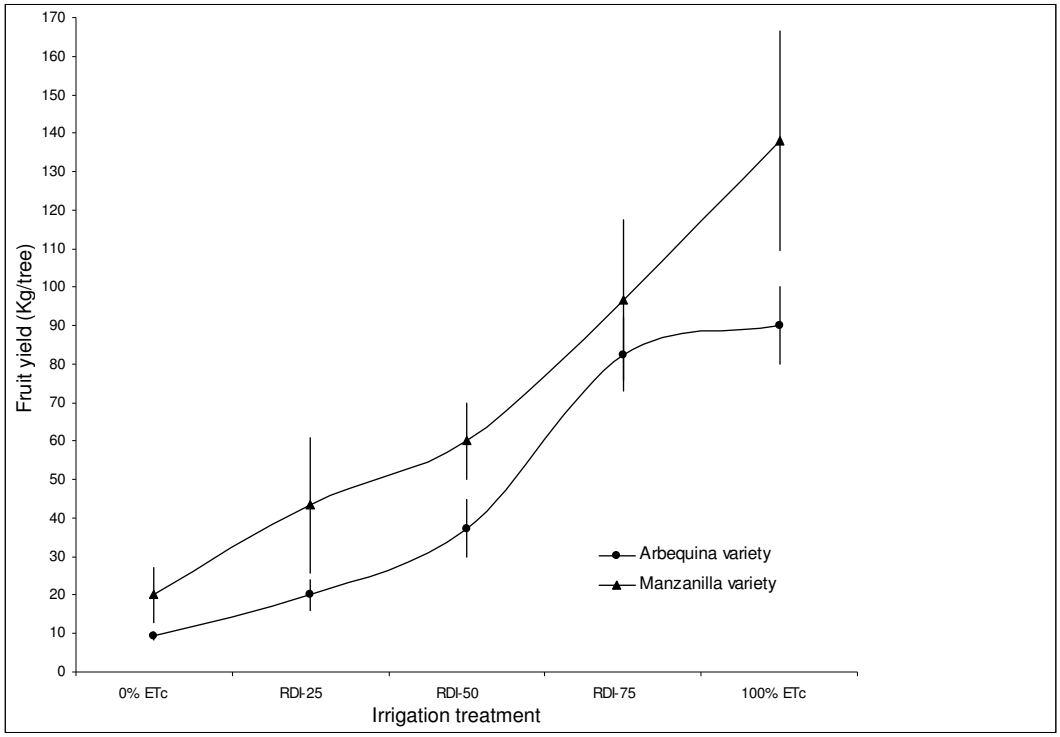
Table 4: Flowering and fructification characteristics from Arbequina and Manzanilla varieties growing under different water irrigation levels. Mean values (n = 6) ± standard deviation values. Mean values from each row followed by different superscript letters present significant differences ($p \leq 0.05$).

Parameter		Treatment				
	Variety	0% Etc	RDI-25	RDI-50	RDI-75	100% Etc
Inflorescence	*Arbequina*	$15.5^{c} \pm 2.8$	$15.4^{c} \pm 2.3$	$16.7^{b} \pm 3.2$	$21.1^{a} \pm 2.8$	$22.7^{a} \pm 1.6$
length	*Manzanilla*	$16.5^{b} \pm 2.6$	$17.8^{b} \pm 2.5$	$19.4^{b} \pm 3.5$	$24.2^{a} \pm 2.8$	$25.0^{a} \pm 1.6$
Number of flowers/	*Arbequina*	$12.3^{c} \pm 2.4$	$13.7^{c} \pm 1.7$	$15.9^{b} \pm 2.2$	$18.2^{a} \pm 2.1$	$19.8^{a} \pm 1.4$
inflorescence	*Manzanilla*	$11.1^{c} \pm 1.1$	$13.2^{b} \pm 1.8$	$14.2^{ab} \pm 3.1$	$16.4^{a} \pm 2.4$	$16.7^{a} \pm 3.1$
Number of fruits/	*Arbequina*	$0.31^{c} \pm 0.05$	$0.38^{c} \pm 0.08$	$0.53^{b} \pm 0.04$	$0.66^{a} \pm 0.10$	$0.71^{a} \pm 0.16$
inflorescence	*Manzanilla*	$0.19^{c} \pm 0.08$	$0.23^{c} \pm 0.06$	$0.43^{ab} \pm 0.1$	$0.46^{a} \pm 0.09$	$0.48^{a} \pm 0.08$
Maturity index	*Arbequina*	$3.53^{c} \pm 0.18$	$3.48^{c} \pm 0.22$	$2.28^{b} \pm 0.33$	$2.06^{a} \pm 0.08$	$2.12^{a} \pm 0.12$
	Manzanilla	$2.25^{c} \pm 0.21$	$2.21^{c} \pm 0.09$	$1.76^{b} \pm 0.15$	$1.53^{a} \pm 0.04$	$1.49^{a} \pm 0.07$

Table 5: Fruit and oil yields from Arbequina and Manzanilla varieties growing under different water irrigation levels. Mean values (n = 6) ± standard deviation values. Mean values from each row followed by different superscript letters present significant differences ($p \leq 0.05$).

		Treatment				
Parameter	**Variety**	0% Etc	RDI-25	RDI-50	RDI-75	100% Etc
Fruit yield	*Arbequina*	9.3 ± 1.15^{a}	20.0 ± 4.08^{a}	37.3 ± 7.51^{b}	82.5 ± 9.57^{c}	90.0 ± 10^{c}
(kg/tree)	*Manzanilla*	20.0 ± 7.07^{a}	43.3 ± 17.5^{a}	60.0 ± 10^{ab}	96.7 ± 20.8^{b}	138.0 ± 28.6^{c}
Oil yield	*Arbequina*	1.86 ± 0.29^{a}	3.99 ± 0.80^{a}	7.09 ± 1.58^{b}	15.3 ± 1.60^{c}	16.9 ± 1.89^{c}
(kg/tree)	*Manzanilla*	3.30 ± 1.02^{a}	6.96 ± 2.92^{a}	9.22 ± 1.53^{ab}	13.7 ± 2.78^{b}	20.0 ± 4.48^{c}
Oil content	*Arbequina*	497.8 ± 21.3^{c}	488.8 ± 11.0^{bc}	466.6 ± 15.2^{ab}	465.6 ± 13.9^{a}	459.4 ± 3.20^{a}
(g/kg, DB)	*Manzanilla*	429.6 ± 5.0^{b}	411.9 ± 5.8^{b}	393.4 ± 33.2^{b}	344.6 ± 11.3^{a}	344.3 ± 21.4^{a}
Oil content	*Arbequina*	198.7 ± 8.4^{b}	199.4 ± 1.8^{b}	189.4 ± 7.1^{a}	186.0 ± 3.9^{a}	188.3 ± 8.0^{a}
(g/kg, FB)	*Manzanilla*	166.2 ± 7.6^{d}	159.7 ± 4.0^{cd}	153.8 ± 8.4^{bc}	142.3 ± 2.2^{a}	144.6 ± 5.8^{ab}

Figure 6: Fruit yield (kg/tree) from Arbequina and Manzanilla varieties growing under different water irrigation levels. Each point represents the average value (with standard deviation bar) of 6 measurements.



The oil yield (kg/tree) response to water supply was similar to that observed for fruit yield: differences in oil yield among treatments were mainly explained by differences in fruit yield. Although significant increases in oil content (g/kg fruit) were found at lower water application levels, such increments can be explained by differences in fruit maturity at the time of harvest (Table 5). These data indicate that, in order to optimize oil yield, it may be more beneficial to harvest non-stressed trees (100 Etc and RDI-75 treatments) later than water-stressed trees.

Minor changes in oil fatty acid composition were observed among irrigation treatments (Table 6). However, in Arbequina variety, a significant increase in oleic acid content took place at higher water application levels (100 Etc and RDI-75 treatments). Furthermore, these irrigation treatments gave fruits with higher total phenol contents. Again, fruit maturity may be the cause of such increments. In Arbequina variety, it has been reported that phenolic compounds reach the highest concentration at fruit maturity indexes between 2 – 2.5, after which it decreases (Uceda et al., 2008).

Table 6: Fatty acid composition (% of total fatty acids) and total phenols (mg/g fruit) of olives from Arbequina and Manzanilla varieties growing under different water irrigation levels. Mean values (n = 6) ± standard deviation values. Mean values from each row followed by different superscript letters present significant differences ($p \leq 0.05$).

Parameter		**Treatment**				
Fatty acids	**Variety**	0% Etc	RDI-25	RDI-50	RDI-75	100% Etc
16:0	*Arbequina*	$21.1^{bc} \pm 0.53$	$21.1^{c} \pm 0.28$	$20.5^{ab} \pm 0.20$	$20.3^{a} \pm 0.29$	$20.3^{a} \pm 0.28$
	Manzanilla	$16.9^{a} \pm 0.41$	$16.3^{a} \pm 1.60$	$15.6^{a} \pm 0.09$	$16.2^{a} \pm 0.56$	$16.0^{a} \pm 0.45$
16:1	*Arbequina*	$2.91^{a} \pm 0.15$	$2.96^{a} \pm 0.16$	$2.57^{a} \pm 0.16$	$2.59^{a} \pm 0.46$	$2.53^{a} \pm 0.29$
	Manzanilla	$2.04^{a} \pm 0.54$	$1.96^{a} \pm 0.23$	$1.59^{a} \pm 0.11$	$1.94^{a} \pm 0.21$	$1.81^{a} \pm 0.33$
18:0	*Arbequina*	$1.60^{a} \pm 0.12$	$1.59^{a} \pm 0.10$	$1.62^{a} \pm 0.02$	$1.59^{a} \pm 0.10$	$1.44^{a} \pm 0.31$
	Manzanilla	$1.39^{a} \pm 0.15$	$1.55^{a} \pm 0.05$	$1.26^{a} \pm 0.51$	$1.57^{a} \pm 0.13$	$1.56^{a} \pm 0.05$
18:1	*Arbequina*	$49.4^{a} \pm 0.63$	$50.1^{ab} \pm 0.93$	$52.9^{bc} \pm 0.65$	$54.1^{c} \pm 1.97$	$54.2^{c} \pm 3.03$
	Manzanilla	$75.7^{a} \pm 1.30$	$75.3^{a} \pm 1.86$	$77.0^{a} \pm 0.34$	$75.5^{a} \pm 1.19$	$76.2^{a} \pm 0.87$
18:2	*Arbequina*	$23.8^{b} \pm 0.66$	$23.3^{b} \pm 0.99$	$21.6^{ab} \pm 0.41$	$20.6^{a} \pm 1.42$	$20.6^{a} \pm 2.40$
	Manzanilla	$3.11^{a} \pm 0.04$	$3.94^{a} \pm 0.41$	$3.62^{a} \pm 0.92$	$3.69^{a} \pm 0.58$	$3.49^{a} \pm 0.40$
18:3	*Arbequina*	$0.86^{a} \pm 0.07$	$0.92^{a} \pm 0.06$	$0.79^{a} \pm 0.02$	$0.85^{a} \pm 0.08$	$0.91^{a} \pm 0.05$
	Manzanilla	$0.92^{a} \pm 0.16$	$0.98^{a} \pm 0.09$	$0.95^{a} \pm 0.08$	$1.03^{a} \pm 0.16$	$0.98^{a} \pm 0.05$
Total phenols	*Arbequina*	$6.38^{a} \pm 0.19$	$5.93^{a} \pm 0.69$	$6.07^{a} \pm 0.38$	$7.55^{b} \pm 0.42$	$7.75^{b} \pm 0.30$
	Manzanilla	$8.64^{a} \pm 0.51$	$12.2^{b} \pm 0.78$	$13.6^{bc} \pm 0.76$	$17.0^{bc} \pm 0.35$	$18.7^{c} \pm 0.28$

Conclusions

The results obtained in this work showed that water stress imposed to olives trees during winter and spring months (a period with a marked water deficit in the olive growing areas in Argentina) has a clear negative impact on tree productivity. Water deficit applied at the end of vegetative shoot growth affect flowering timing, and results in weakening of flowering, shortening of the fruit maturation period and, ultimately, decreased fructification. A scheduled irrigation strategy tending to conserve soil water content is useful to maintain top yields of high quality fruit.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration: guidelines for computing crop water requirements. (FAO irrigation and drainage paper no. 56). FAO, Rome.

Beltrán, G., Uceda, M., Hermoso, M., Frías, L. (2008). Maduración. In El Cultivo del Olivo, ed. by Barranco D, Fernández-Escobar R, Rallo L. Madrid, Spain, pp. 729-776.

Fereres, E., Castel, J.R. (1981). Drip irrigation management. Division of Agricultural Sciences, University of California Publication Leaflet 21259.

Girona, J., Luna, M., Arbonés, A., Mata, M., Rufat, J., Marsal, J. (2002). Young olives trees responses (Olea europaea L. cv. Arbequina) to different water supplies. Water function determination. Acta Hortic. 586: 277–280.

Grattan, S.R., Berenguer, M.J., Connell, J.H., Polito, V.S., Vossen, P.M. (2006). Olive oil production as influenced by different quantities of applied water. Agric. Water Manag. 85: 133-140.

IUPAC. (1992). Standard Methods for the Analysis of oils, Fats and Derivates, 7th edn. Paquot C; Hautffenne A, eds. International Union of Pure and Applied Chemistry, Oxford, England: Blackwell Scientific Publications Inc.

Lavee, S., Hanoch., E., Wodner, M., Abramovich, H. (2007). The effect of predetermined deficit irrigation on the performance of cv. Muhasan olives (Olea europaea L.) in the eastern coastal plain of Israel. Sci. Hortic. 112: 156-163.

Moriana, A., Orgaz, F., Pastor, M., Fereres, E. (2003). Yield responses of a mature olive orchard to water deficit. J. Amer. Soc. Hort. Sci. 128: 425-431.

Pérez-López, D., Ribas, F., Moriana, A., Olmedilla, N., de Juan, A. (2007). The effect of irrigation schedules on the water relations and growth of a young olive (*Olea europaea* L.) orchard. Agric. Water Manag. 89: 297-304.

Pérez-López, D., Gijón, M.C., Moriana, A. (2008). Influence of irrigation rate on the rehydration of olive tree plantlets. Agric. Water Manag. 95: 1161-1166.

Romero, M.P., Tovar, M.J., Girona, J., Motilva, M.J., (2002). Changes in the HPLC phenolic profile of virgin olive oil from young trees (Olive europaea L., Cv. Arbequina) grown under different deficit irrigation strategies. J. Agric. Food Chem. 50: 5349-5354.

Rousseaux, M.C., Benedetti, J.P., Searles, P.S. (2008). Leaf-level responses of olive trees (Olea europaea) to the suspension of irrigation during the winter in an arid region of Argentina. Sci. Hortic. 115: 135–141.

Servili, M., Esposto, S., Lodolini, E., Selvaggini, R., Taticchi, A., Urbani, S., Montedoro, G., Serravalle, M., Gucci, R. (2007). Irrigation effects on quality, phenolic composition, and selected volatiles of virgin olive oils Cv. Leccino. J. Agric. Food Chem. 55: 6609-6618.

Shackel, K.A., Lampinen, B., Sibbet, S., Olson, W. (2000). The relation of midday stem water potential to the growth and physiology of fruit trees under water limited conditions. Acta Hortic. 537: 425-430.

Torres, M., Pierantozzi, P., Cáceres, M.E., Labombarda, P., Fontanazza, G., Maestri, D.M. (2009). Genetic and chemical assessment in Arbequina olive cultivar grown in Córdoba province (Argentina). J. Sci. Food Agric. 89: 523-530.

Uceda, M., Hermoso, M., Aguilera, M.P. (2008). La calidad del aceite de oliva. In El Cultivo del Olivo, ed. by Barranco D, Fernández-Escobar R, Rallo L. Madrid, Spain, pp. 699-727.