Effects of regulated deficit irrigation (RDI) on grape composition in Monastrell grapevines under semiarid conditions

Effet de l´irrigation déficitaire contrôlée sur la composition du raisin du cépage Monastrell, cultivés dans des conditions semi-arides.

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Abstract

The influence of two pre-veraison and post-veraison regulated deficit irrigation (RDI) strategies on yield and grape quality was analyzed during a two year period for mature grapevines (cv. Monastrell) in Southeastern of Spain. Three irrigation treatments were applied: T1 control treatment which was irrigated at 60% ETc for the full season (without water stress), applying 319 mm per year; RDI-1 irrigated equal to the control, except from fruit set to harvest (early June-mid –September) where 50% respect to the control was applied and post-harvest (mid-September-end of October) where 75% respect to the control was applied; the water quantity applied in this treatment was 206 mm per year. RDI-2 irrigated equal to the control except from fruit set to harvest where 25% respect to the control was applied and post-harvest irrigated at 75%, applying 157 mm per year. The severity of water stress was characterized by measurements of midday xylem water potential and photosynthesis rate. The grape quality parameters (º Brix, berry weight, titratable acidity, pH, malic, tartatic, color intensity and anthocyanins and polyphenols contents) were also analyzed at harvest. The influence of water stress in different phenological stages on grape quality and the relationship between berry size, fruit quality and level of water stress was analyzed.

Keywords: berry composition, berry size, deficit irrigation, water stress, photosynthesis.

Introduction

Nowadays one of the most promising methods to improve irrigation efficiency in semiarid and arid regions is regulated deficit irrigation (RDI). RDI is used to manipulate winegrape quality by applying controlled water deficits, usually, immediately after berry set in order to control berry size and vegetative growth (Dos Santos et al. 2007, Dry et al. 2001, McCarthy et al. 2002, Keller 2005, Chaves et al. 2007, Costa et al. 2007). After veraison may also be imposed a water stress in order to enhance anthocyanin accumulation and phenolic compounds (Dry et al. 2001, Kennedy et al. 2002, Ojeda et al. 2002), improving the color and taste of the wine (Goodwin, 2002), although the sugar accumulation and other quality parameters can be reduced (Conde et al. 2007), especially under sever water stress (Hardie and Cosidine 1976). Both irrigation strategies (pre and post-veraison RDI) affect to berry size, reducing also yield and can have different effects on berry quality. Some studies consider that fruit quality is increased by pre-veraison RDI compared to post-veraison RDI based on wines made (Wample and Smithyman, 2002), but other studies did not find an increase in phenolic compounds or antocyanins (Sipiora and Gutierrez-Granda 2002) or even reported a decrease in malic acid by pre-veraison water stress (Conde et al. 2007). In the same way, Ojeda et al. (2002) indicated that post-veraison water stress had a direct effect on biosynthesis of phenolic compounds, positive or negative depending on the compound, the timing of application and the severity of water stress. Nevertheless more recent studies indicate that water stress before or after veraison increase the synthesis and metabolism of the anthocyanins (Castellarini et al. 2007). All these different results show the complexity of the response of the winegrape to water stress in terms of berry quality, depending on several factors, such as, edaphoclimatic conditions, variety, timing of application, severity of water stress or type of compounds.

The aim of the present study was to determine the effects of two RDI strategies applied consecutively during pre and post-veraison periods, from after fruit set to harvest during two years on fruit composition in Monastrell vines under semiarid conditions. We also studied the relationship between some berry quality parameters and water stress level reached in different phenological stages.

Material and methods

Field conditions, plant material and irrigation treatments

This research was conducted in an experimental vineyard of 1 ha located in Jumilla (SE Spain) (lat 38º23’40’’ N, long 1º25’30’’W). The climate is semiarid Mediterranean, with hot and dry summers and mild winters, having an average annual rainfall of 290 mm and annual evapotranspiration accounts for 1200 mm (Table 1). The soil was 60 cm deep and the texture was determined as clay. The variety of *Vitis vinifera* L. studied was Monastrell (syn. Mourvedre) grafted onto 1103 Paulsen rootstock in 1997. The training system was a bilateral cordon trellised to a three-wire vertical system. Planting density was 2.5 m between rows and 1.25 m between plants. Six two-bud spurs (12 nodes) were left at pruning time, according to grower’s practice in the area. The experiment was carried out in 2006 and 2007. All treatments received the same annual amount of fertilizers: 40 kg N, 20 kg P, 60 kg K and 16 kg Mg per ha, which were supplied through the irrigation system. Crop coefficients used in this study were: In April 0.35, in May 0.45, in June 0.52, in July 0.75, in August, 0.60, in September and October 0.45.

The experimental design consisted of three treatments with four replicates per treatment in a randomised complete block design. Three irrigation treatments were applied: a) Control, highly irrigated treatment during all season, at 60% ETc, crop evapotranspiration), and two different regulated deficit irrigated treatments (Table 1). Reference evapotranspiration (ET_o) was calculated by Penman –Monteith method (Allen et al. 1998) using the data collected in the meteorological station located in the same vineyard. Each year the irrigation period started in April and ended on 31 October. The amounts of water applied for each treatment (Table 1) were measured with flow-meters.

Treatment	Budburst-fruit-set	Fruti-set-veraison	Veraison-harvest	Post-harvest	Annual water applied (mm) (2006-2007)	Annual reduction of applied water
Control (60% ETc)	100%	100%	100%	100%	318.9	0
RDI-1	100%	50%	50%	75%	205.5	36
RDI-2	100%	25%	25%	75%	156.7	51

Table 1 Irrigation treatments applied during the experimental period (2006-2007)

Plant water relations measurements

Each year midday xylem water potential (Ψ_x) was determined weekly from the beginning of berry development until harvest. Eight fully-exposed and expanded young leaves were taken per treatment (two leaves per plot). The leaves were enclosed within foil-covered plastic and aluminium envelopes at least 1 h before the midday measurement (McCutchan and Shackel, 1992). Midday xylem water potential was measured at noon (12:00-14:00) using a pressure chamber (PMS Systems).

Gas exchange measurements were taken periodically between 9:00-11:00 a. m (to avoid high afternoon temperature and air vapour pressure deficit), daylight hours, from fruit set to harvest. Stomatal conductance (g_s), net CO_2 assimilation (A), transpiration rate (E) were measured in eight exposed and fully expanded leaves of the mid-portion of main shoots per treatment (three leaves per plot) using a portable photosynthesis analyser IRGA (model, Licor 6400. Li-cor, Lincoln, NE, USA).

Berry and must quality analysis

Berry sampling was done weekly from veraison to harvest, choosing 52 vines per treatment. Groups of five to six berries from different parts of the cluster and from different clusters on the same vine were sampled. Berry samples (ca. 300 g) collected from all vines of the same treatment were placed in plastic bags and stored in ice and taken to the laboratory. All samples were counted and weighted in the laboratory on the sampling day. Total soluble solids (Brix) were determined by refractometry. Juice pH and titrable acidity (TA) were determined by titration with NaOH (Automatic titration Metrohm, mod. 686). Organic acids (malic and tartaric) were analysed by an enzymatic test using automatic titration (HYCEL Lisa 200). Anthocyanins in the must were determined by spectrophotometry measuring absorbance at 520 nm (Puissant-León, 1996) and total phenolics index was determined by spectrophotometry measuring UV absorption at 280 nm (Ribéreau-Gayon *et al.*, 1972).

Statistical analysis

Data were analyzed using analysis of variance (ANOVA) procedures and means were separated by Duncan´s Multiple Range Test using Statgraphics 2.0 Plus software (Statistical Graphics Corp. USA).Relationships between parameters were fitted to linear and non-linear regressions.

Results and discussion

Plant water potential was significantly reduced (more negative) in RDI treatments during pre and post –veraison phases compared to the control (Table 2), but there were not significant differences between RDI treatments in midday xylem water potential. Photosynthesis rate (*A*) also decreased significantly in RDI treatments compared to the control, before and after veraison (Table 2). Moreover RDI-2 had significantly lower values in *A* than RDI-1 in these phases, in spite to have similar values of water potential. Values of *A* in RDI-2 in post-harvest (recovery period) were still significantly lower than the Control, suggesting that recovery of photosynthesis in post-harvest was not complete in this treatment.

Treatment	Budburst-fruit set		Fruit-set-veraison		Veraison-harvest		Post-harvest	
	Ψ_x (MPa)	A (μmol m^{-2} s^{-1}	Ψ_x (MPa)	A (μmol m^{-2} s^{-1}	Ψ_x (MPa)	A (μmol m^{-2} s^{-1}	Ψ_x (MPa)	A (μmol m^{-2} s^{-1}
Control	-0.72	12.58	-1.02a	14.3a	-1.20^{a}	12.78a	-1.10	6.76a
RDI-1	-0.72	12.35	-1.21b	12.75b	-1.34ab	10.45b	-1.15	6.24ab
RDI-2	-0.73	12.77	-1.23b	11.62c	-1.46b	8.69c	-1.11	5.41b
ANOVA	ns	ns	**	***	*	***	ns	*

Table 2 Mean values of midday xylem water potential and net photosynthesis rate for each representative period in 2007 in the different irrigation treatments. ns., not significant; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$ Separation by Duncan´s multiple range test, 95% confidence level.

Both RDI treatments influenced clearly in the most of the berry quality parameters measured at harvest (Table 3). Only some quality parameters such as acidity and pH were not affected by the irrigation treatments. Berry weight and berry soluble sugars (measured by refractrometry º Brix) were significantly reduced in RDI compared to control treatment, with mean values of TSS around 23.3 º Brix in control, 22.4º Brix in RDI-1 and 21.3 º Brix in RDI-2 (Table 3). Total soluble sugars in the berries at harvest were significantly correlated with the levels of leaf photosynthesis maintained during post-veraison period (Figure 1), not during pre-veraison period (data not shown). The positive correlation between *A* and º brix (Figure 1) indicates that the low total soluble solids in the RDI treatments can be explained due to low carbohydrate accumulation in the berries during post-veraison period caused by lower photosynthesis rates in the leaves in this period compared to the control.

Treatment	Berry Fresh weight (g)	TSS (º Brix)	Titratable Acidity (g l^{-1})	Tartaric acid (mg l^{-1})	Malic acid (mg l^{-1})	pH	Color intensity	Extractable anthocyanins (mg l^{-1})	Extractable poliphenols (mg l^{-1})
Control	1.70a	23.3a	2.72	5.34a	1.38a	4.05	4.98a	453a	40.4a
RDI-1	1.22b	22.4b	2.75	5.74b	1.05b	4.07	5.91b	521b	52.2b
RDI-2	1.04c	21.3c	2.68	5.99b	1.10b	4.08	5.75b	493b	46.7c
ANOVA	***	***	ns	***	**	ns	***	*	***

Table 3 Berry quality parameters in the must made from Monastrell winegrapes at harvest for each treatment in 2007. ns., not significant; *P < 0.05; **P < 0.01; ***P < 0.001 Separation by Duncan´s multiple range test, 95% confidence level.

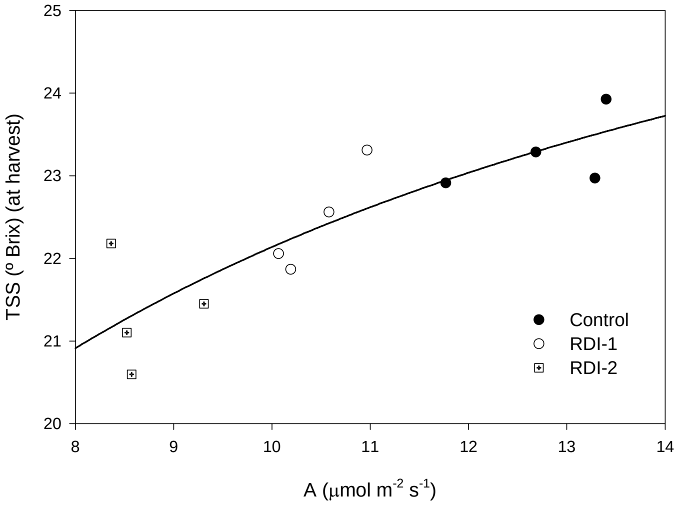

Figure 1 Relationship between mean values of photosynthesis during post-veraison period and total soluble solids (TSS) at harvest. Each single point is the average of two measurements. (y = (28.9 x)/(3.06 +x), r = 0.86 *)**

Berry size was also significantly reduced by RDI and this effect was strongly influenced by the water stress level reached, mainly during pre-veraison phase (from fruit set to harvest).The relationship between fresh berry weight and mean xylem water potential in both periods (Figure 2) indicates a higher sensitivity of berry weight to changes in plant water status before veraison than post-veraison period, indicating that the potential size of the berry is determined mainly before veraison (Figure 2). Other important quality parameters such as colour intensity, extractable anthocyanins and poliphenols in the must increased also significantly in RDI treatments compared to the control (Table 3). Moreover RDI-2 showed significantly lower polyphenols content compared to RDI-1.

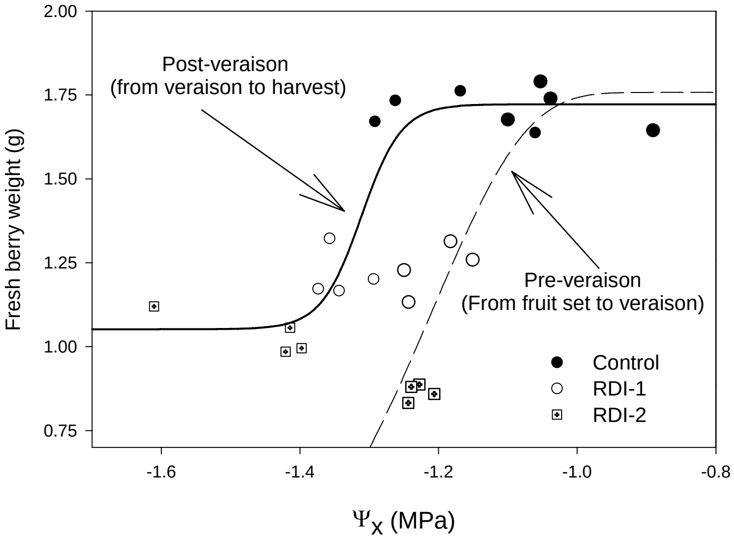

Figure 2 Relationship between fresh berry weight at two different periods (at veraison and at harvest) and mean values of midday xylem water potential (Ψ_x). Each single point is the average of two measurements.

Conclusions

RDI applied consecutively before and after veraison decreased significantly photosynthesis rates depending on the water stress level reached. Both RDI treatments had lower total soluble solids compared to the control, indicating a low carbohydrate accumulation in the berries due to lower photosynthesis rates in the leaves during post-veraison period. Berry size was also significantly reduced by RDI and this effect was strongly influenced by the water stress level reached, mainly during pre-veraison phase (from fruit set to harvest) Anthocyanins and poliphenols were significantly increased by RDI, but without seeing a clear pattern between RDI-1 and RDI-2. More effort has to be done to understand how berry size and water deficit and their interaction determine the synthesis and accumulation of these compounds during ripening period.

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