EFFECTS OF CLUSTER THINNING AND IRRIGATION AMOUNT ON WATER RELATIONS, GROWTH, YIELD AND FRUIT AND WINE COMPOSITION OF TEMPRANILLO GRAPES IN EXTREMADURA (SPAIN)

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Abstract

Aim: The effects of cluster thinning and irrigation regime on vine performance and grape and wine quality of Tempranillo grapevines were studied in a field experiment carried out in Extremadura in Spain.

Methods and results: Treatments were combinations of two irrigation doses (25% and 100% of estimated crop evapotranspiration) and two crop levels (thinned and unthinned vines). Cluster thinning was performed just before veraison to retain five clusters per m^2 of vine leaf area. Results showed that irrigation amount produced important differences in stem water potential, leaf area index and berry growth but cluster thinning did not significantly affect these parameters. However, cluster thinning independently of the irrigation amount, advanced by seven days grape maturity and largely affected the main grape quality parameters, increasing total soluble solids concentration, pH, total anthocyanins and phenolic content and reduced must yield. Wines made from grapes of the thinned treatments also had higher contents of anthocyanins, tanins and colour index. This increasing effect was more noticeable in the lower irrigation dose. Similarly, the higher irrigation amount reduced phenolic content of wines.

Conclusion: Both, lower irrigation rates and cluster thinning, despite decreased yield, improved wine composition. Overall thinning had a larger impact on grape and wine composition than irrigation.

Significance and impact of study: In the semi-arid environment of the Extremadura region of Spain, irrigation in Tempranillo is important to obtain economically sound yield. However, the irrigation dose to apply might vary depending on the desired wine style. Irrigation to replace potential evapotranspiration should be avoided for premium wine production and, in these cases; deficit irrigation is probably preferred as a tool to increase yields but minimizing the negative effects on fruit and wine quality. Cluster thinning, performed just before veraison, can be also applied to accelerate ripening improving the overall fruit phenolic composition.

Keywords: leaf area, phenolics, stem water potential, *Vitis vinifera*

Résumé

Objectif : Les effets de l'éclaircissage des grappes et de la quantité d'irrigation ont été étudiés d'une part sur le développement végétatif et productif de la vigne et d'autre part sur la qualité du vin, sur le cépage Tempranillo dans la région d'Extrémadure, en Espagne.

Méthodes et résultats : Les traitements expérimentaux ont consisté dans la combinaison de deux doses d'irrigation et de deux niveaux de charge. Les résultats montrent un effet significatif de la dose d'irrigation sur le potentiel hydrique, la surface foliaire et le poids des baies. Par contre, l'éclaircissage n'a pas eu d'effet significatif sur ces trois paramètres. Toutefois, et indépendamment de l'état hydrique des souches, la réduction du niveau de charge : 1) a avancé la date de maturation de sept jours, 2) a eu une influence considérable sur les paramètres indicatifs de la maturité phénolique et technologique des baies, 3) a provoqué une réduction du rendement en moût. Les vins élaborés avec les raisins des souches éclaircies ont présenté des valeurs supérieures en IPT, anthocyanes, tannins et intensité colorante, cet effet étant plus important sur les souches les moins irriguées. Les vins élaborés avec des raisins soumis à un déficit hydrique plus important ont présenté une teneur en composés polyphénoliques plus élevée.

Conclusion : Les doses d'irrigation plus faibles et l'éclaircissage des grappes ont amélioré la composition du vin au niveau de la couleur ainsi que la teneur en composés phénoliques, malgré une réduction du rendement de la vendange. En général l'effet de l'éclaircissage a été supérieur à celui de l'irrigation par rapport à la composition du vin.

Signification et impact de l´étude : Dans l'environnement semi-aride caractéristique de l'Estrémadure, l'irrigation du cépage Tempranillo est nécessaire pour atteindre un niveau productif acceptable. Pour produire du bon vin, l'eau apportée ne doit cependant pas être perdue par évapotranspiration. La stratégie d'irrigation déficitaire assure un compromis entre le rendement du vignoble et la qualité du raisin et du vin. L'éclaircissage des grappes juste avant la véraison peut être aussi un outil.

Mots clés : polyphénols, potentiel hydrique, surface foliaire, *Vitis vinifera*

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INTRODUCTION

In semi-arid regions, irrigation is often applied as a technique to increase yield and in occasions to achieve a proper supply-demand vine balance. However, there is evidence that irrigation to ensure the potential vine evapotranspiration reduces wine quality (Williams and Matthews, 1990), perhaps because of an increase in berry size through irrigation. If other berry characteristics, such as skin thickness, are not affected by improving vine water status, larger berries would have a lower skin to pulp ratio. This leads to a dilution of the main berry quality components that are localized in the skin. Irrigation might also indirectly affect berry quality because of increased and prolonged vegetative growth. After veraison, shoot growth may compete for the carbohydrates available for fruit ripening. Increased vegetative growth might also impair cluster microclimate, particularly fruit light exposure (Smart *et al.*, 1985). In other cases, irrigation has led to a delay in obtaining the desirable sugar levels (Bravdo *et al.*, 1984). However, reports also show that severe water stress might be detrimental to fruit quality because of a poor canopy development and reduced leaf assimilation rate thus an inadequate vine capacity to ripen the crop (Hardie and Considine, 1976), particularly under high yield level (Freeman and Kliewer, 1983). Deficit irrigation can be applied as a strategy to reduce the possible negative impact of irrigation on wine quality.

Because of the high dependence of fruit quality on various environmental and endogenous factors (Jackson and Lombard, 1993), the overall effect of irrigation might change according to other cultural practices particularly those affecting the crop level (Bravdo *et al.*, 1984; Poni *et al.*, 1994). Vines with higher crop level seem to benefit more of a higher amount of irrigation both in terms of yield (Lakso *et al.*, 1999) and of fruit composition (Hepner and Bravdo, 1985).

Cluster thinning is in cases applied to regulate the yield levels and to help ripening the crop under poor climatic conditions or excessive crop demand. However, results presented in literature have reported contrasting results, with cluster thinning leading to better fruit quality in some cases (Prajitna *et al.*, 2007; Guidoni *et al.*, 2002), but with no clear effect in some others (Ough and Nagoaka, 1984; Keller *et al.*, 2005). Timing of cluster thinning is certainly important in this sense. For instance, Chapman *et al.* (2004) found significant differences in wine sensory attributes when yield was regulated by winter pruning, but no differences between cluster thinning treatments. Early season thinning might stimulate the vegetative growth reducing cluster light exposure (Naor *et al.*, 2002). Cluster thinning when performed late in the season, e.g. around véraison, should have a lower impact on vine vigor and berry growth (Keller *et al.*, 2008) but it increases the time while vines have to support a high demand from the fruit.

The cultivar Tempranillo is originally from northern, cool regions of Spain and today is the most widely cultivated cultivar for production of red wines all over Spain. It is reputedly to be sensitive to water stress and prone to early leaf senescence (Gómez del Campo *et al.*, 2000). Previous research has shown some beneficial effect of irrigation on fruit ripening, mainly an increase in berry sugar concentration (Esteban *et al.*, 1999; García-Escudero *et al.*, 1991), but has also shown a decrease in the concentration of skin anthocyanins in other cases (Esteban *et al.*, 2001). Intrigliolo and Castel (2008) reported a different effect of irrigation depending on seasons that was related to year differences in crop level. However, Yuste *et al.* (1997) did not find any interaction between irrigation and cluster thinning on must quality when these practical cultures were study together in a multi-factor experiment.

The objective of the present investigation was to study the short-term effects of irrigation amount in thinned and un-thinned vines on vine physiology, yield and fruit and wine quality.

MATERIALS AND ANALYTICAL AND EXPERIMENTAL METHODS

1. Site description

The experiment was carried out during the 2005 season in Extremadura, in a Tempranillo vineyard (*Vitis vinifera* L.) planted in 2001 on Ritcher-110 rootstock at a spacing of 2.5 by 1.2 m (3,000 vines/ha). The vineyard was in Guadajira (38ºN, 6ºW, elevation 198 m). Vines were trained to a vertical trellis on a bilateral cordon system oriented in the North-South direction. Six spurs per vine, two buds per spur, were retained during winter pruning. All treatments were fertilized at a rate of 70-40-94 units ha^{-1} of N, P, K, respectively. The soil at the site has a silt-loam texture. The volumetric water content at field capacity is of 0.34 m^3 m^{-3} and 0.13 m^3 m^{-3} at permanent wilting point.

Budbreak for Tempranillo in this area usually occurs by the early April, flowering by early June; veraison is reached by mid-July with harvest during early September and leaf fall late in December.

The experimental design was a split-plot with four replicates; irrigation being the main factor and thinning the second factor within each irrigation regime. The experimental plots had six rows with eighteen vines per row. Irrigation treatments were based on replacing crop evapotranspiration (ETc) at a rate of 25% ETc (R1) or at 100% ETc (R2). ETc was estimated as the product of reference evapotranspiration (ETo), measured with a weather station located in the plot, and crop coefficient (K_c) according to Allen *et al.*, (1998). Irrigation started when stem water potential reached a level of -0.9 MPa and finished by the end of August. Drip irrigation was applied with pressure-compensated emitters of 4 l h^{-1} located in a single row 120 cm a part. At the end of the season R1 and R2 treatments received a total of 61 and 222 mm, respectively. Seasonal (April to October) ETo and rainfall were 1,147 and 115 mm, respectively. Yearly (harvest to harvest) rainfall was 421 mm.

Within each irrigation regime, two crop levels were established, unthinned (high crop level, H) and thinned (low crop level, L). Thinning was performed when the first berries appear to be changing color and it was based on the vine source capacity estimated by vine leaf area measurements. In the thinned treatments, five clusters per m^2 of vine leaf area were retained.

2. Field determinations

Determinations of water potential were performed with a pressure chamber on a representative plant per experimental plot and two leaves per vine (a total of eight determinations per treatment). Determinations were carried out at midday (11.30 am to 12.30 pm, hr solar) on bagged (stem water potential, SWP) at weekly intervals.

Leaf are index (LAI) was determined by means of canopy analyzer (Licor LAI-2000 Lincoln, NE, USA) measuring four vines per experimental plot (sixteen vines per treatment). Measurements were carried out, just before dawn, under diffuse radiation using the 270º view cap (Licor LAI-2000 Manual). A first reference reading was taken above the canopy, and eight readings were taken below the canopy in order to cover the entire soil allotted per vine. LAI determinations, obtained with LAI-2000, were calibrated against destructive leaf area measurements using a LAI-3100 (LI-COR-Lincoln, NE, USA) leaf area meter.

Yield components and winter pruning weight were determined on ten vines per experimental plot. The yield to pruning weight ratio (Ravaz index) was also calculated to express the vine sink-source balance.

3. Must and wine analysis

Must total soluble solids and acid components were determined in samples of 250 g per experimental plot collected weekly from veraison to harvest. In order to minimize juice losses, berries were collected by removing small portions of clusters. In the laboratory, each berry was then separated by the pedicel. Soluble solids (Brix) was determined by refractometry. Juice pH and titratable acidity (TA) were determined by an automatic titrator (Crison Micro TT). Titration was carried out with a 0.1 N solution of NaOH to an end point of pH 7.0 and results were expressed as g l^{-1} of tartaric acid.

At three times during ripening, veraison, mid-way to harvest and harvest, must phenolic maturity analysis was carried out by a procedure developed in our laboratory. Grape samples of 500 g were destemmed and homogenized with a «Thermomix» centrifuge (Worwek, Germany) at speed power level three during two minutes. Six replicates of 50 g of homogenized sample were then used to extract phenolic compounds. Three samples were used for total phenolics determination after maceration with 50 mL of a hydroalcoholic solution (12% by volume and pH 3.2) with high dose of SO_2 (2 g l^{-1} of SO_2). In the other three 50 g samples, extractable phenolics were obtained by adding a hydroalcoholic solution (12% by volume and pH 3.2) with lower SO_2 dose (75 mg l^{-1}), similar concentration than during vinification. In all cases, after eighteen hours of maceration, the homogenate/ethanol mixtures were centrifuged and in the supernatant (e.g. the extracts) total phenolics compounds were measured according to Ribéreau-Gayon (1970), while anthocyanins were obtained following Di Stefano *et al.*, (2002). Berry total phenolic potencial (TPP) and total anthocyanin potential (TAnP) were then obtained from the high extracting solutions, while berry extractable phenolic potential (ExPP) and extractable anthocyanin potential (ExAnP) from the low SO_2 concentration extracting solutions, respectively. Absorbance measurements were carried out with a spectrophotometer Shimadzu UV-120 (Japan) in duplicated samples. The cellular maturity or anthocyanin extractability (EA) and grapes phenolic maturity (MP) indices were calculated as follows:

$$EA\% = [[(TAnP) - (ExAnP)]/ (TAnP)]*100$$

$$MP (\%) = [(ExPP) - (ExAnP)*0,04]/(ExPP)]*100$$

The TAnP and ExAnP values are expressed in terms of milligrames of malvidin glucoside per litre.

Tartaric and malic acid concentration were obtained in the harvest samples. Tartaric acid was analyzed according to the Rebelein method (Blouin, 1973). Malic acid was obtained by means of automatic analyzer after enzymatic reaction EasyChem Plus (Sestea, Italy).

4. Microvinification procedures

Samples of about 80 kg from each plot (four independent vinifications per treatment) were used for microvinification. Grapes were mechanically crushed, de-stemmed, and fermented in stainless steel containers at a temperature that was maintained between 22 to 28 °C. All lots were sulfited at 50 mg l^{-1} and inoculated with a

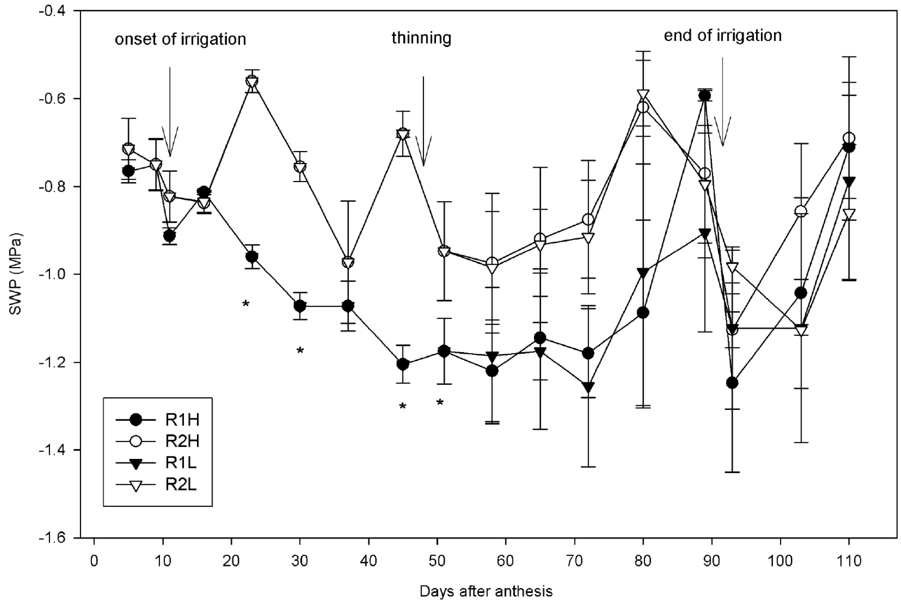

Figure 1 - Evolution of stem water potential (SWP) on the different treatments.
Values are treatment means ± standard deviation of eight leaves measurements. The asterisk indicates significant ($p < 0.05$) effect of the irrigation factor. Crop level and the irrigation by crop level interaction factors were always non significant ($p > 0.05$).

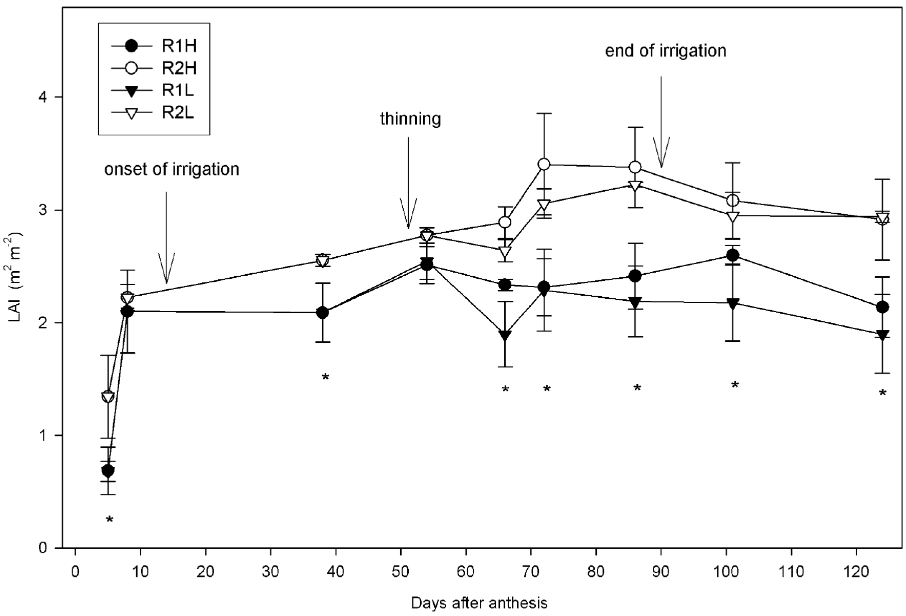

Figure 2 - Evolution of leaf area index (LAI) on the different treatments.
Values are treatment means ± standard deviation of sixteen vines per treatment. The asterisk indicates significant ($p < 0.05$) effect of the irrigation factor. Crop level and the irrigation by crop level interaction factors were always non significant ($p > 0.05$).

commercial yeast strain (Gist Brocades Fermirouge). During vatting, fermenting must wines were punched twice per day. Wines were racked when increase in the total phenolic index leveled off. After that, wines were decanted, sulfited at 50 mg l^{-1} SO_2, bottled and stored at 4 ºC. Wine analysis was carried out four months after bottling. Phenolic composition of wines was determined by measuring the total phenolic index (TPI), anthocyanins content (An), tannins (T), ionization index (Iion), gelatin index (GI), color intensisy (CI) and hue (CH), according to Ribéreau-Gayon *et al.* (2000). Wine color composition was obtained with a colorimeter after measuring the CIELAB coordinates by means of the MSCV software from University of La Rioja, in Spain.

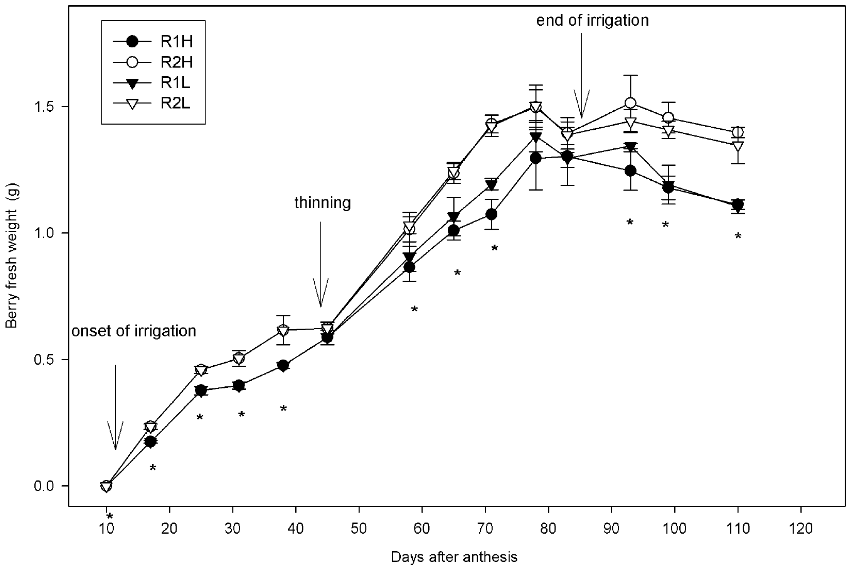

Figure 3 - Evolution of berry fresh weight on the different treatments.

Values are treatment means ± standard deviation of four samples per treatments. The asterisk indicates significant ($p < 0.05$) effect of the irrigation factor. Crop level and the irrigation by crop level interaction factors were always non significant ($p > 0.05$).

Table 1 - Yield and yield components of the different treatments.

Treatment	Berry weight (g)	Cluster weight (g)	# Berries cluster^{-1}	# clusters vine^{-1}	# clusters m^{-2} leaf area	Yield (tn ha^{-1})	Ravaz Index
R1H	1.1	192	172	21	7,0	13.6	7.5
R2H	1.4	278	200	25	8,5	23.6	8.1
R1L	1.2	180	150	15	5,0	9.0	5.9
R2L	1.4	265	188	16	5,2	13.8	4.9
Irrigation	***	***	n.s.	n.s	n.s	***	n.s.
Crop level	n.s	n.s	n.s.	***	***	***	*
Irr*CL	n.s	n.s	n.s.	n.s	n.s	n.s	n.s.

The yield to pruning weight ratio values (Ravaz index) are also indicated.
The level of significance of each factor from ANOVA is shown.
***, * n.s: significant at $p < 0.001$, $p < 0.05$ or non significant, respectively.

5. Statistical analysis

Analysis of variance was performed using the SPSS.V13.0 statistical package. Data were analyzed with irrigation and crop level as main factors, including the irrigation per crop level interaction.

RESULTS

Irrigation dose significantly affected plant water status during part of the irrigation season (figure 1). In the middle of the summer, while the more irrigated treatment had SWP between -0.8 and -1.0 MPa, the R1 treatments generally had values between -1.1 to -1.3 MPa. Cluster thinning, instead, did not affect plant water status.

In all treatments, vegetative growth, in terms of LAI, increased during the first part of the season and leveled off by August (figure 2). By the end of the season, the more irrigated vines had about 33% larger LAI than the R1 treatments. On the other hand, cluster thinning did not have a significant effect on the vegetative growth.

In all treatments, berry growth showed the typical double sigmoid pattern (figure 3). Just before veraison, berry fresh weight accumulation stopped and picked up again after veraison. During the ripening period, there was a reduction in berry fresh weight, which was more noticeable in the less irrigated treatments. Irrigation dose clearly affected berry fresh weight during most part of the fruit growth cycle. At harvest the R2 treatments had 23% larger berries than the R1 treatments (table 1). On the contrary, cluster thinning did not affect berry fresh weight in none of the two irrigation treatments (figure 3). Hence, at harvest, thinned and un-thinned vines had similar berry fresh weight (table 1).

Table 2 - Parameters of must quality at harvest on the different treatments.

Treatment	Total soluble solids (ºBrix)	Tartaric Acid (g l^{-1})	Malic Acid (g l^{-1})	TitratableAcidity (g l^{-1})	pH
R1H	23.3	4.93	1.82	3.43	3.78
R2H	23.3	4.43	2.01	3.80	3.76
R1L	24.3	7.76	1.70	3.44	3.96
R2L	24.4	6.76	2.32	3.90	3.88
Irrigation	n.s.	***	***	n.s	n.s
Crop level	*	***	n.s.	n.s.	***
Irr*CL	n.s	n.s	*	n.s	n.s

The level of significance of each factor from ANOVA is shown.
***, * n.s: significant at $p < 0.001$, $p < 0.05$ or non significant, respectively.

Table 3 - Fruit phenolic maturity at different fruit development stages, veraison, 40 days after veraison, and harvest.

Veraison sample

Treatment	TPP (u.a.)	ExPP (u.a.)	TAnP (mg l^{-1})	ExAnP (mg l^{-1})	EA (%)	MP (%)
R1H	34.4	13.0	280.3	60.8	78	82
R2H	30.4	13.2	267.1	73.3	71	77
R1L	29.9	17.0	278.1	92.0	67	78
R2L	34.5	13.4	308.5	83.8	78	74
Irrigation	n.s.	*	n.s	n.s	n.s	n.s
Crop level	n.s.	*	n.s	n.s	n.s	n.s
Irr*CL	n.s.	n.s.	n.s	n.s	n.s	n.s

40 days after veraison sample

Treatment	TPP (u.a.)	ExPPExP (u.a.)	TAnP (mg l^{-1})	ExAnP (mg l^{-1})	EA (%)	MP (%)
R1H	50.8	34.2	1676	656	62	66
R2H	50.5	35.9	1636	690	65	73
R1L	54.2	34.0	1887	675	63	67
R2L	53.2	30.9	1846	610	61	70
Irrigation	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Crop level	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Irr*CL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Harvest sample

Treatment	TPP (u.a.)	ExPPExP (u.a.)	TAnP (mg l^{-1})	ExAnP (mg l^{-1})	EA (%)	MP (%)
R1H	49.2	32.1	1301	606	52	26
R2H	41.0	27.1	1402	538	62	28
R1L	67.7	46.9	2199	903	59	26
R2L	62.0	39.1	2009	754	63	26
Irrigation	**	***	n.s.	***	***	n.s.
Crop level	***	***	***	***	*	n.s.
Irr*CL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

TPP: total phenolic potential; TAnP: total anthocyanin potential; ExPP: extractable phenolics potential; ExAnP: extractable anthocyanin potential; EA: anthocyanin extractability; MP: contribution of tannins from seeds to the total phenolic content
The level of significance of each factor from ANOVA is shown.
***, **, * n.s: significant at $p < 0.001$, $p < 0.01$, $p < 0.05$ or non significant, respectively.

Irrigation similarly increased yield in both crop level treatments, 62% larger yield over both crop level treatments (table 1). This increase in yield was in most part due to an increase in cluster weight. The decrease in yield due to cluster thinning was proportional to the number of clusters left in the vines, because cluster thinning did not affect the average cluster weight. Irrigation did not affect the yield to pruning weight ratio, e.g. the Ravaz index, while cluster thinning significantly decreased it (table 1).

During all the course of the season the irrigation regime did not significantly affect the soluble solids content of the berries (figure 4 and table 2). Cluster thinning instead, in both irrigation levels, tended to increase berry soluble solid concentration. At harvest, the thinned vines had one degree higher Brix (table 2).

The effect of irrigation regime and cluster thinning on the acidity of the must was not significant (table 2). Must pH was not impaired by irrigation, but it increased in

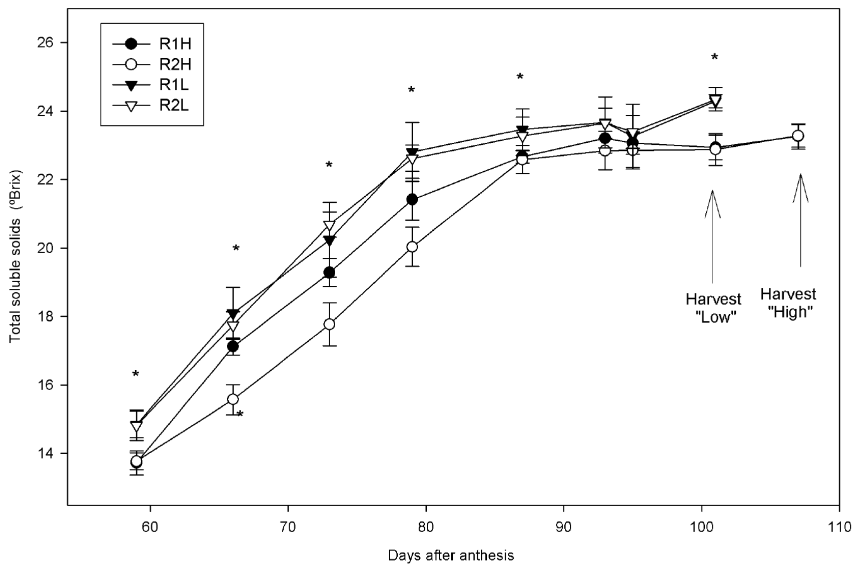

Figure 4 - Evolution of soluble solids (ºBrix) on the different treatments.
Values are treatment means ± standard deviation of four samples per treatments. The asterisk indicates significant ($p < 0.05$) effect of the irrigation factor. Crop level and the irrigation by crop level interaction factors were always non significant ($p > 0.05$).

Table 4 - Wine phenolic composition on the different treatments.

Treatment	TPI (u.a.)	An (mg l^{-1}.)	Iion (%)	Tannins (g l^{-1})	GI (%)
R1H	50.3	291.7	18.1	2.16	67
R2H	45.4	270.2	15.2	1.65	45
R1L	50.8	329.1	22.9	2.57	43
R2L	46.3	274.1	22.8	2.14	36
Irrigation	**	*	*	***	**
Crop level	n.s.	**	***	***	***
Irr*CL	n.s.	**	**	n.s.	***

TPI: total phenolic index; An: anthocyanins content; T: tannins; Iion: ionization index; GI: gelatin index.
The level of significance of each factor from ANOVA is shown.
***, **, * n.s: significant at $p < 0.001$, $p < 0.01$, $p < 0.05$ or non significant, respectively.

the low loaded vines. However, full irrigation increased the malic acid concentration but decreased the tartaric acid level in the must. Cluster thinning did not affect malic acid but it increased the concentration of tartaric acid.

At veraison, none of the treatment had a considerable effect on fruit phenolic composition (table 3). Differences started to appear in the second sample, in between veraison and harvest, and become more considerable and statistically significant by harvest. At this moment, the higher irrigation dose decreased TPP, ExPP and ExAnP. Total anthocyanin potential (TAnP) was instead not significantly affected by the full irrigation regime.

As a consequence, the more irrigated treatment had higher values of anthocyanin extractability. At harvest, the crop level also had a clear effect on the berry phenolic composition. Low loaded vines had a higher concentration of TAnP, TPP, ExPP and ExAnP. The contribution of tannins from seeds to the total phenol content was instead not affected by irrigation or the crop level.

Accordingly wine composition was also modified by irrigation and cluster thinning (table 4). Wine from the more irrigated treatments had lower TPI, An, T, Iion, GI, and color intensity. However irrigation did not modify color hue or its composition (table 5).

Cluster thinning did not affect the wine total phenolic content and increased the anthocyanin content only in the less irrigated treatments (table 4). Wine tannin content increased in the low loaded vines while the gelatin index decreased in wines made from thinned vines. Wine made from the low cropping vines had higher CI (table 5).

DISCUSSION

While irrigation had considerable effects on vine water relations, thinning did not impair SWP. Considering that

Table 5 - Wine color composition on the different treatments.

Treatment	CI	CH	L	a*	b*	c*	H*	S*
R1H	10.2	0.57	51.3	49.2	2.3	49.2	2.7	0.96
R2H	9.1	0.54	55.3	47.4	1.8	47.5	2.1	0.86
R1L	11.6	0.57	44.3	46.8	3.2	47.1	6.6	1.07
R2L	10.3	0.59	51.6	47.8	5.6	48.1	6.7	0.93
Irrigation	*	n.s.	*	n.s.	n.s.	n.s.	n.s.	*
Crop level	*	n.s.	**	n.s.	n.s.	n.s.	***	n.s.
Irr*CL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

CI: color intensity; CH: color hue.
***, **, * n.s: significant at $p < 0.001$, $p < 0.01$, $p < 0.05$ or non significant, respectively.

vegetative growth was similar in thinned and un-thinned vines, the same SWP values obtained regardless the different yield levels suggest a lack of influence of crop level on gas exchange. This has also been observed in other cultivars (Poni *et al.*, 1994; Edson *et al.*, 1995) and in Tempranillo in previous reports (Intrigliolo *et al.*, 2008). Berry and vegetative growth were also not affected by the crop level, probably because cluster thinning was performed late in the season, when most part of vine growth had occurred, and when the potential berry growth (i.e. cell division) was already established. Hence the observed effects of cluster thinning on fruit composition were probably a direct effect of thinning due to the better source to demand ratio of the low yielding vines.

Thinning accelerate ripening, but despite un-thinned vines were harvested later than the thinned ones fruit from the high yield vines still had lower phenolic and sugar concentration. Indeed, thinning lead to wines with a different phenolic profile. Thinning did not increase TPI but improved the contribution of the anthocyanin-tannin combinations to wine color as suggested by the higher Iion obtained in the low yield level. Thinning increased wine tannins but decreased the GI suggesting less toughness and astringency in the wine made from the low yielding vines. The only negative effect of thinning on fruit composition was the increase in wine pH. This might be detrimental to sanitary and aging stability of the wines made from thinned vines and can be due to the increase in tartaric acid most likely because of increased potassium metabolism in the berries of thinned vines as reported in García-Escudero *et al.* (2000).

On the other hand irrigation did not affect must pH but altered the balance between malic and tartaric acid, increasing the first and decreasing the latter. Temperature is the main environmental factor affecting malic acid evolution and concentration in berries (Hale, 1977). Irrigated vines had more vegetative growth that probably reduced cluster exposure to direct solar radiation and therefore cluster temperature-conditions favorable for the retention of malic acid and counteracting the dilution effect by irrigation because of larger berries. This observation agrees with findings made by other authors, who have related acid content with temperature, and with the higher rate of malic acid degradation in non-irrigated vines because of less shading of the clusters by leaves (Smart *et al.*, 1985). Tartaric acid concentrations decreased in irrigated wines. This was most likely because this acid is less affected than malic acid by environmental conditions (Ruffner, 1982) and thus its concentration was probably more determined by the dilution effect as well as by increased precipitation of bitartrate potassium salts (Iland and Coombe, 1988).

Full irrigation detrimentally affected the grape extractable anthocyanins and phenolic potential and, in agreement, it decreased wine phenolic concentrations. This was probably because of a dilution effect due to the larger berries of the more irrigated vines. This confirms that, at in least in varieties for red wine production, applying irrigation to entirely replace the potential evapotranspiration might detrimentally affect the overall wine phenolic composition as reported in other cases (Ginestar *et al.*, 1998; Salón *et al.*, 2005). In addition, the present findings suggest that irrigation also modified the anthocyanins extractability. These results highlight the importance of determining both; total and extractable phenolic compounds, when assessing the grape phenolic composition responses to irrigation. In addition, the different anthocyanin extractability reported between irrigation treatments suggest that wine making procedures, e.g. maceration time, should be carried out according to the vine management in the field.

The effect of thinning on berry phenolic profile was similar in both irrigation regimes. Instead thinning increased more the total anthocyanin content of wine in the less irrigated treatments. Under the more irrigation applied there were not differences in this factor suggesting that dilution effect counteracted the better source-sink balance of the thinned vines.

CONCLUSION

Results reported here studied the short-term (single season) effects of irrigation on vine physiology, yield and grape and wine composition. In the semi-arid environment of the Extremadura region of Spain, irrigation in Tempranillo is crucial to increase vine productivity. However, the irrigation regime to apply should be considered with caution because replacing entirely vine evapotranspiration is likely to detrimentally affect fruit and wine phenolic composition. For premium red wine production deficit irrigation can be suggested as a tool to improve fruit and wine phenolic profile. On the other hand, cluster thinning, even if applied late in the season, can be successfully used as a strategy to reduce the overall vine demand, accelerate and improve fruit ripening without affecting berry or vegetative growth. However, growers should take into account the yield reduction and labor costs associated with cluster thinning. Further studies are needed to analyze the longer term effects of these cultural practices in order to identify carry over effects and season by treatment interactions.

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