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Regulated deficit irrigation effects on yield, fruit quality and vegetative growth of 'Navelina' citrus trees

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Abstract

An experiment on regulated deficit irrigation (RDI) was performed during two growing seasons (2007 and 2008) in a drip-irrigated orchard of Navelina/Cleopatra in Senyera (Valencia, Spain). Two RDI treatments, where water application was reduced to 40% and 60% of the «irrigation dose» (ID), were carried out during the initial fruit enlargement phase (Stage II, 17th July to 2nd September). The rest of the year they were irrigated at 110% ID. These treatments were compared with a control, where irrigation was applied without restriction during the whole year at 110% ID. The ID was obtained from the evapotranspiration data, as well as from the characteristic variables of drip irrigation for the specific experimental orchard. The effects of the treatments on yield, fruit quality, and vegetative growth are discussed in relation to tree water status (midday stem water potential, Ψ_{st}). Minimal Ψ_{st} values reached in the treatment with the highest stress intensity were –1.71 and –1.60 MPa in 2007 and 2008 respectively. These Ψ_{st} values reached as a consequence of the water reduction in the RDI summer treatments applied in this study did not affect yield or fruit quality, allowing water savings between 16% and 23%. In conclusion, water restriction during summer, and once «June drop» has finished, favours the better use of water resources by Navelina citrus trees, achieving an increase of water use efficiency (between 14% and 27% in this case), provided that an appropriate irrigation in autumn allows for tree recovery.

Additional key words: citrus trees; drip irrigation; Navelina; stem water potential; water relations; water use efficiency.

Resumen

Efectos del riego deficitario controlado sobre el crecimiento, producción y calidad de la fruta en cítricos de la variedad Navelina

Se ha realizado un experimento de riego deficitario controlado (RDC) durante 2007 y 2008 en una parcela de Navelina/Cleopatra regada por goteo en Senyera (Valencia, España). Se aplicaron dos tratamientos RDC al 40 y 60% de la dosis de riego (ID) durante el periodo de crecimiento inicial del fruto (Fase II, 17/07 al 02/09). El resto del año se regaron al 110% de la ID. Estos tratamientos se compararon con un control, regado todo el año al 110% de la Dr, determinada a partir de la evapotranspiración, así como de los parámetros característicos del riego por goteo de la parcela de ensayo. Los efectos de los tratamientos sobre la producción y calidad de la cosecha, así como sobre el crecimiento vegetativo, se discuten en relación al estrés hídrico producido (potencial del tallo al mediodía solar, Ψ_{st}). Los valores mínimos de Ψ_{st} alcanzados por el tratamiento más estresado fueron de –1.71 y –1.60 MPa en 2007 y 2008 respectivamente. Estos valores de Ψ_{st} alcanzados como consecuencia de la reducción del riego en los tratamientos RDC en verano aplicados en este trabajo, no produjeron mermas en la producción ni en la calidad de la cosecha, permitiendo ahorros de agua entre el 16 y el 23%. Se concluye que la reducción del riego en verano, tras la finalización de la caída de junio, predispone a los cítricos de la variedad Navelina a aprovechar mejor los recursos hídricos, lográndose un aumento en la eficiencia en el uso del agua (entre 14 y 27% en este caso), siempre y cuando un riego adecuado permita la recuperación de los árboles en otoño.

Palabras clave adicionales: cítricos; eficiencia en el uso del agua; Navelina; potencial hídrico del tallo; relaciones hídricas; riego por goteo.

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Introduction

The use of water in irrigated crops represents approximately 70% of the total of the different applications in the entire world (FAO, 2006). Therefore, a small reduction in the amount of water used for irrigation can mean an important rise in the availability of water for other uses. This, in addition to the increasing irrigation costs, demands the application of substantial changes in the irrigation methodology, so as to obtain profitable yields, even and more and more frequently, using water supplies inferior to the amount required by the trees for their maximum growth and yield. Therefore, it is of uttermost importance to know the effects water deficit has on yield and fruit quality.

One of the options proposed for a more efficient use of irrigation water is the application of regulated deficit irrigation (RDI) (Mitchell *et al.*, 1984), which is based on the restriction of water supplies during certain stages of crop development, when yield and fruit quality have low sensitivity to a reduction in water, providing normal irrigation during the rest of the season, especially during the «critical periods» or phenological stages with a higher sensitivity to water deficit (Mitchell *et al.*, 1984; Chalmers *et al.*, 1986).

In order to adequately control how the application of RDI affects water stress on the tree, it is important to use appropriate plant water indicators. The best variable related to tree water status is leaf water potential, Ψ (Elfving *et al.*, 1972; Garnier and Berger, 1985; Améglio *et al.*, 1999), measured with a pressure chamber (Peretz *et al.*, 1984). Leaf water potential can be obtained at midday (Ψ_{md}) or pre-dawn (Ψ_{pd}). There is a certain controversy with the use of Ψ_{md} or Ψ_{pd}. Although the latter is more stable and reflects tree recovery over night, it does not indicate the status of the plant at the moment of highest demand. González-Altozano and Castel (1999, 2000) found that Ψ_{pd} was the best water stress indicator in citrus trees. However, in the present work the water potential was determined at midday, as performing measurements before dawn involved practical complications.

Numerous studies (McCutchan and Shackel, 1992; Shackel *et al.*, 1997; Naor, 2000; Choné *et al.*, 2001; Ortuño *et al.*, 2006) propose the measurement of stem water potential (Ψ_{st}) as an alternative to leaf water potential. It is defined as the water potential measured in a non-transpiring leaf in balance with the xylem after being wrapped in a bag for 2-3 hours.

In this study, Ψ_{st} has been used, given that, according to numerous authors (Choné *et al.*, 2001; Naor, 2006; Ortuño *et al.*, 2006), is a significant and more reliable indicator of water status and early water deficit in plants, and it is considered an useful tool for irrigation scheduling in fruit trees. Other advantages are that it offers less variability and that it seems to be well-related to tree and fruit growth and quality on a wide range of soils and with different irrigation systems.

González-Altozano and Castel (1999, 2000, 2003a,b) carried out several RDI tests on an experimental orchard of '*Clementina de Nules*' citrus trees, in which there were compared different levels of water restriction in the main phenological periods of crop development, showing the effects of the different treatments on yield, fruit quality and water use efficiency.

The conclusions drawn from these experiments showed that the effects of RDI treatments depend on the phenological period in which the water restriction is applied. Thus, the application of RDI in period I (spring, flowering and fruit set) produced a decreased shoot elongation in the first growth flush, fruitlet drop on restarting irrigation when the restriction had been intense, off-season flowering, and a higher vegetative growth. The harvest suffered a reduction due to the high flower and fruitlet drop, without affecting fruit quality and size.

During period II, summer (initial fruit enlargement), the application of RDI caused off-season flowering, but of lesser significance than the one produced in the RDI treatments in autumn. Water restriction during this period did not affect yield or fruit quality, and allowed important water savings (8-22%).

Abbreviations used: AE (application efficiency), BR (before restriction), DOY (day of year), DW (dry fruit weight), EC_{1-5} (electric conductivity), ER (at the end of the restriction), ETc_li (crop evapotranspiration at local irrigation conditions), ETo (reference crop evapotranspiration), FW (fresh fruit weight), H (at harvest), ID (irrigation dose), Kc (crop coefficient), K_l (local coefficient), R (during restriction), RDI (regulated deficit irrigation), Re (effective rainfall), SA (percentage of shaded area), SAR (sodium adsorption ratio), STR (servicio de tecnología del riego), TA (titratable acidity), TSS (total soluble solids), UE (uniformity of emission), V (fruit volume), V_{calc} (fruit volume calculated from experimental measurements), V_{exp} (fruit volume obtained experimentally), Vtop (volume of the tree top), WUE (water use efficiency), ΔSA (increment of the percentage of shaded area), ΔVtop (increment of the volume of the tree top), Ψ (leaf water potential), Ψ_{md} (leaf water potential at midday), Ψ_{pd} (leaf water potential at pre-dawn), Ψ_{st} (stem water potential).

Water deficit during period III (end of summer-autumn) resulted in a decrease in yield (13-23%) due to the smaller fruit size caused by a slower growth rate in the final stages of crop development. As for fruit quality, an increase of sugars and acids was noticed.

These experiments also defined different Ψ_{pd} threshold values to avoid negative effects according the phenological period considered, thus in spring, Ψ_{pd} should not surpass –0.5 MPa (without water stress), whereas in summer –1.2 MPa (around Ψ_{st} –1.9 MPa) should not be exceeded.

Therefore, the phase of initial fruit enlargement (July or July and August) is the most suitable for the application of RDI on '*Clementina de Nules*' citrus trees, considering that no reduction of yield, fruit size or quality is produced during this period, provided that the threshold value of Ψ_{st} is not surpassed, and with significant water savings (González-Altozano and Castel, 1999, 2000, 2003a,b). In addition, the citrus fruit has the capacity of compensating growth after a water deficit period, being able to reach their potential size, which depends on the intensity of water stress that was applied.

Nevertheless, the response to the reduction of water supply may be species-dependent and vary considerably depending on timing and severity of the cultural treatments, soil type and other site-specific factors (Treeby *et al.*, 2007).

The aim of this work is to show that the previous results about the possibility of saving water without affecting neither yield nor fruit quality in '*Clementina de Nules*' can also be applied to the 'Navelina' citrus trees. Therefore, an experiment on RDI was performed during 2007 and 2008 in a commercial orchard located in Senyera (Valencia). Two water deficit treatments were applied in summer (the least sensitive period to water stress for citrus trees) and they were compared to a well-irrigated treatment.

This work describes the effects on yield and fruit quality of the RDI treatments applied in the experiment, as well as its effects on vegetative growth of the trees in relation to tree water status determined by midday stem water potential (Ψ_{st}).

Material and methods

The experiment was carried out in two growing seasons (2007 and 2008), on a commercial drip-irrigated plot of 1 ha in Senyera, Valencia (39° 3' N, 0° 30' W, 23 m a.s.l.) planted in 1982 with 'Navelina' orange trees (*Citrus sinensis* L. Osbeck) grafted on 'Cleopatra' mandarin (*Citrus reshni* Hort.) at a spacing of 5 × 5 m.

The soil is sandy-loam deep with pebbles of alluvial origin, with an average organic matter content of 1.69%, an electric conductivity ($EC_{1\text{-}5}$) of 0.14 dS m^{-1}, 45.15% of active $CaCO_3$, and a pH in water (1/25) of 8.67. It is also poor in total nitrogen (0.05%), available potassium (0.30 meq K^+ 100 g^{-1}) and phosphorus (21.53 mg P kg^{-1} Olsen).

The irrigation water used had an average electrical conductivity (at 25°C) of 0.94 dS m^{-1}, with a chloride content lower than 2 meq Cl L^{-1} and a SAR value of 7.21.

Climatic data were provided by the meteorological station belonging to the «Servicio de Tecnología del Riego» (STR) in Villanueva de Castellón (Spain), located at less than 1,000 m from the experimental plot. The climate is Mediterranean semi-arid. The rainfall and the corresponding evaporative demand were 869 mm and 1,160 mm respectively in 2007, being 796 mm and 1,124 mm respectively, in 2008. The average annual rainfall in the period between 2000 and 2008 (the years of which the local meteorological station has registered information) was 595 mm and the average annual ETo was 1,111 mm. Mean annual air temperature is around 17°C.

The trees of all treatments received the same amount of fertilizers through the irrigation system, being 260-65-130 kg · ha^{-1} per year of N, P_2O_5, and K_2O respectively, split in weekly applications from April to October. Control of plagues and other cultural practices were the habitual in the area and identical in all treatments. Trees were not pruned during these seasons.

Irrigation treatments

The irrigation treatments were established according to the crop evapotranspiration at local irrigation conditions (ETc_li) calculated from the reference crop evapotranspiration (ETo, Penman Monteith) and rainfall. The irrigation dose (ID) was determined weekly using the following equation:

$$Id = ETc\_li - \mathrm{Re} = K \cdot F \cdot ETo - \mathrm{Re} \qquad [1]$$

where K is a coefficient that includes the crop coefficient (Kc = 0.54 in 2007 and 0.61 in 2008) determined according to Castel (2001) for citrus trees depending on the percentage of shaded area (SA) on this plot. The

SA value used was the average of the trees on the plot in May 2007 and 2008 (SA = 54 and 62%, respectively) considering a spacing of 5 × 5 m. Application efficiency (AE = 0.86), uniformity of emission (UE = 0.74) and local coefficient [K_l = 0.67 in 2007 and 0.76 in 2008 according to Aljibury *et al.* (1974) depending on SA] gave a coefficient K specific for this plot of 0.58 in 2007 and 0.73 in 2008, using the following equation:

$$K = \frac{K_c \cdot K_l}{AE \cdot UE} \qquad [2]$$

The significant increase of K from one year to the other was due to the increase in tree size, which was not pruned in any of the studied seasons.

Re in equation [1] is the effective rainfall determined according to recommendations of STR, and F is a factor related with the level of deficit irrigation of each treatment. In this study F was 0.40, 0.60 and 1.10 depending on the treatment and phenological period.

Three irrigation treatments were applied: a control treatment, irrigated at 110% of ID weekly, and two RDI treatments which received the same ID as the control except during the initial fruit enlargement phase (from 17/07 until 02/09), where 40% (T1) and 60% (T2) of ID was applied. These treatments received an average of 40.1 and 60.8% of ETc, respectively, during the water deficit periods considering the two years of study.

The established irrigation treatments, the dose applied, and the duration of each are summarized in Table 1.

The irrigation system consisted of a double line (1.8 m spaced) of drip-irrigation with eight self-regulating drippers per tree with an average flow of 7.4 L h^{-1} per dripper. Irrigation frequency, identical for all treatments, varied between six irrigations per week in summer and two irrigations per week in winter.

Table 1. Irrigation treatments applied during the experimental period (2007 and 2008)

Treatments	Phenological period	Water applied	
		Deficit period	Rest of the year
Control	Whole season	110% ID	110% ID
T1-40%-II	Initial fruit	40% ID	110% ID
T2-60%-II	enlargement (II)	60% ID	110% ID

ID: irrigation dose. Deficit period: from 17/07 to 02/09.

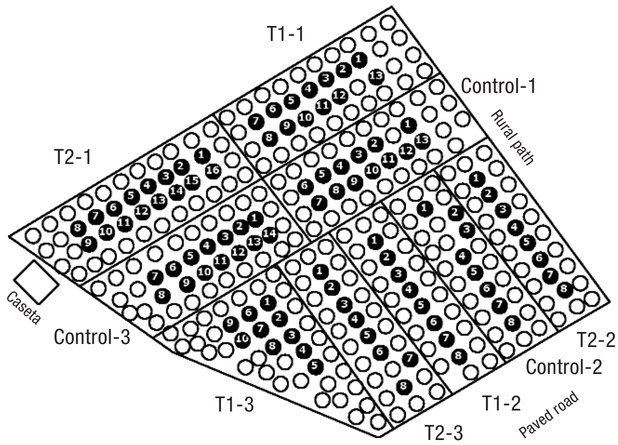

Figure 1. Experimental plot showing the distribution of each replicate of the applied treatments. The blank circles represent the guard trees.

The statistical design was a randomised complete-block with three replicates per treatment. Each experimental unit consisted of a minimum of three rows with 10 trees per row, using perimeter trees as guard. Thus, yield and fruit quality variables are based on a minimum of eight trees per experimental unit (Fig. 1).

Applied water was determined from weekly water-meters readings for each irrigation replicate.

Tree water status measurements

Midday stem water potential (Ψ_{st}) was measured weekly around 12 h (GMT) in the most growing season except during the winter when the measurements were less frequent, using a pressure chamber following the procedures described by Turner (1981). Ψ_{st} was measured on two leaves per tree, which had been wrapped in bags at least 2 hours previously, and on two trees per individual plot on each of the three replicates per treatment. A threshold value of Ψ_{st} = –1.9 MPa was established to avoid negative effects in RDI summer treatments.

Fruit growth

Sixteen fruits per tree were selected and tagged from three trees per treatment (one for each replicate). Equatorial fruit diameter was measured weekly from the beginning of July until harvest. A good correlation was found between the fruit volume obtained experimentally (V_{exp}) through displacement (Archimedes's principle), and the volume calculated indirectly from experimental measurements of the equatorial and polar diameters (V_{calc}). The relationship found was:

$$V_{calc}\ (cm^3) = 0.9687 \cdot V_{exp} \qquad (r^2 = 0.9832)$$

On the other hand, fresh fruit weight (FW) and dry fruit weight (DW) were determined in four fruits randomly selected per replicate, before restriction (BR), during restriction (R), at the end of the restriction (ER), and at the end of the season, at harvest (H). First, volume (V) and FW were determined for each fruit. Then, they were cut up and introduced into an oven at 50°C until reaching constant weight, after which DW was determined. The relations V DW^{-1}, and FW DW^{-1} were used to study the influence of RDI treatments on the accumulation of fresh and dry matter in fruit.

Yield and fruit quality

At the end of each season during the commercial harvest (8th January and 17th November the first and second season respectively), yield and its components were determined in eight trees per replicate (24 trees per treatment). The average fruit weight was evaluated by counting the number of fruits in a minimum of eight boxes per individual plot, previously weighed (about 20 kg box^{-1}). Fruit quality variables: peel, juice, sugars (total soluble solids, TSS), acid content (titratable acidity, TA), soluble solids, pH, and vitamin C, were determined at harvest on samples of nine fruits per individual plot (27 fruits per treatment), following the procedures described by González-Sicilia (1951).

Fruit abscission

With the aim of verify that RDI treatments began after the end of «June drop», as well as to check the treatments effects on fruit abscission, the number of fruits fallen were registered weekly each season in two trees per replicate from flowering till harvest.

Vegetative growth

Trunk perimeter was measured at the beginning and at the end of each season, at about 30 cm above the ground, as well as the diameter of the tree top in perpendicular and parallel directions to the lines, and the minimum and maximum height of eight trees per replicate. From these measurements, the percentage of shadowed area (SA, %), the volume of the tree top considered as an ellipsoid (Vtop, m^3), as well as the increment of the volume of the tree top (ΔVtop, m^3), and the increment of the percentage of shaded area (ΔSA, %), in each season, were determined.

The yield to SA ratio (kg of fruit produced per SA) has been termed «yield efficiency» and the relationship between yield and ΔSA has been used to express resources partitioning between vegetative and productive growth.

Water use efficiency (WUE) has been defined as the ratio between yield and total applied water (irrigation + rainfall).

Statistical analysis

Statistical analyses were performed using the SPSSv16 package (SPSS Inc., Chicago IL) with one-way analysis of variance (ANOVA), given that data fit the assumptions of the parametric tests (test K-S). Differences among treatments were studied with Tukey test (95%).

Results

The evolution of midday stem water potential (Ψ_{st}), as well as that of fruit volume and their relative diameter growth in relation to the control are presented in Figure 2. In this figure, rainfall and the ETo evolution are also shown.

In the control trees, the Ψ_{st} values were around –0.8 MPa and although very low values were reached by the end of the season (around –1.65 MPa), before water restriction period, hardly any differences in Ψ_{st} were found between the different treatments, which maintained a high level, showing total absence of water stress in both years. After the beginning of the restriction, a slow and continual drop in Ψ_{st} was detected in RDI treatments as the water deficit period progressed. In both years, minimum potential values were reached at the end of this period, and the higher the restriction level, the lower they dropped. Two weeks after restarting normal irrigation, trees of both RDI treatments had completely re-hydrated in both seasons.

The evolution of Ψ_{st} during both years, reflects well the restriction periods and the water cut-offs which had been decided upon one-sidedly by the growers during

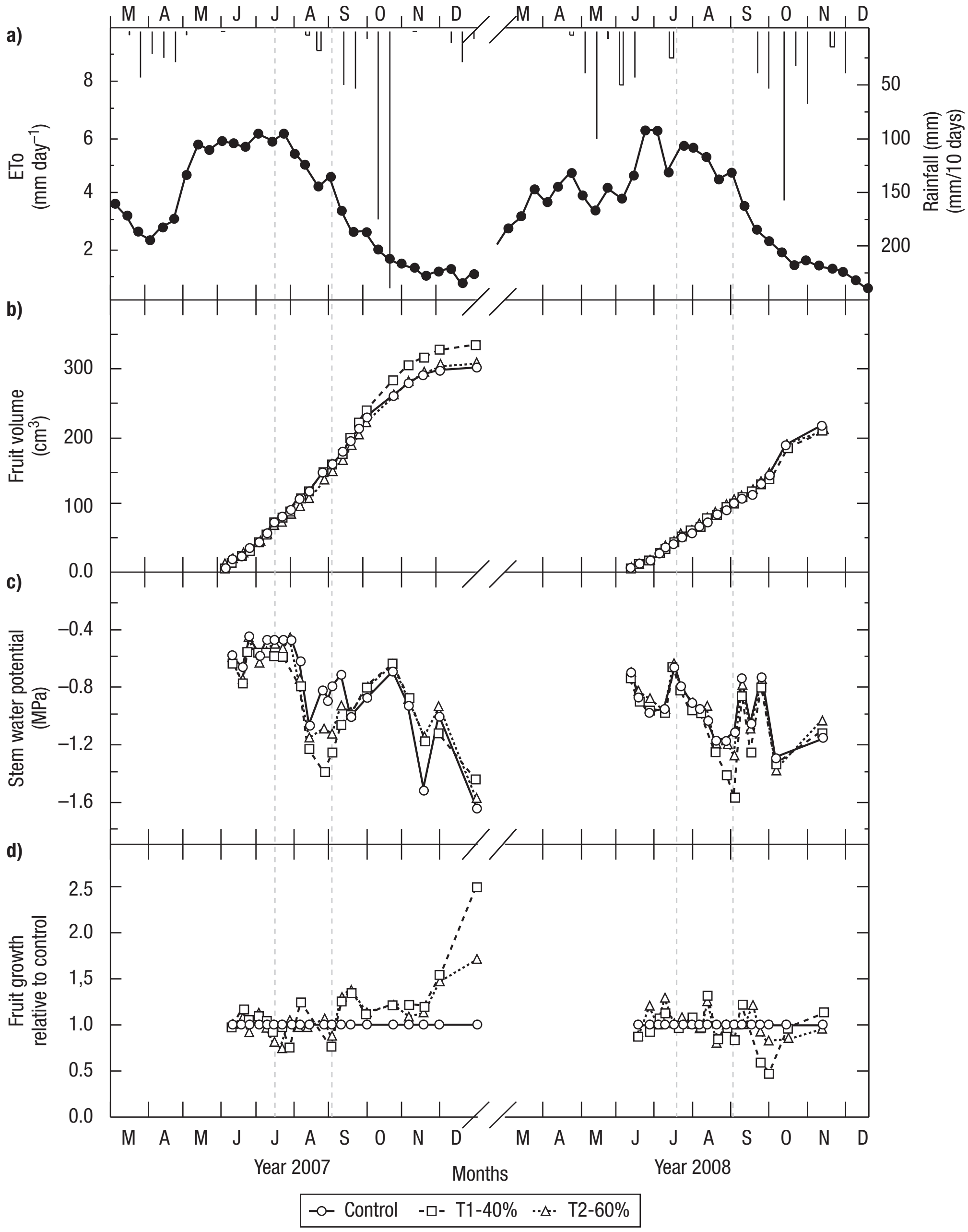

Figure 2. Evolution of: ETo and rainfall (a), fruit volume (b), midday stem water potential (c), and relative diameter fruit growth of RDI treatments in relation to the control (d), in 2007 and 2008. The vertical lines show the beginning and the end of the restriction period. Irrigation treatments were a control (110% ID) and T1 and T2 RDI treatments (40% and 60% ID applied at II-Initial fruit enlargement). Harvest dates were 8th January and 17th November, the first and second season respectively.

November and December in 2007, and during September and October in 2008. These water cut-offs produced rapid and important drops of Ψ_{st} in all treatments in autumn. In consequence, in 2007, Ψ_{st} reached the minimum values (–1.65 MPa) in the control treatment the day of year (DOY) 365, while in 2008, similar Ψ_{st} values were found in all treatments with a minimum value of –1.41 MPa (T2, DOY 281).

Measurements carried out on 31 August in 2007 and 2008 detected Ψ_{st} values in T1 treatment around –1.71

and –1.60 MPa respectively, which led to the decision to stop the restriction in the RDI treatments although the established Ψ_{st} threshold value of –1.9 MPa had not been reached, so as to allow the trees to recover before harvest.

After starting the restriction period, a slight deceleration of fruit growth was observed in the deficit treatments. However, only small differences were detected with respect to the control in 2007 (Fig. 2b), which, as discussed below, did not affect the final fruit weight. The analysis of variance indicated that during the restriction period of 2007, significant differences were found in the fruit diameter due to the treatment ($p < 0.05$), where the fruits of the T2 treatment showed a smaller diameter than those of the control. However, these differences disappeared as soon as irrigation at normal dose restarted, observing a rapid recovery. After the end of the restriction, the relative diameter fruit growth of the treatments T1 and T2 clearly exceeded the control one (Fig. 2d), although the differences were not statistically significant.

On the other hand, water restriction during the summer of 2008 did not produce differences in fruit growth between treatments. Although fruit growth accelerated after the restriction period, this occurred at the end of the season, coinciding with a period of rainfall and showed no differences between treatments (Fig. 2b).

Table 2 shows the evolution of the volume as well as the accumulation of fresh and dry weight in the fruit of the different treatments, by the relations Volume/Dry_Weight (V DW^{-1}) and Fresh_Weight/Dry_Weight (FW DW^{-1}). Before restriction, these relations were similar in all the treatments. During the restriction period, RDI fruit continued on accumulating dry material, thus reducing the relation V DW^{-1} and FW DW^{-1} with respect to the control (Table 2) being the differences statistically significant ($p < 0.05$). The compensating growth produced in fruit of the RDI treatments in 2007 (Fig. 2d), gave rise to similar results between treatments at harvest, as they were before the restriction (Table 2). The differences between RDI treatments and control at harvest in 2008, were only significant for the relation FW DW^{-1} of T1 with respect to the control. In the other cases, differences were not significant although the found values indicated higher relative dry weight accumulation in the stressed treatments and, as a consequence, these fruits still had certain capacity of growth at harvest.

Table 3 shows the influence of irrigation treatments on yield and its components. Significant differences were observed between years in yield ($p < 0.05$). Thus, on average, yield in control treatment in 2008 was 91% higher than in 2007. These differences were mainly due to the number of fruit · $tree^{-1}$ (242 in 2007 and 593 in 2008, in the control treatment) given that differences in average fruit weight were not so marked (296 and 232 g in 2007 and 2008, respectively in the control treatment). Despite the fact that fruit size differed

Table 2. Relations Volume/Dry_Weight (V DW^{-1}) and Fresh_Weight/Dry_Weight (FW DW^{-1}) in each year, before restriction (BR), during restriction (R), at the end of the restriction (ER) and at harvest (H). Average results of 12 samples per treatment

		Year 2007		Year 2008	
		V DW^{-1}	**FW DW^{-1}**	**V DW^{-1}**	**FW DW^{-1}**
BR	T1-40%	3.74	3.82		
BR	T2-60%	3.72	3.83		
BR	control	3.82	3.85		
R	T1-40%	5.51	5.01	5.59	6.27
R	T2-60%	5.21	4.68	5.62	6.41
R	control	5.28	4.84	5.50	6.45
ER	T1-40%	6.20*	5.74*	6.36	5.51*
ER	T2-60%	5.98*	5.68*	6.22	5.79*
ER	control	7.30	6.61	6.87	6.31
H	T1-40%	6.86	6.52	6.39	6.11*
H	T2-60%	6.92	6.51	6.80	6.59
H	control	6.70	6.50	7.12	6.98

* indicates significant differences with respect to control treatment of each year ($p < 0.05$).

Table 3. Influence of irrigation treatments on yield and its components of 'Navelina' citrus trees. Irrigation treatments were a control (110% ID) and T1 and T2 RDI treatments (40% and 60% ID applied at II-Initial fruit enlargement)

Variables	Year 2007			Year 2008		
	Control	T1-40%	T2-60%	Control	T1-40%	T2-60%
Irrigation (mm)	516	396	431	515	410	429
Water savings (%)	—	23	16	—	20	16
Yield (kg tree^{-1})	70.5	79.2	84.1	134.4	140.4	146.8
Relative yield (%)	100	112.4	119.4	100	104.5	109.3
Nº fruits tree^{-1}	242	281	309*	593	637	680
Average fruit weight (g)	296.0	292.1	282.3	231.6	220.5	217.9

* indicates significant differences with respect to control treatment of each year ($p < 0.05$).

among treatments during the water restriction (Fig. 2d), no differences between treatments were detected in this sense at the end of the season (Table 3).

Water restriction during period II (summer, initial fruit enlargement), did not affect yield nor fruit weight in any of the two years of study, allowing water savings between 16% and 23%, depending on the year and treatment.

The analysis of variance only detected significant differences in relation to the control in the number of fruits· tree^{-1} ($p = 0.05$) between the T2 treatment and the control in 2007.

Table 4 shows the influence of irrigation treatments on fruit quality. The obtained values for the different variables indicate that high fruit quality was reached in all treatments, without finding significant differences neither between treatments in any of the studied variables or between years.

Figure 3 shows the number of fallen fruits per tree on the indicated dates in each of the treatments during the year 2008. The fruitlet drop trend was similar to the previous year (data not shown), without detecting significant differences between the treatments in any of the studied years. In both years, the «June drop» had concluded by the end of the month (DOY 182), and before the start of the restriction treatments (DOY 199). The end of the restriction neither produced fruitlet drop in any of the treatments or years. However, in 2008 a fruitlet drop higher than normal and similar in all treatments was detected near harvest time, which had not been observed in 2007.

Table 5 shows the influence of irrigation treatments on vegetative growth in each season. In 2007, although no significant differences were observed between treatments with respect to the variables that define tree size (trunk perimeter, SA, Vtop), differences were detected in the increments of shaded area percentage (ΔSA) and of tree top volume (ΔVtop). It should be pointed out that the main ΔSA and ΔVtop occurred in the treatments with restricted irrigation.

In 2008, those observations were confirmed, although differences were only detected with respect to the control in the ΔSA. ΔVtop differences were not significant, although results showed the same trend as in 2007. The fact that significant differences were not detected may be due to the higher measurement error in the height of the trees.

Table 4. Influence of irrigation treatments on fruit quality of 'Navelina' citrus trees. Irrigation treatments were a control (110% ID) and T1 and T2 RDI treatments (40% and 60% ID applied at II-Initial fruit enlargement)

Variables	Year 2007			Year 2008		
	Control	T1-40%	T2-60%	Control	T1-40%	T2-60%
% peel	26.44	26.89	27.08	26.22	26.59	26.36
Vit. C (mg/100 g juice)	70.31	65.05	68.68	67.61	68.25	63.34
% juice	50.86	50.46	51.66	46.28	46.57	43.80
TTS (°Brix)	10.6	10.6	10.7	9.10	9.50	9.87
TA (% acids)	0.89	1.08	1.05	0.92	1.15	1.01
Maturity index	12.08	9.84	10.37	10.10	8.29	10.09
pH juice	3.46	3.33	3.36	3.10	3.12	3.14

Note: no significant differences were detected between treatments of each year ($p > 0.05$).

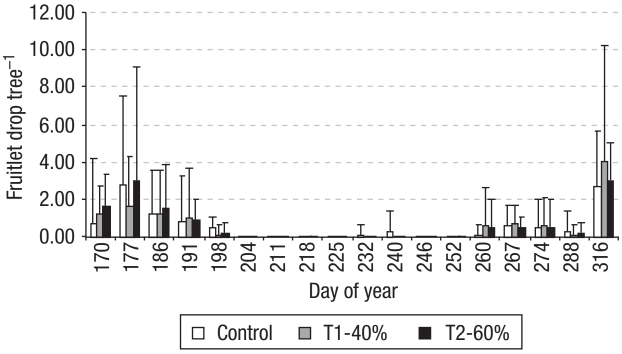

Figure 3. Evolution of number of fruitlet drop per tree in 2008. Date are mean ± standard deviation.

In addition, the irrigation restrictions did not affect the flowering process of the growth flush after June in any of the treatments (information not reflected).

The influence of irrigation treatments on yield efficiency (kg of fruit produced per SA), resources partitioning (relationship between yield and ΔSA), as well as on water use efficiency (WUE), is shown in Table 6.

Yield efficiency (yield SA^{-1}) was similar in all treatments in the two years of study, while WUE was higher in RDI treatments than in the control, although the differences were only statistically significant ($p < 0.05$) in 2007. Against all expectations, vegetative growth of the RDI trees was higher than that of the control in both years leading to lower yield · ΔSA^{-1} values ($p < 0.05$). This effect could not be due to pruning, as trees were not pruned during the experiment.

The higher crop load in 2008 gave rise to both higher yield efficiency and water use efficiency than 2007 ($p < 0.05$).

Discussion

The values of Ψ_{st} obtained in control treatment correspond to values of Ψ_{md} characteristics of well-irrigated citrus trees (Syvertsen and Albrigo, 1980).

During the water restriction period, the lowest Ψ_{st} value (around –1.71 MPa) was reached in the most severe restriction treatment. González-Altozano and Castel (1999, 2003a) found in '*Clementina de Nules*' citrus trees that with lower stress levels in stage II ($\Psi_{pd} \geq -1.2$ MPa, corresponding to $\Psi_{st} \geq 1.9$ MPa) no significant effects were produced. These Ψ_{st} values did not suggest significant water stress levels according to (Domingo *et al.*, 1996), taking into account the aforementioned relationship between Ψ_{st} and Ψ_{pd}.

As for fruit growth, only slight differences of the water deficit treatments with respect to the control

Table 5. Influence of irrigation treatments on vegetative growth of 'Navelina' citrus trees. Irrigation treatments were a control (110% ID) and T1 and T2 RDI treatments (40% and 60% ID applied at II-Initial fruit enlargement)

Variables	Year 2007			Year 2008		
	Control	T1-40%	T2-60%	Control	T1-40%	T2-60%
Trunk perimeter (m)	0.76	0.80	0.78	0.77	0.84	0.82
SA (%)[a]	52.20	56.41	53.63	57.09	65.89	63.18
Vtop (m^3)[b]	22.94	25.69	24.37	28.39	32.14	30.84
ΔSA (%)[c]	1.86	5.24*	5.45*	4.88	9.48*	9.55*
ΔVtop (m^3)[d]	2.02	3.84*	3.81*	4.37	5.31	5.37

[a] SA: percentage of shaded area. [b] Vtop: tree top volume. [c] ΔSA: increment of the shaded area percentage. [d] ΔVtop: increment of tree top volume. * indicates significant differences with respect to control of each year ($p < 0.05$).

Table 6. Influence of irrigation treatments on relations between vegetative and productive variables, and water use efficiency (WUE) of 'Navelina' citrus trees. Irrigation treatments were a control (110% ID) and T1 and T2 RDI treatments (40% and 60% ID applied at II-Initial fruit enlargement)

Variables	Year 2007			Year 2008		
	Control	T1-40%	T2-60%	Control	T1-40%	T2-60%
Yield SA^{-1} (kg cm^{-2})	1.35	1.40	1.57	2.35	2.13	2.32
Yield (kg) ΔSA^{-1}	37.9	15.11*	15.43*	27.53	14.81*	15.37*
WUE (kg m^{-3})	2.04	2.50*	2.59*	4.11	4.67	4.81

* indicates significant differences with respect to control treatment of each year ($p < 0.05$).

were detected during the restriction period in 2007. The absence of differences between treatments in 2008 is presumably due to the higher crop load, which limited these effects.

The acceleration of relative fruit growth observed in the water deficit treatments after restarting normal irrigation in 2007 has also been described in citrus trees (Cohen and Goell, 1988), pear (Mitchell *et al.*, 1984; Caspari *et al.*, 1994), apple (Ebel *et al.*, 1995) and apricot (Ruiz-Sánchez *et al.*, 2000). This compensating growth was maintained until harvest promoted by a higher fruit growth relative to control, becoming even more noticeable by the end of the year, when Ψ_{st} showed certain levels of stress as a result of the water cut-offs occurred during November and December, affecting especially the control, possibly because these trees were not used to scarcity of water.

In 2008, after the restriction period, the compensating fruit growth occurred near the end of the season and without differences between treatments. This might be explained by the fact that, although in 2008 the trees reached a lower stress level than in 2007, it was maintained during September and October, affecting even the control, as demonstrated by the evolution of the Ψ_{st}, due to the aforementioned water cut-offs carried out by the growers considering the insufficient rainfall in autumn. This fact prevented the compensating fruit growth from starting until, five weeks prior to harvest, irrigation and rainfall allowed it. The absence of differences between treatments reinforces this hypothesis. This constraint of fruit growth is the typical effect produced by the autumn deficit irrigation treatments (González-Altozano and Castel, 1999, 2003a), and it confirms that the trees are not to suffer stress during the autumn months so as not to affect fruit size (Goldhamer *et al.*, 2002; Pérez-Pérez *et al.*, 2009). The absence of differences in fruit growth rate between treatments in autumn can be explained by the similar stress levels suffered by all treatments.

The differences between RDI treatments and control in the relations V DW^{-1} and FW DW^{-1} during the harvest of 2008, although not significant, show that possibly, at harvest, the fruits of the RDI treatments still had certain capacity of growth with respect to the control.

As for yield, the fact that, in 2007, the number of fruits/tree of the T2 treatment was significantly higher than the one of the control, should not be attributed to irrigation, considering that fruit set had taken place before starting the restriction and this did not cause important fruitlet drop during the treatments. What stands out is the important water saving attained with the RDI treatments compared with the control (between 16 and 23%) obtaining similar yield and fruit size in all treatments. Nevertheless, an important difference is observed between years with respect to the number of fruits per tree, which clearly conditioned fruit size (due to the competition), and yield. In this respect, other authors (Rowe and Johnson, 1992; Berman and DeJong, 1996; Naor *et al.*, 1999), found that peach and nectarine size decreases with increasing crop load. Although yield was very high in 2008, it could have been higher if it had been irrigated conveniently in September-October, and/or if harvest had been delayed, taking into account that the fruits continued growing at a high rate during harvest, as shown in Figure 2b.

The different fruit quality variables showed usual values (Primo, 1982), and the maturity index was among the range considered of consumer's global best appreciation in the variety studied (UNECE, 2003) in both years, which indicates that the fruit of this experiment was mature. Although in 2007 this could be attributed to the delay in harvest, in 2008 it shows that, despite the early harvest, the fruit was sufficiently mature in the three treatments.

For citrus fruit, it is commonly known that deficit irrigation applied during the first stage of fruit development (stage II as defined by Bain, 1958), increases total soluble solids (TSS) and decreases acid levels (TA) at maturation (Treeby *et al.*, 2007). Nevertheless, our results showed that there were no effects of water restriction in TSS levels neither in 2007 nor in 2008 which were very similar in all treatments. Also, TA level in the control was lower than in RDI treatments. This fact could be explained by the stress suffered by all treatments in autumn, affecting more the control, as the lower Ψ_{st} values reached in this treatment indicate, especially in 2007. The effect of the RDI treatments on TA values were similar to those found by González-Altozano and Castel (1999, 2003a) in the treatments in which irrigation was restricted during autumn (stage III).

In both seasons, the juice content was considerably greater to the minimum value established for the 'Navel' citrus group (UNECE, 2004), and similar to those found by other authors in «lane late» citrus fruit (Pérez-Pérez *et al.*, 2009). Sanchotene (1998) indicates for this variety normal values of 48.2% weight, while the results found in the fruit of this experiment showed higher values (51% on average) in 2007 and lower values (45.6% on average) in 2008. This finding shows that the mentioned bigger crop load and irrigation deficit during autumn in the second year prevented sufficient fruit hydration, considering that the peel content was similar in both years, with 26% on average.

Considering all these findings, it can be concluded that fruit quality was high in all treatments, including the ones with water deficit, and that the applied water restriction did not affect fruit quality.

The restriction, which started once the «June drop» had finished, did not cause fruitlet drop in any of the treatments or years. Neither did the irrigation restriction produce any negative effects on the sprouting. All shoots produced were exclusively vegetative so there were no «off-season» fruit at harvest and therefore there was no increased competition for assimilates among fruit. These results are in agreement with those obtained by González-Altozano and Castel (2000) in the summer RDI treatments applied to '*Clementina de Nules*' citrus trees. The higher fruitlet drop observed in 2008 near harvest time may be attributed to the very heavy fruit load of the trees.

As for vegetative growth, the important increments observed, both in the shaded area percentage (ΔSA) and in the tree top volume (ΔVtop), in the RDI treatments in 2007, indicate that the water restriction was no impediment to vegetative growth. Everything leads to the conclusion that the irrigation restrictions caused the desired effects with respect to a better water use efficiency in these trees, which were able to take better advantage of the intense autumn rainfall in 2007 than the control trees. These effects on the vegetative growth are not usual when deficit irrigation is applied during period II, the first stage of fruit development (Mitchell *et al.*, 1989).

The fact that, in the deficit treatments of 2008, only differences in ΔSA were observed and not in ΔVtop may be attributed to an error of measurement of the tree height, and although the differences of ΔVtop were not significant, the same tendency was observed in both years.

In conclusion, for Navelina citrus trees, irrigation at 40% of ID can be scheduled in summer, during the initial fruit enlargement phase, with the certainty that no important stress level will be caused to the trees, and that neither yield, fruit size nor quality will be affected. In this case water savings between 20% and 23% have been achieved leading to an increase in water use efficiency.

As the application of RDI delays the achievement of maximum fruit size, the appropriate irrigation dose in the final growth stages (autumn) is important, so as not to affect yield or fruit size, as well as allowing for sufficient time between the end of the restriction period and harvest.

The crop tree can affect the capacity of fruit recovery (compensating growth). If the crop load of the trees is high, more attention must be paid to avoiding stress from the beginning of September.

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