INFLUENCE OF IRRIGATION ON WATER STATUS, PRODUCTIVITY, YIELD AND MUST COMPOSITION IN TEMPRANILLO GRAPEVINE UNDER DUERO VALLEY ZONE CONDITIONS

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Abstract
This study analyzes the influence of moderate irrigation on plant water status (leaf water potential), productivity (dry matter and yield) and fruit quality (berry size, ºBrix, pH, titratable acidity, phenolic compounds) of Tempranillo grapevine in the Duero river Valley, at the A.O. Cigales. Irrigation treatments applied were: 0% and 20% ETo. The experimental trial was located in Valladolid (Castilla y León, Spain). The 12-year-old vines grafted onto 110 Richter rootstock were vertical trellis trained, through bilateral cordon, and spur pruned. Vine spacing was 2645 vines per ha (2.7 m x 1.4 m).
The application of irrigation has increased the leaf water potential level and provoked an important increase of dry matter production as well as yield. The water stress caused by the lack of watering has increased sugar concentration, pH, titratable acidity and phenolic compounds concentration, through the berry size reduction. The application of moderate doses of irrigation causes an improvement of water status and an important increase of productivity and yield conditioned by the climatic characteristics of the zone (Valley of the Duero river) and the soil of the experimental trial. Nevertheless, a reduction of the must quality of Tempranillo grapevine can take place due to the irrigation.

Résumé
Cette étude a pour but d'évaluer la modification de l'état hydrique (potentiel hydrique foliaire), le comportement productif (matière sèche et rendement) et la expression qualitative (poids de baie, degrée Brix, pH, acidité totale, concentration polyphénolique) de la varieté Tempranillo dans la Vallée du Douro, à l'A.O. Cigales, comme conséquence de l'application d'une irrigation modérée. Pour développer l'essai on a appliqué les suivantes doses d'arrosage: 0% et 20% de ETo. L'essai experimental a été situé à Valladolid (Castilla et León, Espagne). Les ceps ont été plantés en 1993, sur porte-greffe 110R, et ont été conduites en espalier, menés en cordon Royat bilateral et taillés en coursons, avec une densité de plantation de 2645 ceps/ha (2.7 m x 1.4 m).
L'aplication d'irrigation a permis d'apprécier une augmentation du potentiel hydrique foliaire et un accroissement important de la production de matière sèche et du rendement. Le stress hydrique dérivé de l'absence d'irrigation a provoqué un accroissement de la concentration de sucres, le pH et l'acidité totale, ainsi que la concentration polyphénolique du moût par la diminution du poids de baie. Dans les conditions de l'essai (zone de la Vallée du Douro) et avec la densité de plantation utilisée, l'application de doses modérées d'irrigation cause une amélioration de l'état hydrique de la vigne et une importante augmentation de la productivité du vignoble et du rendement, mais il peut occasionner une réduction de la qualité du raisin de Tempranillo.

Introduction
Traditionally, vineyards have been grown without irrigation in most of the quality grape production areas of Spain. On these areas, the growing cycle of vines develops under a clear water deficit that limits yield and, in some cases, the quality of grapes. It is well known the decisive influence of water availability on vegetative development and grapevine production (Winkler *et al.* 1974, Smart *et al.* 1983, Carbonneau 1998). This influence modifies the expression of quantity and quality of any variety placed on a concrete "terroir" (Bessis & Adrian 2000).

The irrigation of the vineyard can have many effects. Talking about the vegetative development, the water supply improvement provokes a vine vigor increase (Smart *et al.* 1983) and an increase in the conversion of the intercepted radiation into dry matter (Monteith 1977). Yield is higher when vines are irrigated, thus McCarthy *et al.* (1992) quantifies the yield increase between 0.16 t/ha and 0.7 t/ha per each 10 mm added as irrigation doses. The irrigation effects on grape quality described along the bibliography are variable and, in some cases, contradictory. In general, excessive irrigation provokes delay on ripening, lower sugar concentration, higher acidity and lower must pH. On red varieties, irrigation can cause a decrease on the polyphenolic concentration related to the increase of berry size and to the reduction of water stress.

This study has been set out in order to know the productive and qualitative response of Tempranillo variety to the apply of deficit irrigation doses on ecological semiarid conditions, as there are commonly on the Duero Valley area.

MATERIALS AND METHODS

Location. The trial was carried out in Valladolid, central-northern Spain, along 2002 and 2003. The experimental vineyard of Tempranillo variety grafted onto 110 Richter was planted in 1993. Vines were vertical trellis trained, 2-bud spur pruned in a bilateral Royat cordon. The number of shoots per unit of soil surface was 39600/ha and plant density was 2645 vines/ha (2.7 x 1.4 m). The row orientation was north-south (+ 25º). ET daily average during irrigation period was 3.89 mm in 2002 and 3.58 mm in 2003. Annual rainfall was 176 mm and 483 mm in 2002 and 2003, respectively.

The soil is highly stony (70% of thick elements along the first 100-cm depth), without physical or chemical limitations which allows a good drainage, high infiltration speed and low water storage capacity (70 mm . m^{-1}). Most part of the grapevine root system is located along the first 60-cm depth of soil.

Experimental design. The experimental design for water regime consisted of randomized blocks with 4 replications and elemental plot of 9 control vines. Two treatments of drip irrigation were applied: 20% ET (20) y 0% ET (00). The total amount of water applied was 71 mm and 51.5 mm in 2002 and 2003 respectively, weekly distributed from June till September. The irrigation started in June 24^{th} in 2002 and in July 7^{th} in 2003.

Control of yield along both years was made in order to reach the balance between yield and leaf area, focused on getting adequate ripening. According to the behavior of the vineyard observed the previous years, in 2002 the relation SA/yield was limited to 1.8 m^2/kg in treatment 20. In 2003 this relation was reduced until 1.1 m^2/kg. The small cluster size of the treatment 00 made unnecessary its control of yield, so in both years the relation SA/yield was higher than 3 m^2/kg. Yield prediction was based on the number of clusters counted, estimation of number of berries per cluster and estimation of berry weight according to the weight observed the previous years.

Experimental determinations. Plant water status was evaluated through leaf water potential measured before dawn by means of pressure chamber technique. All measurements were made from June until harvest. Dry matter of renewable parts of the vine (shoots + leaves + clusters + second crop) has been evaluated from twelve representative shoots of each experimental treatment at the end of each vegetative cycle. Grape yield and number of clusters were measured on each control vine. Just before harvest time a sample of 200 berries per treatment and replication was picked, weighted and crushed. Total acidity (expressed as g/l of tartaric acid), pH and total soluble solids (^{o}Brix) were measured over an aliquot part of the must. In the left part of the must, concentration of polyphenolic substances (total polyphenols index, total and extractable anthocyanins) were measured through method of Glories (2001).

RESULTS AND DISCUSSION

Pre-dawn leaf water potential. The predawn leaf water potential shows, along the two years of study, a decrease tendency during the cycle in the non-irrigation as well as in the irrigation water regime (figure 1). In the middle of August 2002 and the first days of September 2003 the vine water stress was reduced due to the occasional rainfalls, but the increasing tendency of water stress was maintained after those moments in both experimental treatments. Once the irrigation was started, the irrigated treatment showed higher values than the non irrigated one, with statistically significant differences between both (table 1). In 2002 the non irrigated treatment reached a minimal value of -0.77 MPa in July and maintained the leaf water potential around -0.7 MPa during the rest of the season. These values represent a strong water stress (Carbonneau 1998). During the same year, although watering was applied, the treatment 20 reached high water stress levels with values under -0.5 MPa in some concrete moments (Carbonneau 1998). The higher quantity of rainfall in 2003 avoided getting so low values as it happened in 2002. The non irrigated treatment showed values that indicates a strong water stress (-0.6 MPa) only at the end of the vegetative cycle. The irrigated treatment showed a light stress that became more evident at the end of the cycle, reaching a minimum value of -0.48 MPa.

Similar results were obtained by different authors (Yuste 1995, Cuevas 2001, Pérez 2002), who found that neither the non-irrigation nor the apply of minimum doses of irrigation avoid the decrease of the soil water content along the season and, consequently, the water stress of the vines were more intense over the season. The cited authors point out the evident influence of the irrigation on the pre-dawn leaf water potential even when the doses applied are very low.

Global productivity. The dry matter production per unit of soil surface has responded to the different water regimes applied (table 2). Irrigation provoked highly significant differences between treatment 20 and treatment 00 on both years. The irrigation caused an increase in total dry matter of 56% in 2002 and 86% in 2003. The increase of dry matter, caused by the irrigation, has been due to the decrease of the water stress level during the season and the correspondent higher photosynthetic activity (Gomez del Campo 1988; Albuquerque 1993).

Yield. The irrigated treatment has showed much higher yield than the non irrigated treatment in both years of study (table 2). In 2002 the irrigation caused an increase on yield of 138% while in 2003 the increase was about 85%. In 2002 the increase was due to the differences in cluster size and berry size, whereas in 2003 the number of clusters contributed to the increase of yield.

The higher water stress of the treatment 00 has reduced the berry size (McCarthy 1997, Ojeda *et al*. 2002, Roby *et al*. 2004) as well as the fertility, expressed as the number of berries per cluster (Buttrose 1974).

Grape quality

<u>Berry size.</u> Irrigation has provoked an increase of berry size about 85% in 2002 and 28% in 2003, with respect to the non-irrigation regime. In 2002 the low soil water content in the non-irrigation treatment provoked a very important reduction of berry size, whereas the irrigated treatment obtained a regular berry size. In 2003, the higher water content at the beginning of the vegetative cycle reduced the differences between treatments with respect to the berry size, although these differences continued being evident. Taking into account the berry growth pattern and the water and solutes transport (Ollat *et al*. 2002), the better water status of the treatment 20 allowed the regular incoming of water and soluble solids into the berry that increased the berry growth along the ripening period.

<u>Soluble solids</u>. The treatment 00 showed a higher concentration of soluble solids than the treatment 20, in both 2002 and 2003, although the differences were not statistically significant in 2003 (table 3). The higher sugar concentration of treatment 00, in 2002, was due to a concentration process, as it can be deduced by the berry growth evolution (data non showed) during the ripening period. The concentration process was provoked by the intense water deficit suffered by the non irrigated vines along that year.

The similar results on the final sugar concentration among treatments in 2003 were related with the lower water stress in the treatment 00 (table 1) and its lower yield (table 2). Yuste (1995), Cuevas (2001) and Pérez (2002) found the same result while studying the irrigation effect on Tempranillo variety. Cuevas (2001) said that the lower carbon assimilation on non irrigated vine leaves could be compensated by a higher leaf area per unit of grape weight.

<u>Total acidity.</u> Total acidity has been higher in the non irrigated treatment on both years, although the differences have been statistically significant only in 2002 (table 3). The higher berry size of the treatment 20 has contributed to the reduction of total acidity. Some authors like Mullins *et al.* (1998) and Ollat *et al.* (2002) said that the metabolic stability of the tartaric acid implies that the decrease of its concentration could be due to a phenomenon of dilution provoked by the increase of berry size. Taking into account that most part of the malic acid is metabolized along warm ripening periods, the

total acidity mainly depends on the concentration of tartaric acid (Winkler *et al*. 1974, Mullins *et al.* 1998).
pH. The treatment 00 has showed pH values significantly higher than the treatment 20 in both years of study. The simultaneous existence of higher total acidity and higher pH in treatment 00 should be related with a higher accumulation of potassium on berries, since potassium concentration is one of the most affecting factors to the must pH (Boulton 1980, Esteban 1995, Ollat *et al.* 2002). In this way, Boulton (1980) said that the reduction of photosynthetic activity of the leaves is related with the potassium transport from these towards the berries. So, the higher water stress of treatment 00 and the decrease of the photosynthetic activity could have caused a higher potassium accumulation on berries and also a higher pH.
Polyphenols. The non irrigated treatment has showed a higher polyphenolic concentration expressed through out total polyphenols index, total and extractable anthocyanins, in 2002 as well as in 2003 (table 3), with statistically significant differences for each parameter, except total polyphenols index in 2003. Both berry size and water stress status of the non irrigated treatment are responsible for its higher polyphenolic concentration. Many authors (McCarthy 1997, Ojeda *et al.* 2002, Roby *et al.* 2004) have demonstrated the influence of the berry size through out the skin/pulp relation on the phenolic concentration. Besides, the water stress affects the polyphenolic synthesis as Ojeda *et al.* (2002) and Roby *et al.* (2004) have said.

CONCLUSIONS

In spite of the low irrigation doses applied, the irrigation has had a decisive effect on the physiologic activity of the vineyard. As a consequence of it, both global dry matter production and yield have clearly increased.

The pre-dawn leaf water potential has clearly showed the differences on water status between vines poorly irrigated and non irrigated vines.

The water stress derived from no irrigation has caused an improvement in the quality of grapes through out the increase of sugar concentration and, especially, the increase of the polyphenolic concentration, in spite of the remarkable decrease on yield.

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Tables

Table 1. Predawn leaf water potential (MPa) of treatments 20 (20% ETo) and 00 (0% ETo) in 2002 and 2003. Analysis of variance, signification levels: - (ns), * (p<0.05), ** (P<0.01).

2002	14/06/2002	19/07/2002	20/08/2002	26/09/2002
20	-0.33	-0.51	-0.39	-0.54
00	-0.36	-0.77	-0.68	-0.73
	-	**	*	**

2003	05/06/2003	19/06/2003	04/07/2003	18/07/2003	29/07/2003	13/08/2003	26/08/2003	10/09/2003	23/09/2003
20	-0.09	-0.08	-0.31	-0.24	-0.27	-0.28	-0.48	-0.31	-0.47
00	-0.11	-0.08	-0.29	-0.37	-0.41	-0.57	-0.59	-0.49	-0.60
	-	-	-	**	*	**	*	**	*

Table 2. Dry matter production, grape yield, bunch number, bunch weight and berry size treatments 20 (20% ETo) and 00 (0% ETo) in 2002 and 2003. Analysis of variance, signification levels: - (ns), * (p<0.05), ** (P<0.01).

2002	dry matter ($g \cdot m^{-2}$)	yield ($kg \cdot m^{-2}$)	bunch number ($bunch \cdot m^{-2}$)	bunch weight (g)	berry size (g)
20	377.64	0.460	2.79	0.165	1.69
00	240.97	0.193	2.81	0.069	0.91
	**	**	-	**	**

2003	dry matter ($g \cdot m^{-2}$)	yield ($kg \cdot m^{-2}$)	bunch number ($bunch \cdot m^{-2}$)	bunch weight (g)	berry size (g)
20	573.99	1.093	5.30	0.206	1.63
00	307.38	0.589	4.27	0.137	1.27
	**	**	*	**	**

Table 3. Soluble solids, total acidity, pH, T.P.I., extractable anthocyanins and total anthocyanins treatments 20 (20% ETo) and 00 (0% ETo) in 2002 and 2003. Analysis of variance, signification levels: - (ns), * (p<0.05), ** (P<0.01).

2002	soluble solids (ºBrix)	total acidity TA (g/l)	pH	T.P.I	extractable anthocyanins (mg/l)	total anthocyanins (mg/l)
20	23.25	4.53	3.64	85.15	1232	1732
00	25.95	5.09	3.78	94.60	1772	2244
	**	**	*	-	*	**

2003	soluble solids (ºBrix)	Total acidity TA (g/l)	pH	T.P.I	extractable anthocyanins (mg/l)	total anthocyanins (mg/l)
20	22.27	4.23	3.87	40.56	903	1711
00	22.55	4.75	4.03	47.78	1351	2344
	-	-	*	**	**	**

Figures

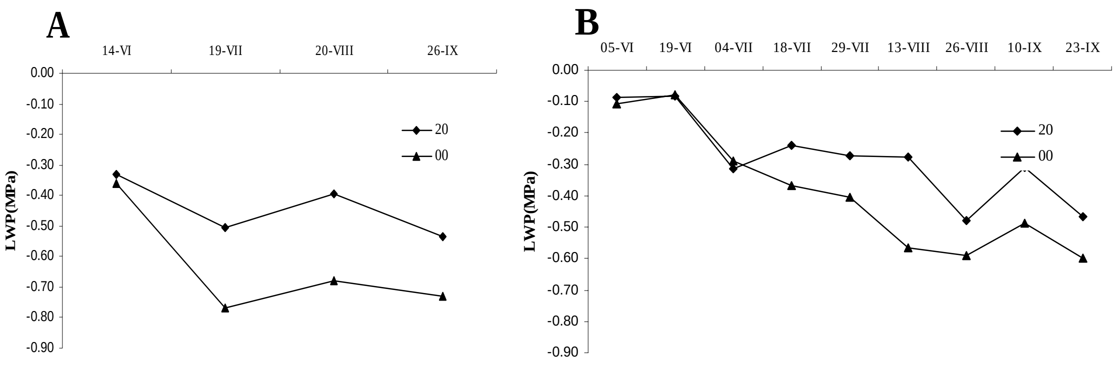

Figure 1. Seasonal evolution of predawn leaf water potential (MPa) of treatments 20 (20% ETo) and 00 (0% ETo) in 2002 (A) and 2003 (B).