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Response of table grape cultivar 'Autumn Royal' to regulated deficit irrigation applied in post-veraison period

O. Blanco[1]*, J. M. Faci[1] and J. Negueroles[2]

[1] *Unidad de Suelos y Riegos (Unidad Asociada EEAD-CSIC). Centro de Investigación y Tecnología Agroalimentaria de Aragón CITA, DGA. Avda. Montañana, 930. 50059 Zaragoza. Spain*
[2] *Grupo ALM. Avda. César Augusto, 3, 7º B. 50004 Zaragoza. Spain*

Abstract

A field experiment was performed from 2006 through 2008, to evaluate the effect of a postveraison regulated deficit irrigation (RDI) on the yield and quality of the seedless table grape 'Autumn Royal', especially on berry cracking. Three irrigation treatments were applied: a control (T1), irrigated at 100% of the net irrigation requirements (NIR), and two RDI treatments (T2 and T3) irrigated as T1 except from postveraison till harvest, when different percentages of NIR were applied, 80 and 60% NIR in T2 and T3, respectively. Irrigation timing was split from one daily application during 2006 and 2007 to two daily applications during 2008 Average yield in T1 was 46.3 and 46.1 t ha^{-1} in 2006 and 2007, respectively. RDI treatments presented similar yield values to T1, with a water saving in T3 of 94 and 144 mm in 2006 and 2007. However, in 2008 T3 treatment showed a yield reduction with respect to T2 of 13 t ha^{-1}. The maximum yield was achieved in treatment T2 (52.6 t ha^{-1}) and the minimum in treatment T3 (39.3 t ha^{-1}) with a water difference of 54 mm. Berry cracking was greater than 10% in 2006 and 2007 without differences between treatments, while it was negligible in 2008. This result suggests that the change in irrigation timing performed in 2008 could have a beneficial effect in berry cracking since two irrigation applications were performed in that year, one at night and the other one at noon. However the results are not conclusive.

Additional key words: berry cracking; fruit quality; light interception; seedless grape; soil ground cover; *Vitis vinifera* L.; water stress.

Resumen

Respuesta del cultivar 'Autumn Royal' de uva de mesa a un riego deficitario controlado en la fase de postenvero

Desde 2006 a 2008 se realizó un ensayo de campo para conocer el efecto del RDI aplicado en postenvero en la producción y calidad de la uva de mesa apirena 'Autumn Royal', especialmente en el rajado de la baya. Se aplicaron tres tratamientos de riego: un control (T1), que recibió un 100% de las necesidades de riego netas (NIR), y dos tratamientos RDI (T2 y T3) regados como el T1 excepto en la fase desde envero a cosecha, que recibieron el 80 y 60% de las NIR (T2 y T3). La aplicación de riego varió de un riego diario en 2006 y 2007 a dos en 2008. Los valores medios de producción de T1 en 2006 y 2007 fueron de 46 t ha^{-1}. Los tratamientos RDI fueron muy similares al control, con un ahorro de agua de T3 frente a T1 de 94 mm en 2006 y 144 mm en 2007. No obstante, en 2008 el tratamiento T3 tuvo una reducción en la producción respecto a T2 de 13 t ha^{-1}, con la máxima producción en T2 (52,6 t ha^{-1}), y una diferencia en el riego de 54 mm. No hubo efecto significativo en el rajado de las bayas, siendo superior al 10% en 2006 y 2007 mientras que fue inapreciable en 2008. Estos resultados pueden deberse al cambio en el momento de aplicación del riego, pues en 2008 se aplicaron dos riegos, uno por la noche y otro a mediodía solar. Sin embargo estos resultados no son concluyentes.

Palabras clave adicionales: calidad del fruto; estrés hídrico; rajado de baya; suelo sombreado; uva apirena; *Vitis vinifera* L.

* Corresponding author: oblanco@aragon.es
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Abbreviations used: ECe (electrical conductivity of a saturated soil extract), ETc (crop evapotranspiration), ET_0 (reference evapotranspiration), FDR (frequency domain reflectometry), Kc (crop coefficient), NIR (net irrigation requirements), RDI (regulated deficit irrigation), SAR (sodium adsorption ratio), TCSA (trunk cross sectional area), θv (soil volumetric water content).

Introduction

In 2007 the vineyard surface for table grape production in Spain covered an extension of 19,445 ha, with a production of 264,407 t, whereas the vineyard surface for wine production was 1,109,195 ha with a production of 5,698,942 t of grapes (MARM, 2008). Most of the table grape production is located in Valencia, Murcia and Andalucia, with 96% of Spain's table grape surface. In Aragón, table grape production is not widely introduced, though some commercial vineyards are achieving very high yields and very high quality. The success of the introduction of this crop in new irrigation areas in this region seems to be due to the use of new cultivars, favourable climatic conditions and low incidence of pests and diseases.

There are many studies which show that water stress in vines promote changes in vegetative growth, yield and grape quality. The effect of water stress in grape cultivars especially depends on the timing of the growth cycle in which it is applied and on the intensity and duration of the stress. For the last two decades, regulated deficit irrigation (RDI) has been successfully used in orchards (Ebel and Proebsting, 1993; Renquist *et al*., 1994; Caspari *et al*., 1994, 1996; Sánchez Blanco and Torrecillas, 1995; Boland *et al*., 2000a,b; Mpelasoka and Behboudian, 2002; Romero *et al*., 2004; Fereres and Soriano, 2007). In vineyards, RDI techniques have been especially used in wine grapes, applying a reduction in irrigation in the phase of maturation in order to maintain yield and improve the quality of the grape juice (Ferreyra *et al*., 2004; Chalmers *et al*., 2004, 2008). Williams and Araujo (2002) studied the leaf water status on Chardonnay and Cabernet wine varieties under different irrigation treatments. They found good correlation between the midday leaf water potential, stem water potential and the depth of water in the soil profile. Keller (2004) found that RDI in combination with low application of nitrogen, affects the quality of the berries in wine varieties. Keller *et al*. (2008) studied the interaction of RDI and crop load in Cabernet grapevines. They found minor effects of RDI in the yield but a high effect of the cluster thinning with a yield reduction of 35%. No interactive effects of RDI and crop load were found.

RDI studies on table grape are limited. Araujo *et al*. (1995a,b) compared the soil water extraction, growth and water use efficiency of young table grape cv. 'Thompson seedless' under drip and furrow irrigation. The authors found similar values of irrigation efficiencies, shoot growth of the vines and water use efficiency in both irrigation systems. However, their results indicated that the drip irrigation system had a higher potential to control vine growth with variable application of water and nitrogen. El-Ansari *et al*. (2005) studied the effects of post-veraison RDI in the quality of table grapes cv. 'Muscat of Alexandria'. Their results showed that the severe RDI decreased firmness and acidity and increased total soluble solids of the berries. In an experiment with the table grape cultivar 'Danlas' under different irrigation regimes, Ezzahouani and Williams (2007) found that the highest yield and berry weights were obtained in the most irrigated treatment and no significant differences were observed in berry acidity between treatments. One aspect that should be considered is that berry quality variables of table grape differ from the wine grapes. In table grape varieties the berry size, firmness, colour, acidity and total dissolved solids are important variables as shown by Williams *et al*. (2010). Table grape RDI studies in different regions are required to better understand its advantages and limitations.

Autumn Royal is a seedless table grape cultivar with a high commercial value, with a big berry, purple-black to black in colour that matures around mid-September in the lower part of the Ebro Valley in Aragón. This cultivar is susceptible to berry cracking, which is a serious problem because it increases the labour required since the bunches need to be cleaned during the maturation phase until the harvest. At harvest, the cracked berries also must be manually removed to avoid bunch rot. Several authors have studied this problem in different table grape varieties, although due to its complexity a definitive solution to solve this problem has not been reached (Considine and Kriedemanm, 1972; Matthews *et al.*, 1987). Another problem in this cultivar is the weak attachment of the berries to the rachis, so bunches must be very carefully handled in order to avoid the berry loosening (Dokoozlian *et al.*, 2000).

The aim of this trial is to ascertain the effect of two strategies of RDI applied from veraison to harvest on the yield and berry quality of table grape Autumn Royal cultivar, especially with regard to berry cracking.

Material and methods

A field experiment was carried out from 2006 to 2008 in a four-year-old table grape vineyard, located in the Santa Barbara commercial orchard of the ALM

Group, in the county of Caspe (Zaragoza, Spain) (41.16°N, 0.01°W). The vineyard is located in a plot of 4 ha with a general slope of the terrain of 1%. The soil of the plot has been developed upon colluvial deposits of higher river terraces. It is deep, properly drained, with quite coarse textures, a considerable percentage of stones, with a high calcium carbonate content (> 40%) that sometimes limits the development of roots, with no sodicity (SAR = 2.4) and slightly salty (Electrical conductivity, ECe < 4 dS m^{-1}) (Soil Survey Division Staff, 1993). The soil is classified as a Xeric calcigypsid, coarse loamy, mixed (gypsic), thermic (Soil Survey Staff, 1999, 2006).

Climatic characterization of the three experimental years was performed using the data from the Caspe meteorological station from the SIAR net (National Net of Agrometeorological Stations for Irrigation). The UTM coordinates of the station are: altitude 175 m, UTMX 745309 and UTMY 4576848 (41.19°N, 0.05°W). The annual values of reference evapotranspiration (ET_0) were 1,525, 1,455 and 1,388 mm in 2006, 2007 and 2008, respectively. The annual values of rainfall were 248, 259 and 355 mm in 2006, 2007 and 2008, respectively. The climate is arid with an average mean annual temperature of 15.2°C, high maximum summer temperatures (37.2°C from June to September for the three years), low summer precipitation (73 mm from June to September for the three years), and high summer ET_0 (810 mm from June to September for the three years). From January to March the rainfall values were 177, 190 and 191 mm in 2006, 2007 and 2008, respectively (Fig. 1).

The vineyard consisted of cv. 'Autumn Royal' grafted on Richter 110 rootstock planted at a distance of 2.5 m between vines and 3.5 m between rows. The vineyard is irrigated with a drip irrigation system with one lateral in each row of vines with integrated self compensating emitters of a discharge of 2.2 L h^{-1}, spaced 0.5 m. During the irrigation seasons of 2006 and 2007 irrigations were applied once each night. In 2008 the irrigation timing was changed from a single night application to two irrigation events, one at noon and a second one after midnight.

The vineyard is cultivated as a Spanish horizontal trellis system, with vertical metallic posts which holds a wire net located at 2.2 m, where the vine canopy develops. The trellis system is covered with a clear screen (Criado and López, Almería, Spain) above the ground level for crop protection at a height of 2.5 to 3.0 m. The reduction of solar radiation of this clear screen was measured in the field and resulted in a value of 15%. The vineyard was managed according to the usual cultural practice in the farm. Bunch pruning was performed just after fruit set in order to obtain a uniform bunch load per vine. The initial trunk cross sectional area (TCSA, cm^2) was calculated from the perimeter measurements at the beginning of the experiment in 2006 to check that the initial vines conditions were not different. No differences among treatments and replicates were found. The final TCSA was also calculated at the end of 2008 to check differences in vegetative growth.

To study the effect of different levels of irrigation water, three irrigation treatments, based upon a percentage of the net irrigation requirements (NIR = K_c*ET_0 – Effective rainfall) from veraison till harvest, have been applied: a control (T1), irrigated at 100% of the NIR and two RDI treatments (T2 and T3), irrigated as T1 during all irrigation season, except during the postveraison till harvest period when diffe-

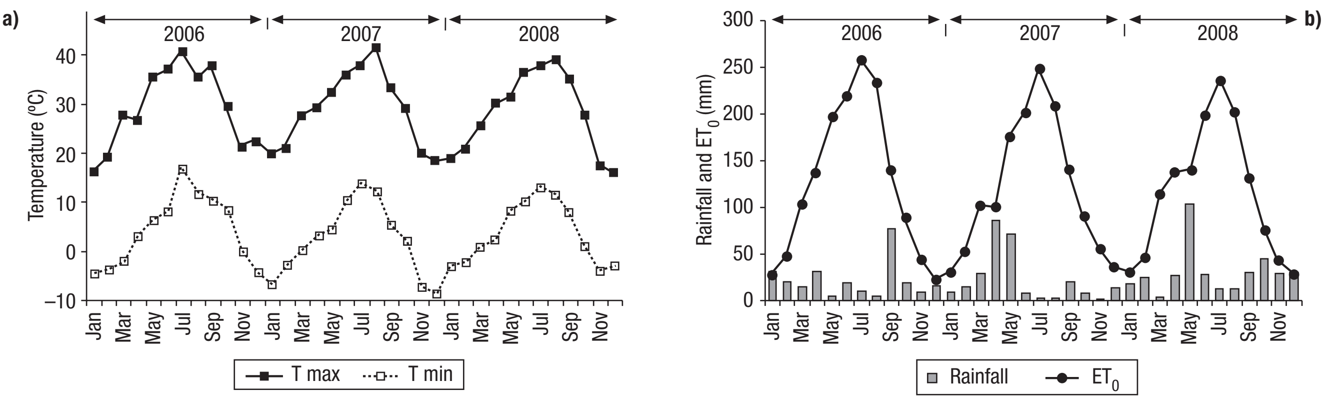

Figure 1. Monthly mean values of the meteorological variables during the three study years. Maximum and minimum air temperatures (a) and rainfall and Penman Monteith ET_0 values (b).

rent percentages of NIR were applied, 80% and 60% NIR in T2 and T3, respectively. Daily crop evapotranspiration values (ETc) were determined using the ET_0 calculated with the Penman Monteith equation, with data from the SIAR meteorological station located in Caspe and the Kc values obtained from FAO's methodology calculations (Allen *et al*., 1998).

The experimental design was a randomized block with three replications. The experimental unit was a plot of 15 vines: three adjacent rows of 5 vines each. The three central vines of the central row were used for sampling and data recording. To apply the different irrigation treatments, drip lines of treatments T2 and T3 were changed from veraison to harvest. Laterals with 1.6 L h^{-1} integrated self compensating emitters, spaced 0.45 m, were used in treatment T2 and laterals with 1.6 L h^{-1} integrated self compensating emitters, spaced 0.6 m, were used in treatment T3. Accordingly, for the same irrigation timing, the three treatments were applied. Volumetric water meters were installed to record the amount of water applied.

Soil volumetric water content (θv) was measured at 0.1, 0.2, 0.3 and 0.5 m depth with a frequency domain reflectometry (FDR) probe (Enviroscan, Sentek, Pty Ltd. South Australia). Two probes per treatment were installed in the row of vines in two sites. Since the emitters were installed at different short distances to create a homogeneous wetted band along the lines of vines, two FDR probes were installed at 0.5 and 1.25 m from the central vine to obtain a mean value of the soil water content in each treatment. Hourly readings of the 24 sensors of the FDR permanent probes were stored in a datalogger. The six access tubes that contain the FDR probes were vertically inserted in the soil by drilling a hole of a bigger diameter than that of the access tube because of the high gravel content of the soil. To avoid air gaps and ensure a good contact between the access tubes and the soil around it, the space between the access tube and the soil was filled with soil slurry.

Different vegetative variables, such as phenology by visual observation (Baggiolini, 1952; Coombe, 1995), and canopy cover evolution by digital photography have also been controlled. Pictures were taken with a digital camera (Olympus, model µ810, China) placing the camera on the ground and focused upwards to a quarter of the whole spacing of a vine (1.25 × 1.75 m). The images were processed with the GIMP program (available at www.gimp.org), by selecting exactly the quarter of the vine area. The program transforms the picture into black (leaves and branches) and white (clear screen) pixels. The histogram of the black and white pixels was calculated, giving a value of the percentage of the black pixels which represents the shaded ground cover.

In the autumn season, each vine of the experimental unit was individually harvested, counting the number of bunches and weighing the total yield. The harvest was performed in one pick in 2006 and 2008 and two picks in 2007. A subsample of two bunches per vine was processed in the laboratory for different measurements. To calculate the percentage of cracking, the cracked and healthy berries of each subsample were counted and weighted. Firmness (Durofel, Agro Technology, France), weight and size (longitudinal and equatorial diameter) were measured in a subsample of 20 berries. Total soluble solids content (pocket refractometer PAL-1, Atago, Japan), titratable acidity (tartaric acid g L^{-1}) and pH of the grapes' juice were measured.

Statistical analyses were performed using Analysis of Variance (ANOVA) and General Linear Model (GLM) procedure of the SAS 9.1 software (SAS Institute, 2004). Multiple comparisons among treatments were performed using Duncan test at $p = 0.05$.

Results

During the three study years irrigation was applied daily from April to October. The maximum depths of irrigation water were applied in treatment T1 with seasonal values of 562, 877 and 808 mm in 2006, 2007 and 2008, respectively. The amounts of water applied in 2007 and 2008 were around 200 mm higher than in 2006 (Table 1). Soil water recharge at the beginning of the irrigation season in 2006 was an important source of water due to rainfall in the winter of 2006. Rainfall from April to September was 143, 186 and 209 mm in 2006, 2007 and 2008, respectively.

Differential irrigation in treatments T2 and T3 started in the veraison phase that occurred on July 19^{th} 2006, August 7^{th} 2007 and August 7^{th} 2008 and lasted till grape harvest, which was performed at the same date in the three treatments each year. Harvest was performed on September 20^{th} 2006, October 2^{nd} 2007, and September 18^{th} 2008.

The reduction of irrigation water in treatments T2 and T3 did not show a clear reduction in the soil water storage from the dates of irrigation reduction until the date of harvest. The results of soil water content (θv)

Table 1. Irrigation amounts (mm) from berry veraison to harvest (RDI period) and seasonal values (Total) from April to September in the three experimental years

	2006		2007		2008	
	RDI period[1]	Total	RDI period[2]	Total	RDI period[3]	Total
T1	237	562	367	877	268	808
T2	192	516	296	807	217	756
T3	144	468	222	733	163	702

[1] From 19 Jul to 20 Sep. [2] From 07 Aug to 02 Oct. [3] From 07 Aug to 18 Sep.

Table 2. Monthly average values of the daily soil water storage (mm), measured with FDR probes, in the first 0.5 m of the soil profile in the three irrigation treatments from July to September during the three study years

	2006			2007			2008		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
July	142.5	140.2	135.9	163.1	173.3	201.8	167.3	173.9	190.1
August	148.6	161.5	145.1	170.7	181.1	188.4	175.8	184.2	198.8
September	167.7	195.3	178.5	172.8	183.9	205.2	168.9	181.8	203.7

stored in the first 0.5 m of the profile did not show an effect of the RDI treatments during the three experimental years (Table 2). However soil water storage increased in all the treatments from 2006 to 2007 and 2008, which is consistent with the increase in the irrigation doses (Tables 1 and 2). Figure 2 presents the evolution of the water depth stored in the soil profile from 0 to 0.5 m in the three irrigation treatments during the months of July, August and September of 2006. Each line of the figure is the average of the two FDR probes of each treatment located by the drip line. The high increase in the soil water storage that occurred in the three treatments on 13 September of 2006 was due to heavy rainfall on that date.

Vegetative growth was almost the same during the three study years for the three treatments. The canopy cover values in veraison, in the three treatments and in the three study years, were very similar and no significant differences were found (Table 3). In all cases the values of canopy cover were higher than 81%. Canopy cover would probably have reached a 100% but usual management practices include pruning the shoots apex in the central area of the vine rows in order to increase light penetration to the lower areas of the vine canopy and bunches. The trunk cross sectional area (TCSA) at the beginning of 2006 and at the end of the experiment in 2008 in the different treatments were not significantly different (Table 4).

In 2006 and 2007 no significant effect of the irrigation treatments in grape yields were found (Table 4). The grape production in all treatments in these years was higher than 46 t ha^{-1}, which may be considered very high for this kind of vineyard system. In 2007, there was an early pick in September 26th that was estimated in 7 kg vine^{-1} and, therefore, this value was added to the final pick. The number of bunches per vine and bunch mean weight in 2006 and 2007 were not affected by the irrigation treatments (Table 5). The mean values for the three treatments for these two years were: 62.4 bunches vine^{-1}, and 0.64 kg bunch^{-1} in 2006 and 49.8 bunches vine^{-1} and 0.81 kg bunch^{-1} in 2007. The high variability in the productive variables has contributed to the lack of significant effect of the irrigation treatments among these variables between treatments in 2006 and 2007.

On the other hand, in 2008 significant differences were found, with greater yield in T2 (46.0 kg vine^{-1}) compared to T1 (37.1 kg vine^{-1}) and T3 (34.4 kg vine^{-1}). The number of bunches per vine was also higher in T2 (56.0) than in T3 (43.0). No significant

Table 3. Mean values of percentage soil shading by the vines (%), at the berry veraison phase in the three irrigation treatments during the three study years

Treatment	2006	2007	2008
T1	83.3	85.8	88.7
T2	83.4	89.3	84.8
T3	81.1	89.3	90.3

No significant effect ($p \leq 0.05$).

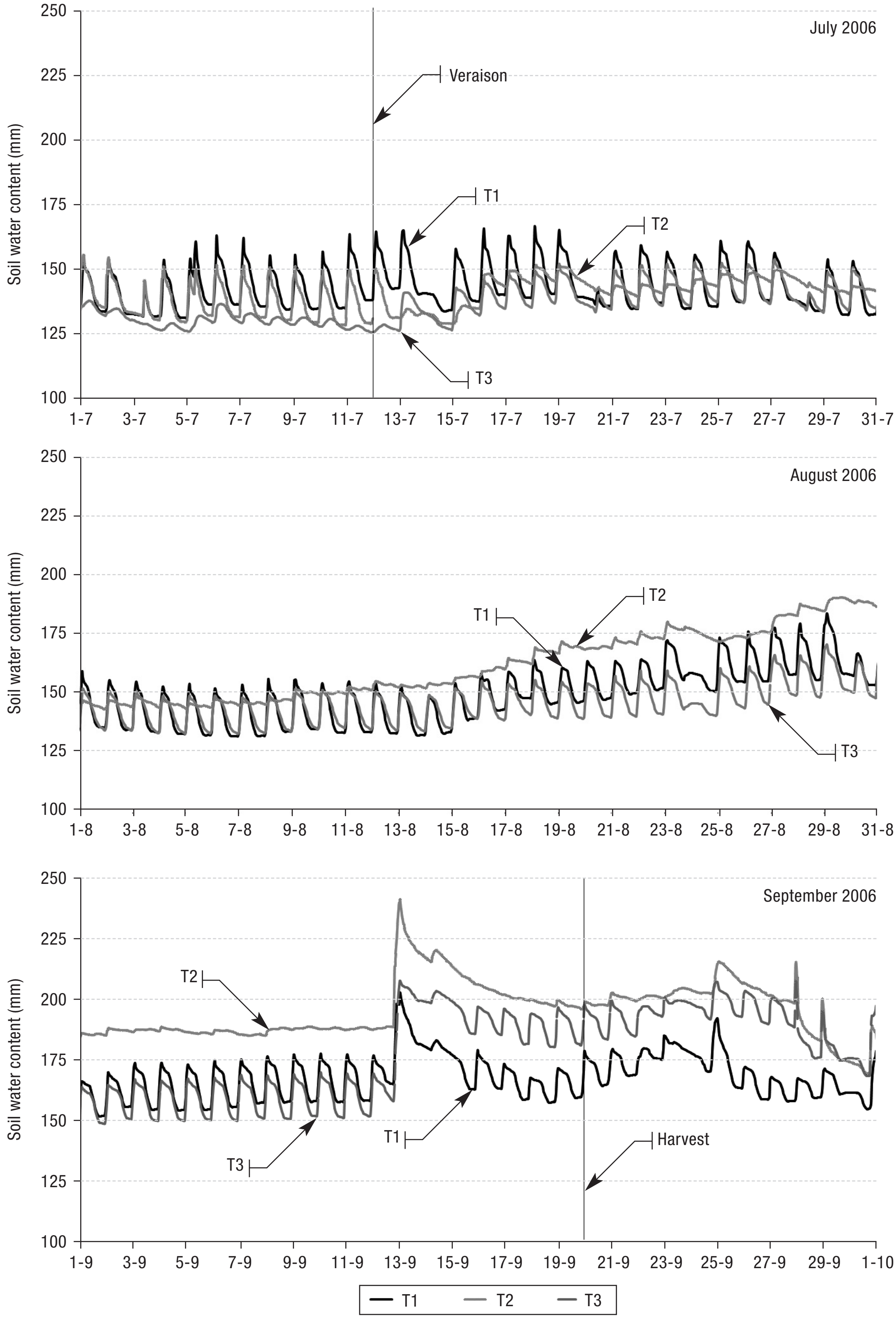

Figure 2. Evolution of the water storage (mm) accumulated in the soil profile from 0 to 0.5 m depth in the three irrigation treatments during the months of July, August and September of 2006. Each line is the average of the two FDR probes installed in each treatment.

Table 4. Mean values of the initial and final trunk cross sectional area, annual grape yield, and accumulated productivity in the three irrigation treatments during the three study years

	TCSA (cm^2)		Annual grape yield (kg $vine^{-1}$)			Accumulated productivity ($kg\ cm^{-2}$ TCSA)
	Initial[1]	Final[1]	2006[1]	2007[1,2]	2008	
T1	11.71	29.1	34.9	36.8	37.1[b]	10.1[b]
T2	11.73	32.9	50.6	41.8	46.0[a]	13.0[a]
T3	11.70	31.3	36.1	42.4	34.4[b]	10.3[b]

[1] No significant effect ($p \leq 0.05$). [2] An estimated amount of 7 kg $vine^{-1}$, from an early pick, has been added. [3] Within columns, values followed by the same letter are not significantly different at $p \leq 0.05$

differences were observed in mean bunch weight averaging 0.78 kg per bunch (Table 5). The accumulated productivity ($kg\ cm^{-2}$ TCSA) during the three years of the study was determined and significant differences between treatments were found, with the highest value for T2 (13.0 $kg\ cm^{-2}$), 3 $kg\ cm^{-2}$ higher than T1 and T3 (Table 4).

Nevertheless, the grape quality variables (Tables 6 and 7) were very similar throughout the three study years, and showed no significant differences among treatments in terms of size, weight, firmness, soluble solids content, juice acidity and pH. In addition, in 2008 the berries at harvest had greater acidity and soluble solids content than in the preceding years due to a delay in the ripening that year. The mean soluble solids content values were 18.0, 16.3 and 15.3°Brix in 2006, 2007 and 2008, respectively. The mean total acid content was 2.7 tartaric acid g L^{-1} in 2006 and 2007, and 3.7 tartaric acid g L^{-1} in 2008. The berry cracking percentage was between 13% and 17% in 2006 and 2007, respectively, whereas it was almost negligible in 2008. This fact may be due to the change in the irrigation application.

Table 5. Mean number of bunches per vine and bunch mean weight in the three irrigation treatments during the three study years

	Treatment	2006[1]	2007[1,2]	2008
No. bunches $vine^{-1}$	T1	58.0	47.3	49.2[ab]
	T2	71.2	54.0	56.0[a]
	T3	58.1	48.2	43.0[b]
Bunch mean weight (kg)	T1	0.60	0.78	0.74[a]
	T2	0.70	0.77	0.83[a]
	T3	0.62	0.88	0.79[a]

[1] No significant effect ($p \leq 0.05$). [2] An estimated amount of 10 bunches $vine^{-1}$, from an early pick, has been added. [3] Within columns, values followed by the same letter are not significantly different at $p \leq 0.05$.

Discussion

Regulated deficit irrigation (RDI) is successful in improving crop yield quality and reducing water use when water availability is a problem, as many studies have proved (Ebel and Proebsting, 1993; Boland *et al.*, 2000a,b; Mpelasoka and Behboudian, 2002; Romero *et al.*, 2004; Fereres and Soriano, 2007). Most of the studies have been focused on peaches, apple trees and other deciduous horticultural species, but very few on table grapes.

The results achieved in 2006 and 2007 showed that the water irrigation reduction applied in the most restricted treatment (T3) did not create a soil moisture deficit big enough to decrease the productive variables of the vines. The most restricted irrigation treatment

Table 6. Grape quality variables: berry cracking, firmness, juice's soluble solids content, titratable acidity and pH in the three irrigation treatments during the three study years

	Treatment	2006[1]	2007[1]	2008
Berry cracking (%)	T1	10.4	14.7	Insig.[2]
	T2	13.4	15.0	Insig.
	T3	15.2	21.4	Insig.
Firmness (%)	T1	85.6	80.3	78.9
	T2	86.1	80.6	77.1
	T3	83.7	81.1	82.9
Soluble solids content (°Brix)	T1	19.0	16.5	15.5
	T2	17.1	16.3	14.8
	T3	18.0	16.3	15.6
Acidity (g L^{-1})	T1	2.8	2.7	3.8
	T2	2.8	2.8	3.6
	T3	2.6	2.7	3.7
pH	T1	4.0	3.7	3.8
	T2	4.0	3.6	3.8
	T3	4.1	3.7	3.9

[1] No significant effect ($p \leq 0.05$). [2] Insig.: negligible berry cracking values.

Table 7. Berry dimension variables: volume, weight, longitudinal and equatorial diameter in the three irrigation treatments during the three study years

	Treatment	2006[1]	2007[1]	2008[1]
Volume (mL)	T1	6.39	6.04	6.11
	T2	6.44	6.49	6.39
	T3	6.94	6.26	6.22
Weight (g)	T1	7.0	6.3	6.5
	T2	6.9	6.8	6.9
	T3	7.3	6.6	6.6
Longitudinal diameter (mm)	T1	29.5	26.2	25.5
	T2	29.6	27.2	26.4
	T3	29.4	28.1	26.3
Equatorial diameter (mm)	T1	19.7	19.8	20.1
	T2	19.5	29.8	20.2
	T3	20.1	20.1	20.0

[1] No significant effect ($p \leq 0.05$).

when compared to the control treatment resulted in a water saving of 93 mm in 2006 and 144 mm in 2007. These values represent a water saving of around 16% of the total irrigation depth in both years. On the other hand, in 2008 RDI significantly affected the grape production: T2 was the most productive treatment with 52 mm less irrigation than T1 and 54 mm more than T3. The water saving in T2 in relation to T1 was only 6%. The better behavior of T2 is also confirmed by the significantly highest accumulated productivity value (kg cm^{-2} TCSA) during the three years of the study obtained in this treatment. Nevertheless, other non-controlled agronomical factors could have affected these results.

The soil moisture data presented in Table 2 and Figure 2 do not explain the soil water regime of the different treatments in the experiment. In theory the T1 treatment soil moisture should be higher than RDI treatments from veraison to harvest since T1 received the highest amount of irrigation water. However, the control treatment (T1) had lower soil moisture storage than RDI treatment from July to September. Daily data of soil moisture storage in this period in 2006 showed that the control treatment (T1) had similar values than RDI treatments (T2 and T3) in veraison but at harvest T1 showed lower values than T2 and T3. Soil moisture data did not explain the different irrigation regimen of the different treatments in our experiment. In addition, isolated stem water potential values, measured from veraison to harvest, did not show any significant differences between irrigation treatments. Williams *et al.* (2010) working with the table grape cultivar 'Thompson seedless' found a high range of midday leaf water potential in their irrigation treatments. They also found a good relation of midday leaf water potential measured in veraison and harvest with the berry weight. However in our results we found similar values of stem water potential (data not shown).

The water stress applied to the vines in the RDI treatments has not been enough to affect the water status of the plants and the berry quality in the three irrigation treatments. Among these quality variables, berry cracking is an important and expensive problem when growing high quality fruit, especially table grapes. This problem is generally attributed to a sudden increase in water supply, although the lack of calcium in the fruit has also been pointed out as its cause (Opara *et al.*, 1997). This was the reason for reducing the water amount at the postveraison phase in RDI treatments. In our study, the 'Autumn Royal' cultivar showed high berry cracking levels in 2006 and 2007 (between 14% and 17% of the berries were affected), whereas in 2008, the level of damage was negligible. The differences in the irrigation regime in 2008 with two irrigation applications per day in relation to one daily application in 2006 and 2007 can explain the differences in berry cracking results in 2008. These results support the idea that frequent water applications to the 'Autumn Royal' vines eases this problem, while sudden supplies of great amounts of water increases its development. The water application at daytime might have improved the water supply to the berries at the moment of maximum evaporative demand since one of the two irrigation application in 2008 was made at noon. However the effect of the split irrigation on berry cracking is not still clear. With our results it has not been possible to link the berry cracking intensity to the amount of water supply in irrigation.

The overall results during the three study years showed that table grape growing, using the Spanish trellis system, under the arid conditions of the Middle Ebro Valley, is economically feasible. High grape yields of very good quality are obtained and irrigation can be partly reduced at postveraison without affecting grape yield and quality.

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References

ALLEN R.G., PEREIRA L.S., RAES D., SMITH M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. Irrig and Drain Paper 56. FAO, Roma, Italy.

ARAUJO F., WILLIAMS L.E., GRIMES D.W., MATTHEWS M.A.,1995a. A comparative-study of young 'Thompson Seedless' grapevines under drip and furrow irrigation .I. Root and soil water distributions. Sci Hortic 60 (3-4), 235-249.

ARAUJO F., WILLIAMS L.E., MATTHEWS M.A., 1995b. A comparative study of young 'Thompson Seedless' grapevines (*Vitis vinifera* L.) under drip and furrow irrigation. II. Growth, water use efficiency and nitrogen partitioning. Sci Hortic 60(3-4), 251-265.

BAGGIOLINI M., 1952. Les stades repères dans le développement annuel de la vigne et leur utilisation pratique. Rev Romande Agric Vitic Arboric 8, 4-6.

BOLAND A.M., JERIE P.H., MITCHELL P.D., GOODWIN J., 2000a. Long-term effects of restricted root volume and regulated deficit irrigation on peach: I. Growth and mineral nutrition. J Am Soc Hortic Sci 125(1), 135–142.

BOLAND A.M., JERIE P.H., MITCHELL P.D., GOODWIN J., 2000b. Long-term effects of restricted root volume and regulated deficit irrigation on peach: II. Productivity and water use. J Am Soc Hortic Sci 125(1), 143-148.

CASPARI H.W., BEHBOUDIAN M.H., CHALMERS D.J., 1994. Water-use, growth, and fruit yield of 'Hosui' Asian pears under deficit irrigation. J Am Soc Hortic Sci 119(3), 383-388.

CASPARI H.W., BEHBOUDIAN M.H, CHALMERS D.J., CLOTHIER B.E., LENZ F., 1996. Fruit characteristics of 'Hosui' Asian pears after deficit irrigation. Hortscience 31(1), 162-162.

CHALMERS Y.M., KELLY G., KRSTIC M.P., 2004. Partial rootzone drying of *Vitis vinifera* cv. 'Shiraz' winegrapes in a semi-arid climate. Acta Hort (ISHS) 664, 133-138.

CHALMERS Y.M., KRSTIC M.P., DOWNEY M.O., LOVEYS B.R., DRY P.R., 2008. Impacts of sustained deficit irrigation on quality attributes and flavonoid composition of 'Shiraz' grapes and wine. Acta Hort (ISHS) 792, 163-169

CONSIDINE J.A., KRIEDEMANM P.E., 1972. Fruit splitting in grapes: determination of the critical turgor pressure. Aust J Agric Res 23, 17-24.

COOMBE B.G., 1995. Growth stages of the grapevine. Aust J Grape Wine Res 1, 100-110.

DOKOOZLIAN N., PEACOCK B., LUVISI D., VASQUES S., 2000. Cultural practices for 'Autumn Royal' table grapes. Pub TB17-00. Cooperative Extension. Tulare County. University of California. 3 pp.

EBEL R.C., PROEBSTING E.L., 1993. Regulated deficit irrigation may alter apple maturity, quality, and storage life. Hortscience 28(2), 141-143.

EL-ANSARI D.O., NAKAYAMA S., HIRANO K., OKAMOTO G., 2005. Response of 'Muscat' table grapes to post-veraison regulated deficit irrigation in Japan. Vitis 44(1), 5-9.

EZZAHOUANI A., WILLIAMS L.E., 2007. Effect of irrigation amount and preharvest irrigation cutoff date on vine water status and productivity of 'Danlas' grapevines. Am J Enol Vitic 58, 333-340.

FERERES E., SORIANO M.A., 2007. Deficit irrigation for reducing agricultural water use. J Exp Bot 58(2), 147-159.

FERREYRA R., SELLES G., PERALTA J., VALENZUELA J., 2004. Effect of water stress applied at different development periods of 'Cabernet Sauvignon' grapevine on production and wine quality. Acta Hort (ISHS) 646, 27-33.

KELLER M., 2004. Deficit irrigation and vine mineral nutrition. J Am Soc Hortic Sci 56(3), 267-283.

KELLER M., SMITHYMAN R.P., MILLS L.J., 2008. Interactive effects of deficit irrigation and crop load on 'Cabernet Sauvignon' in an arid climate. Am J Enol Vitic 59(3), 221-234.

MARM, 2008. Anuario de estadística agroalimentaria y pesquera. Ministry of the Environment and Rural and Marine Affairs. Madrid, Spain. 908 pp. [In Spanish].

MATTHEWS M.A., CHENG G., WEINBAUM S.A., 1987. Changes in water potential and dermal extensitivity during grape berry development. J Am Soc Hortic Sci 112(2), 314-319.

MPELASOKA B.S., BEHBOUDIAN M.H., 2002. Production of aroma volatiles in response to deficit irrigation and to crop load in relation to fruit maturity for 'Braeburn' apple. Postharvest Biol Technol 24, 1-11.

OPARA L.U., STUDMAN C.J., BANKS N.H., 1997. Fruit skin splitting and cracking. Horticultural Reviews 19, 217-262.

RENQUIST A.R., CASPARI H.W., BEHBOUDIAN M.H., CHALMERS, D.J. 1994. Stomatal conductance of lysimeter-grown Asian pear trees before and during soil-moisture deficits. J Am Soc Hortic Sci 119, 1261-1264.

ROMERO P., BOTIA P., GARCÍA F., 2004. Effects of regulated deficit irrigation under subsurface drip irrigation conditions on vegetative development and yield of mature almond trees. Plant Soil 260, 169-181.

SÁNCHEZ BLANCO M.J., TORRECILLAS A., 1995. Aspectos relacionados con la utilización de estrategias de riego deficitario controlado en cultivos leñosos. In: Riego deficitario controlado (Zapata M., Segura P., ed). Mundi-Prensa. pp. 43-66. [In Spanish].

SAS INSTITUTE, 2004. SAS/STAT user's guide release. Release 9.0. Statistical Analysis Institute, Cary, NC.

SOIL SURVEY DIVISION STAFF, 1993. Soil survey manual. Natural Resources Conservation Service, Handb 18. USDA, Washington, DC.

SOIL SURVEY STAFF, 1999. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys, 2nd ed. USDA-Natural Resources Conservation Service, Washington, DC. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/tax.pdf.

SOIL SURVEY STAFF, 2006. Keys to soil taxonomy, 10th ed. USDA-NRCS, Washington, DC. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/keys/keys.pdf.

WILLIAMS L.E., ARAUJO F.J., 2002. Correlations among predawn leaf, midday leaf, and midday stem water potential and their correlations with other measures of soil and plant water status in *Vitis Vinifera*. J Am Soc Hortic Sci 127(3), 448-454.

WILLIAMS L.E., GRIMES D.W., PHENE C.J., 2010. The effects of applied water at various fractions of measured evapotranspiration on reproductive growth and waterproductivity of 'Thompson Seedless' grapevines. Irrig Sci 28(3), 233-243.