Effect of post veraison regulated deficit irrigation in production and berry quality of Autumn Royal and Crimson table grape cultivars

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Abstract

A field experiment was performed in drip-irrigated two seedless table grape vineyards (Vitis vinifera L. cv. Autumn Royal and Crimson) from 2007 to 2009 in a semiarid area of north-eastern Spain to evaluate the effect of post veraison regulated deficit irrigation (RDI) on the grape yield and quality. The same experimental layout was used in both cultivars. Two RDI treatments were compared with a full irrigation treatment in both cultivars. The full irrigation treatment (T1) was irrigated at 100 % of the net irrigation requirements (NIR). The

RDI treatments (T2 and T3) were irrigated as T1 except from veraison until harvest, which received 80 % and 60 % of NIR, respectively. Average water saving in T3 was around 15 % of the seasonal water applied in the treatment T1 while this saving in T2 ranged between 6 to 8 %. Similar grape yields were obtained in the different irrigation treatments for the Autumn Royal cultivar during 2007 and 2009. However in 2008 the yield of T2 (46.0 kg vine^{-1}) was significantly higher than in T3 (34.4 kg vine^{-1}). For the Crimson cultivar, the grape yield of T3 was significantly lower than T2 in 2007 and 2008. In 2009 low grape yields were obtained in all treatments of the Crimson cultivar and no differences were observed between them. The quality parameters of the berry in both cultivars were not affected by the irrigation treatments. Berry cracking in Autumn was high in 2007 ranging from 14.7 to 21.4 % and very low in 2008 and 2009 ranging from 1.5 to 4.3 %. The reduction of berry cracking was attributed to the splitting of the irrigation dose in two applications per day, one at midday and the other one at night. Significant differences between irrigation treatments were observed in the CIELab color parameters of the berry skin in the Crimson cultivar. The overall results during the three study years showed that high grape yields of very good quality can be obtained with moderate regulated deficit irrigation in the post veraison phase without affecting grape quality in the Autumn and Crimson seedless cultivars in the arid conditions of the lower Ebro Valley in north-eastern Spain.

1. Introduction

In 2010 the vineyard surface for table grape production in Spain covered an extension of 16,000 ha, with a total grape production of 237,000 Mg, whereas the vineyard surface for wine production was 980,000 ha with a production of 5,900,000 Mg (MAAMA, 2011). About 94 % of the table grape production is located in the coastal areas of south of Spain. In the north of Spain, plantation of some commercial vineyards have been recently performed, they are achieving very high yields and with very high quality in some areas such as the lower Ebro river basin. The high productivity and quality of this crop in new irrigated areas in this region seems to be due to the use of new cultivars, favorable climatic conditions and low incidence of fungus diseases.

Many studies around the world have been performed on the effect of deficit irrigation (DI) on the response of crops. Recent reviews of literature agree to indicate that DI is a very useful tool to stabilize yields and increase water productivity in areas with water scarcity (Fereres and Soriano, 2007; Geerts and Raes, 2009; Ruiz-Sanchez et al., 2010). When irrigation water supply is limited, DI becomes a useful agronomic tool since water productivity should be the objective rather than the maximization of the yield per unit of area (Geerts and Raes, 2009). The term regulated deficit irrigation (RDI) is used when the DI is applied in the drought tolerant phenological stages of the crop that often are the early vegetative stages and the late maturation stages. For the last three decades, RDI has been successfully used in orchards of different fruit species such as peaches (Prunus persica) (Chalmers et al., 1981; Boland *et al*., 2000a,b; Girona et al., 2003; Lopez et al., 2008), apricot (Prunus armeniaca) (Ruiz-Sanchez et al., 2000, Perez-Sarmiento et al., 2010), plums (Prunus domestica) (Intrigliolo and Castel, 2005), cherries (Prunus avium) (Marsal et al., 2010), pears (Pyrus communis) (Marsal et al., 2002), almonds (Prunus amigdalus) (Romero *et al*., 2004; Goldhamer et al., 2006; Stewart et al., 2011), olive (Olea europaea) (Iniesta et al., 2009) and citrus (Citrus sinensis) (Garcia-Tejero et al., 2010; Ballester et a., 2013).

In wine vineyards, full irrigation is not recommended since it increases the berry size and this produces a decrease of the skin pulp ratio which is detrimental for the wine quality

(Ruiz-Sanchez et al., 2010). RDI techniques have been widely used in wine grapes (Acevedo-Opazo et al., 2010; Santesteban et al., 2011; Ortega-Farias et al., 2012). The general practice of RDI in vineyards consists in a reduction of irrigation in the pre veraison or post veraison phases in order to maintain yield and improve the quality of the must (Wade et al., 2004; Ferreyra *et al*., 2004; Chalmers *et al*., 2004). The veraison represents the transition between the berry growth to the berry ripening and it is characterized by a change in the color of the skin of the berries. Usually improvement of must quality is associated with increases of the pulp skin ratio, intensity of the color, anthocyanins and total soluble solids contents (Williams and Matthews, 1990).

In table grape vineyards usually full irrigation is recommended since maximum production and size of the berries is desired (Blanco et al., 2010). In table grape cultivars the berry size, firmness, sweetness and color are important variables as shown by Williams *et al*. (2010). These berry quality parameters differ from the wine quality parameters and therefore irrigation practices to optimize berry quality can be quite different. Deficit irrigation studies in table grape are very limited. However deficit irrigation can be of interest to improve some of the quality parameters of the berries such as color, total dissolved solids and aromas (El-Ansary et al. 2005).

El-Ansari *et al*. (2005) compared the effects of moderate (irrigation 2 days after soil water potential reached -15 kPa) and severe post veraison RDI (irrigation 4 days after soil water potential reached -15 kPa) with a control treatment (irrigation when soil water potential reached -15 kPa) on the quality of table grapes cv. ‘Muscat of Alexandria’. Their results showed that the moderate RDI had no effect on berry weight or juice quality at harvest. However the severe RDI decreased berry size, 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.

The cultivation of seedless table grape cultivars have increased considerably in the last decades since consumers of many countries appreciate very much the lack of seeds in the berries and the firmness and sweetness of these new varieties. Spain is the first European producer of seedless table grapes. Autumn Royal presents a high commercial value, with a big berry, purple-black to black in color that matures around mid-September in the lower Ebro river valley. This cultivar is susceptible to berry cracking, which is a serious problem because it increases the labor required since the clusters need to be cleaned during the maturation phase until the harvest. At harvest, the cracked berries also must be manually removed to avoid cluster 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 clusters must be very carefully handled in the harvest in order to avoid the berry loosening (Dokoozlian *et al.*, 2000).

Crimson is also a late-season red seedless table grape cultivar extensively cultivated in California and Europe. This variety has excellent eating characteristics; berry texture is firm and crisp, and its flavor is sweet and excellent. One of the main problems of this cultivar is the lack of color at harvest. It is critical that clusters be exposed to adequate sunlight during ripening for maximum fruit coloration. The lack of incident radiation in the clusters and the excessive crop loads delay maturity and decrease coloration. One extended practice to avoid this problem is the shoot thinning and the removal of basal leaves surrounding the clusters in order to increase the incidence of light in the clusters in the overhead trellis systems.

The aim of the study is to ascertain the effect of two levels of RDI applied from veraison to harvest on the yield and berry quality of table grapes Autumn Royal and Crimson cultivars. The hypothesis is that changes in irrigation management and the application of RDI in the post veraison phase can maintain yield and improve berry quality and specially decrease berry cracking in the Autumn cultivar and improve the skin color redness of the Crimson cultivar.

2. Material and methods

2. 1. Experiment description

The same field experiment was conducted in the Autumn Royal and Crimson plots of a commercial vineyard located in the Santa Barbara commercial orchard, in the county of Caspe (Zaragoza, Spain) (41.16 ºN, 0.01 ºW) during 2007, 2008 and 2009. Both table grape cultivars were grafted on Richter 110 rootstock (V. berlandieri x V. rupestris) planted at a distance of 2.5 m between vines and 3.5 m between rows. Row direction was northwest to southwest. The vines were planted in 2002 in a sandy loam soil. The vine rows were planted in an elevated soil levee around 0.3 m high and 1 m wide. The soil of the plots 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 %), with no sodicity (SAR = 2.4) and slightly saline (Electrical conductivity, ECe < 4 dS m^{-1}) (Soil Survey Division Staff, 1993). The soil is classified as a Xeric calcigypsic, coarse loamy, mixed (gypsic), thermic (Soil Survey Staff, 1999, 2006). The average values of soil field capacity and permanent wilting point in the 0-30 cm soil layer were 26 % and 10 % in gravimetric basis. The average soil bulk density was 1600 Kg m^{-3}. The vines were trained to an overhead Spanish horizontal trellis system, with vertical metallic stakes which holds a wire grid located at 2.2 m, where the vine canopy develops. The trellis system is covered with a white screen net made of high-density polyethylene (Criado and

Lopez, Almería, Spain) at a height of 2.5 to 3.0 m above the ground level for crop protection. This net was translucent with individual openings of 12 mm^2 (2.2 mm x 5.4 mm). The reduction of solar radiation of this net measured in the field was 15 % (Moratiel and Martínez-Cob, 2012). The vineyard was managed according to the usual cultural practice in the farm. Cluster pruning was performed just after fruit set in order to obtain a uniform bunch load per vine. The vineyard was 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 2007 irrigation season irrigations were applied daily at night. In 2008 and 2009 the irrigation timing was changed from a single night application to two irrigation events, one at noon and a second one after midnight. Each vine had four main branches and every winter the vines were pruned to maintain this structure. An additional summer pruning of the shoots in a strip 0.5 m wide between vine rows was performed around veraison to improve light penetration in the clusters. Soluble fertilizers were applied with the drip irrigation system.

Climatic characterization of the three experimental years was performed using the data from the automated agrometeorological station “El Suelto-Plano Espés” of the SIAR network (Spanish National Network of Agrometeorological Stations for Irrigation). The station is located in Caspe County at UTM coordinates: UTMX 745309, UTMY 4576848 (41.19º N, 0.05º W) and altitude of 175 m. This station records semi-hourly data of air temperature, air relative humidity, wind speed and direction, solar radiation and precipitation. An automated meteorological station was also installed in the vineyard in order to obtain precipitation data in the experimental plots.

Daily values of vineyard crop evapotranspiration (ET_c) for the three studied years were estimated multiplying the reference evapotranspiration (ET_0), computed using the FAO Penman-Monteith (Allen et al., 1998) by crop coefficients (Kc) adjusted for this particular vineyard. The daily meteorological data recorded at the “El Suelto-Plano Espés” station were used for estimation of ET_0. Seasonal curves of daily Kc were developed using the procedure described by Allen et al. (1998). First, the duration and dates of the different crop growth stages needed for the calculation of the Kc were determined from the soil ground cover data that was measured by digital photography along the crop cycle in the different treatments of both cultivars (Blanco et al., 2010). Secondly, tabulated vineyard crop coefficient values (Allen and Pereira, 2009) were adjusted for three characteristics: a) the precipitation and average ET_0 during the initial stage, and the averages of wind speed and minimum relative humidity recorded at the “El Suelto-Plano Espés” station during mid and end-season stages; and c) the effect of the plastic mesh in reducing ET_c using a net coefficient of 0.65 determined by Moratiel and Martínez-Cob (2012) in a vineyard neighbor to this experiment.

2.2. Experimental design and irrigation treatments

In each cultivar the experimental design was a randomized block with three replicates. The experimental unit was a subplot 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. Three irrigation treatments, based upon a percentage of the net irrigation requirements ($NIR = K_c*ET_0 - Rainfall$) 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 post veraison till harvest period when different percentages of NIR were applied, 80 % and 60 % of NIR in T2 and T3, respectively. In order to apply the differential irrigation treatments, the original drip laterals of treatments T2 and T3 were changed from veraison to harvest. In treatment T2 drip laterals with 1.6 L h^{-1} integrated self compensating emitters, spaced 0.45 m, were installed and in treatment T3 laterals with 1.6 L h^{-1} integrated self compensating emitters, spaced 0.6 m, were installed. In treatment T1 the original lateral drip lines with integrated self compensating emitters of 2.2 L

h^{-1}, spaced at 0.5 m were used. Irrigation duration was the same in all treatments but the differential irrigation was based in the lateral discharge. Volumetric water meters were installed to record the amount of water applied in each treatment.

2.3. Measurements

Soil volumetric water content (θv) was measured at 0.1, 0.2, 0.3, 0.5 and 0.8 m depth with a frequency domain reflectometry (FDR) probe (Enviroscan, Sentek Technologies, Pty Ltd., Stepney, S.A. 5069, South Australia). Two probes per treatment were installed in the row of vines at two sites in each treatment and cultivar. Since the emitters were installed at short distances to create a homogeneous wetted band along the lines of vines, two FDR probes were installed in the vine rows at 0.5 and 1.25 m from the central vine of the experimental unit to obtain a mean value of the soil water content in each treatment. Hourly readings of the 24 sensors of the FDR permanent probes in each table grape cultivar were stored in a datalogger. The six access tubes per cultivar that hold 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 stoniness 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. Hourly values of θv were taken during the three experimental years in both table grape cultivars.

The trunk perimeter was measured at 1 m above the soil surface at the beginning and end of the growing season in 2008 and 2009 in both cultivars. Data were used to determine the trunk cross section (TCS, cm^2) and the absolute and relative growth of the trunk vines.

Phenology by visual observation (Coombe, 1995), and canopy cover evolution using digital photography were determined. Photographs were taken with a digital camera Olympus, model μ810 (Olympus, Tokyo, Japan) placing the camera on the ground and focused upwards covering a quarter of the whole spacing of a vine (1.25 × 1.75 m). The images included the leaves (green color) and branches (brown color) against the white color of the net. The images were processed with the GIMP program (available at www.gimp.org), by selecting exactly a quarter of the vine area. The GIMP program was used to transform 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 represented the shaded ground cover.

During fall, the central three vines of each experimental unit in both cultivars were individually harvested, counting the number of clusters and weighing. A subsample of two clusters per vine was processed in the laboratory to control the berry quality parameters. Weight, size (longitudinal and equatorial diameter) and firmness (Durofel, Agro Technologie, 76440 Forges Les Eaux, France) were measured in a subsample of 20 berries. Total soluble solids content measured with a pocket refractometer model PAL-1 (Atago Co., LTD, Minato-Ku, Tokyo, Japan) pH and titratable acidity (tartaric acid g L^{-1}) of the grapes' juice were measured. To determine the percentage of berry cracking in the different irrigation treatments of the Autumn cultivar, two additional clusters were processed, separating and weighing the healthy and cracked berries. Color CIELab parameters were determined in a subsample of 20 berries per experimental unit in each treatment of the Crimson cultivar using a colorimeter Konica Minolta model CR-200 (Konica Minolta Inc., Tokyo, Japan). The CIELab is a very complete model to define the color that was developed by the French Commission Internationale de l'éclairage, hence its CIE initials. The model describes all the colors visible to the human eye. The model uses three coordinates: L* represents the lightness of the color (L* = 0 yields black and L* = 100 indicates white), a* represents its position between red/magenta and green (negative values indicate green while positive values indicate magenta) and b* represents its position between yellow and blue (negative values indicate blue and positive values indicate yellow). The CIELab model has been used widely to measure the color of different fruits including grapes (Carreno et al., 1996).

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 $P = 0.05$.

3. Results

Figure 1 presents the monthly values of precipitation recorded in the experimental vineyard, and air temperature and air relative humidity recorded in the automated agrometeorological station "El Suelto-Plano Espés" during the three study years. Precipitation is not evenly distributed along the year. Maximum monthly values of precipitation occurred in the spring months. Annual precipitation in the experimental plot was 274, 310 and 288 mm in 2007, 2008 and 2009, respectively. The average annual precipitation for the period between 2004 and 2011 in the automated agrometeorological station "El Suelto-Plano Espés" was 304 mm. Temperature regimes were very similar in the three study years. The average annual mean temperature was 14.9, 14.8 and 15.8 ºC in 2007, 2008 and 2009, respectively. The evolution of air relative humidity was also very similar in the three study years. An increase of the air relative humidity was observed in the months of April 2007, May 2008 and April 2009, corresponding with the maximum precipitation values.

The annual values of reference evapotranspiration (ET_0) were 1455, 1388 and 1502 mm in 2007, 2008 and 2009, respectively. Maximum monthly values of ET_0 occurred in July with values of 249, 236 and 252 mm in 2007, 2008 and 2009, respectively (Table 1). The seasonal values of the calculated vineyard evapotranspiration (ET_c) were almost the same in both cultivars. In the Autumn cultivar the seasonal ET_c varied between 890 mm in 2007 and

813 mm in 2009. In the Crimson cultivar the seasonal ET_c varied between 894 mm in 2007 and 842 mm in 2009 (Table 1).

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 varying between 808 mm in 2008 to 877 mm in 2007 in the Autumn cultivar and between 704 mm in 2008 and 855 mm in 2007 in the Crimson cultivar (Table 2). The irrigation water applied in treatment T2 was around 60 mm lower than the irrigation water applied in T1 in both cultivars. In treatment T3 this reduction was 123 mm in the Autumn cultivar and 126 mm in the Crimson cultivar. Rainfall during the irrigation season in both cultivars was 235, 256 and 231 mm in 2007, 2008 and 2009, respectively.

Differential irrigation in treatments T2 and T3 started in the veraison phase that occurred on August 7 in 2007 and 2008 and July 15 in 2009 in the Autumn cultivar. In the Crimson cultivar the veraison phase started in July 30 in 2007, August 7 in 2008 and July 22 in 2009. Differential irrigation lasted till the end of grape harvest, which was performed at various picks and at different dates between the middle of September until middle of October.

The reduction of irrigation water in treatments T2 and T3 in both cultivars did not show a clear decrease in the soil water content during the period of RDI. The monthly values of the average soil water content (ϴv) in the row of vines in the top 0.8 m of the soil profile during the post veraison phase did not show lower values in the RDI treatments during the three experimental years (Table 3). During the three years the average volumetric soil water content in the top 0.8 m soil layer increased in all treatment in both cultivar along the season reaching maximum values in August and September. In 2007 an important reduction of ϴv was observed in October. In general terms the ϴv was higher in Crimson than in Autumn. In 2007 the ϴv of the different treatments was higher in Crimson than in Autumn in all measurements. In 2008 treatments T1 and T2 had higher values of ϴv in Crimson than in

Autumn. However in treatment T3 very similar values of ϴv were obtained in both cultivars. In 2009 treatment T2 had also higher values of ϴv in Crimson than in Autumn but very slight differences were found between cultivars in treatments T1 and T3. The seasonal average value of ϴv for the three treatments and both cultivars varied between a minimum of 32.3 % and a maximum of 41.1 %.

Vegetative growth of both cultivars was very similar in the three experimental years in both cultivars. Very little variation in the evolution of the soil ground cover along the three studied seasons was observed between the different irrigation treatments (Figure 2). Canopy development was faster in the Crimson than in the Autumn cultivar. Maximum values of soil ground cover (around 90 %) were reached slightly sooner in the Crimson than in the Autumn cultivar. Canopy cover would probably have reached 100 % but usual management practices include a slight thinning of the shoots in a central band between the vine rows in order to increase light penetration to the lower areas of the vine canopy and clusters. The sharp decrease in soil ground cover observed in the Crimson cultivar in 2009 (Figure 2) was due to a more severe manual thinning performed the first week of August. This thinning reduced the soil ground cover from around 90 % to 75 % while in the others seasons the thinning was lower. Maximum values of soil ground cover were reached around the beginning of the veraison phase in each cultivar and almost at the same time in the three irrigation treatments during the three study years (Figure 2). No significant differences of soil ground cover at the veraison phase were found between treatments. In 2007 and 2008 all the treatments in both cultivars reached almost full cover with values of soil ground cover ranging between 84.3 and 90.6 %. In 2009 soil ground cover at the veraison phase ranged between 89.6 and 91.6 % in the Autumn cultivar and between 72.9 and 76.4 % in the Crimson cultivar (Table 4).

No significant differences of the trunk cross section (TCS) of the vines between treatments were found in 2008 and 2009 in both cultivars (Table 5). The average value of

TCS for the three irrigation treatments in 2008-2009 was 25.6 cm^2 in Autumn and 33.4 cm^2 in Crimson. The TCS was lower in the Autumn cultivar than in the Crimson cultivar. Similar results were found in the relative growth of the trunk cross section (RGTCS) with lack of significance between treatments in both years (Table 5). However, the RGTCS in the Autumn cultivar was higher than in the Crimson cultivar. The average value of RGTCS for the three irrigation treatments in was 73 % in Autumn and 55 % in Crimson.

Results of grape production, number of cluster and average weight of the cluster of the different treatments in the Autumn and Crimson cultivars varied between years (Table 6). In 2007 no significant differences were observed in these variables between irrigation treatments in the Autumn cultivar. However in the Crimson cultivar significant differences between treatments were observed. Grape production (28.9 kg $vine^{-1}$) and the number of clusters (62.4 clusters $vine^{-1}$) of T3 were significantly lower than corresponding values in T2 (47.7 kg $vine^{-1}$ and 101.4 clusters $vine^{-1}$). No effect of the irrigation treatments on the cluster weight was observed. The average cluster weight for the three treatments was 0.79 kg in Autumn and 0.47 kg in Crimson (Table 6).

In 2008 differences between treatments were observed in both cultivars in the grape production and on the number of clusters. Grape production and the number of clusters per vine of T3 were significantly lower than corresponding values in T2 in both cultivars. As in 2007 no effect of the irrigation treatments in the cluster weight was observed in both cultivars. The average cluster weight in 2008 in Autumn (0.79 kg) was very similar to the weight of the previous year. However in the Crimson cultivar the cluster average weight in 2008 (0.73 kg) was higher than in 2007 (0.47 kg) (Table 6).

In 2009 no significant differences were found in the grape production and the number of clusters per vine between the different treatments in the Autumn and Crimson cultivars. The number of clusters per vine in Autumn was lower than in previous years. However the cluster average weight in 2009 was higher in all irrigation treatments than in previous years. Cluster mean weight of treatment T3 of the Autumn cultivar was significantly higher than the rest of the treatments. The grape production and number of clusters per vine of Crimson in 2009 were lower than in previous years. Probably the yield reduction in 2009 was due to the incidence in 2008 and 2009 of late-season bunch stem necrosis (BSN) or sugar accumulation disorders in this cultivar. This physiological disorder affected the normal translocation of assimilates to the cluster producing soft shriveled berries that decreased yield and affected the commercial harvested clusters (Krasnow et al., 2010). The causes of these physiological disorders are uncertain but they are generally associated with nitrogen, calcium or magnesium deficiency, nutritional imbalances and excess precipitation or rainfall (Caps and Wolf, 2000; Krasnow et al., 2010). No significant differences were found between treatments in the Crimson cultivar in 2009 with an average cluster weight of 0.48 kg. This value was similar to the one in 2007 but lower than that of 2008.

The berry quality variables were very similar throughout the three study years (Table 7). No significant effects of irrigation treatments were found in the berry weight, diameter, height, firmness, and ºBrix and pH of the grape juice in both cultivars and in the different study years. There was a year effect in some of the studied parameters. In the Autumn cultivar the berry size was bigger in 2009 than in 2007 and 2008. The firmness and ºBrix in 2008 in Autumn and Crimson cultivars were lower than in the other two years. This was probably due to a delay in the ripening in 2008 due to meteorological conditions. The high variability in the grape production, number of clusters per vine, cluster average weight and berry quality parameters have contributed to the lack of significant effect of the irrigation treatments among these variables in the different study years.

There are important differences between the Autumn and Crimson cultivars mainly in the color of the skin, size and sweetness of the berry. The average weight of the berry measured in all irrigation treatments and study years in the Autumn was around 7.0 g while in the Crimson cultivar was 4.7 g. The average berry diameter was 20.2 mm in the Autumn cultivar and 16.9 mm in the Crimson cultivar. The average berry height was 24.1 mm in the Autumn cultivar and 23.0 mm in the Crimson cultivar. The berry firmness was a little higher in Autumn (68.2 %) than in Crimson (61.4 %). The sweetness of the berry juice was also lower in Autumn (16.6 º Brix) than in Crimson (21.0º Brix). The pH of the berry juice was similar in both cultivars with an average value of 3.9.

The berry cracking percentage in the Autumn cultivar was between 14.7 % in T1 and 21.4 % in T3 in 2007 whereas it was almost negligible in 2008 and 2009 with values ranging between 1.5 and 4.2 % (Table 8). The low cracking values in 2008 and 2009 may be due to the change in the irrigation practice in 2008 and 2009 that consisted in splitting the daily irrigation dose in two applications per day, one at midday and the other application at night. However there is not a clear evidence of this fact since other physiological and meteorological factors can affect berry cracking. No significant differences were found in the berry cracking percentage between irrigation treatments in 2007 and 2008. In 2009 the berry cracking was significantly higher in T1 (4.2 %) than in T2 (1.5 %) and T3 (2.2 %); however the values of berry cracking in that year were very low and no problems were detected in the commercial harvest.

CIELab color parameters of the berry skin of the Crimson cultivar measured at harvest were determined for the different irrigation treatments and study years (Table 9). The L* represents the lightness of the color, the a* represents its position between red and green and b* its position between yellow and blue. All the color parameters varied in a narrow range and the differences between irrigation treatments and years were low. The L* ranged between 29.9 and 36.1, a* ranged between 6.5 and 10.9 and b* ranged between 5.6 and 7.2. The skin color of the berries in all the treatments and study years was red and quite uniform in the clusters. However significant differences were detected between the irrigation treatments in the different years. In 2007 the a* parameter of T1 (9.5) was significantly higher than in treatments T2 (7.6) and T3 (7.5) and no differences were found in the L* and b* parameters. In 2008 no differences were found in L*, a* and b* parameters between irrigation treatments. In 2009 the L* parameter of T3 was significantly lower than that of T1 and T2. The a* parameter of T3 was higher than that of T1 and T2. The b* parameter of T3 and T1 were lower than that of T2. These differences between treatments did not show a clear tendency in the change of color due to the irrigation treatments.

4. Discussion

Many studies have demonstrated that RDI is a practical and useful technique to improve fruit quality and reduce irrigation application when water availability is limited (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 performed on deciduous and citrus orchards but very few on table grapes.

The most restricted irrigation treatment (T3) of the present study resulted in an average water saving ranging from 105 to 144 mm per irrigation season when compared to the control treatment (T1). This water saving represents around 15 % of the seasonal applied irrigation water of the control treatment T1. Water savings in T2 in relation to the control ranged between 51 and 70 mm per irrigation season (water savings of 6 to 8 % of water applied in T1).

The soil moisture data presented in Table 3 did not explain clearly the soil water regime of the different irrigation treatments during 2007 to 2009. In theory the soil moisture of treatment T1 from veraison to harvest should be higher than in T2 and T3 since T1 received the highest amount of irrigation water. However the control treatment (T1) in both cultivars had similar values of soil moisture or even lower than RDI treatments (T2 and T3) in August and September. In general all the values of soil moisture were very high, even higher than field capacity. Probably these high values of soil water content were due to the location of the FDR access tubes, adjacent to the emitter lateral in the row of vines. However some differences were observed between treatments in the grape yield and the number of clusters per vine. The highest differences between treatments in grape yield occurred in the Crimson cultivar in 2007. The lowest productivity of treatment T3 of the Crimson cultivar was confirmed by the lowest accumulated grape production (kg $vine^{-1}$) and productivity (kg cm^{-2} of TCS) values during the three years of the study (Table 10). These accumulated productivity parameters in T3 were significantly lower than in T2 in the Crimson cultivar and no significant differences were found between treatments in the Autumn cultivar. Nevertheless, other non-controlled agronomical factors and the high variability of the observed variables contributed to decrease the significance of the statistical analysis. It seems that there was a higher effect of the meteorological conditions of each year than that of the irrigation treatments. As an illustrative example, the production of the three irrigation treatments of the Crimson cultivar in 2009 were around half of the yield obtained in the other two study years and no significant differences were found between treatments in that year. However this production reduction was not observed in the Autumn cultivar that had similar production levels than the other years. Probably in the 2009 season the incidence of the late season bunch stem necrosis that occurred in 2008 and a more severe cluster pruning were the causes of this grape yield reduction. The decrease in grape production in Crimson in that year was due to the lower number of clusters per vine and lower cluster mean weight while in Autumn cultivar, besides a lower number of clusters per vine, the grape yield was maintained similar to the other years due to a higher cluster mean weight in 2009 (Table 6).

Among the quality parameters, berry cracking is an important and expensive problem when growing high quality fruit, especially table grapes. This problem is generally attributed to the lack of calcium in the fruit or to an excess water application in the maturation phase (Opara *et al*., 1997). This was the reason to study RDI in the post veraison phase. In our study, the Autumn Royal cultivar showed high berry cracking levels in 2007 (between 14 % and 17 % of the berries were affected), whereas in 2008 and 2009, the level of damage was negligible. The differences in the irrigation regime in 2008 and 2009 with two irrigation applications per day instead one daily application in 2007 can explain the differences in berry cracking results. These results support the idea that frequent water applications to the Autumn cultivar eases this problem, while sudden supplies of great doses of water increases its development. The water application at midday might have improved the water supply to the berries at the moment of maximum evaporative demand. 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 RDI treatments in the Crimson cultivar produced significant differences in the CIELab color parameters of the berry skin but no trends in these parameters were clearly observed. However in general the color of the berry was red in all treatments and years.

The overall results during the three study years showed that it is economically feasible to grow these types of table grape cultivars in the arid conditions of the Middle Ebro Valley. High grape yields of very good quality can be obtained with a careful management and moderate regulated deficit irrigation in the postveraison phase without affecting grape yield and quality.

Acknowledgements

This study has been financed by the RTA2005-00038-C06-00 project (Education and Science Ministry, Instituto Nacional de Investigaciones Agrarias, INIA) and the CSD2006-00067 project (CONSOLIDER-INGENIO 2010 Program, Government of Spain). The authors would like to thank the technicians and employees of the CITA for their valuable help in the field experiment instrumentation, grape harvest and laboratory analysis. The technicians and employees of the Santa Bárbara commercial orchard in Caspe are also acknowledged.

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