Influence of climate and deficit irrigation on grapevine physiology, yield and quality attributes, of the cv. Touriga Nacional at Douro Region

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ABSTRACT
The Douro Region located in Northeast Portugal, within the Douro river basin, is surrounded by craggy mountains that confer it characteristic Mediterranean like climate with important inter-annual variability, were grapevines are exposed to severe water stress during the summer period, which in some years strongly affects their "vintage" behaviour. In order to mitigate these effects a study was conducted in a commercial vineyard with cv Touriga Nacional growing under three water regimes: non-irrigated (NI) and two irrigation strategies (WR1-30% ETc and WR2-60% ETc), in three selected years (2005, 2007 and 2009) which according the classification proposed by Winkler and co-authors put this place in the zones V, III and IV, respectively. The results showed that non-irrigated grapevines experienced severe water stress and consequently lower photosynthetic rates, due to stomatal and mesophylic limitations. By contrast, moderate levels of irrigation had a positive impact on leaf gas exchange rates, ~~and~~ on yield and berry quality.

Key Words: *grapevine, climate, water stress, Douro Region.*

1 INTRODUCTION
Wine production is strongly influenced by the climate, which is considered a major factor in the ecosystem interactions that define "terroir" [11]. The climate varies from region to region and from one year to another resulting in the vintage effect with important impact on wine prices [12]. The importance of climate on vine physiology can be

described by the growing degree days and water stress experienced by vines [12, 14]. In Mediterranean field conditions, as in the Douro region, water deficits usually develop gradually during the summer and are normally associated with high temperature and irradiance stresses [2]. The climate is characterized by a notable inter-annual consistency of global insolation, temperature, and potential evapotranspiration along with significant annual and seasonal variation in precipitation, that develops deficit water balance [8], give rise to situations of intense summer stress with different limitations to photosynthesis [9], and constraints to quality under sever water limitations [10, 1, 5]. Projections of future warming at Douro region scale reveal higher growing season temperatures, increases in extreme temperatures, fewer cold events that are not as cold, more and higher heat stress events, and a lower diurnal temperature range will likely continue challenging the ability to adequately grow grapes and produce quality wine [6]. In order to mitigate these effects, vine growers promote evolutionary adaptation of cultural practices, introducing the irrigation in their vineyards. However, given the multiple characteristics of the topography, soil, variety and rootstocks and the scarcity of water resources, the knowledge of the water management strategies has been one of the most pertinent issues in the region. The aim of this work was to explore the effects of climate and irrigation levels in three different years on physiology, yield and quality attributes.

2 MATERIALS AND METHODS

This study was carried out in a section of a commercial vineyard (Touriga Nacional *x* 196-17), at Quinta dos Aciprestes (Real Companhia Velha), planted in 1998 (2,2m x 1m) in schist complex soil, on a vertical slope orientation of 25%, and trained on bilateral *Royat* with 12 buds per plant. The site has a Mediterranean-type climate with average annual rainfall of 560 mm. During the study years, 2005 was a very drought year, below the mean values, while 2007 and 2009 have similar annual precipitation, but with different seasonal pattern, with higher rainfall in 2007 growing season (Figure 1).

Three water regimes with four replications were imposed: non-irrigated (NI), and two water application strategies, WR1 (30% ETc) and WR2 (60% ETc). The water application start when the predawn leaf water potential (Ψ_{pd}) reach the value of -0,3 MPa (late June till mid-July), and stop near 2 weeks before the harvest, with drip pressure compensating 2,3 L/h emitters at 1,0 m spacing between two adjacent vines. During the seasons, the water stress was accessed through Ψ_{pd}, measured in six uncovered leaves (n=24), every 7 or 15 days, with a pressure chamber (model PMS 600). Climate data was collected with an automatic weather station (model ADCCON 733), located in the middle of the parcel. Leaf gas exchange measurements were performed in 2009 using a portable IRGA (LCpro+, ADC, Hoddesdon, UK), operating in the open mode. Net CO_2 assimilation rate (A), stomatal conductance (g_s), transpiration rate (E), ratio of intercellular to atmospheric CO_2 concentration (C_i/C_a) and intrinsic water use efficiency (A/g_s) were estimated from gas exchange measurements using the equations developed by [13]. Berry ripening was followed weekly, and at harvest, yield, vigour, pruning weight per vine was determined in 20 samples, and fruit composition using a 200 berry samples, for analysis of soluble solids (ºBrix), pH, titratable acidity, phenols and total anthocyanins as proposed by [4].

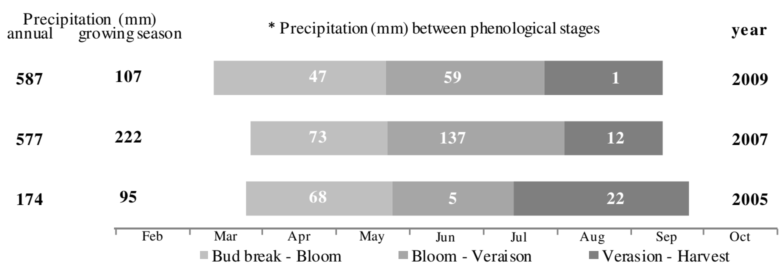

Fig 1 - Precipitation and phenology in 2005, 2007 and 2009.

3 RESULTS AND DISCUSSION

Table 1 exhibits the behaviour of the three years related to the temperature and the heat load during the summer, expressed in growing degree days (GDD) and number of the days with temperatures above the optimum for photosynthetic activity. The data shows substantial differences in GDD between the coolest year 2007, and the warmest year, 2005. In the warmer years we also note a very important percentage of days with temperature greater than 35ºC, with 2005 experiencing 50% of the days as compared to 12%, in 2007. The values in GDD observed, put this local in a Region III, IV and V, at 2007, 2009 and 2005, respectively, according with the classification proposed by [14] *in* [7].

Table 1 – Average growing season temperature (GST), growing degree-days (GDD), number of days with temperature >30ºC and >35ºC, % of the days with temperature >35 ºC from June to August, predawn leaf water potential (n=10) at veraison and ripening and (14) classification in 2005, 2007, 2009 and mean values for period 2002-2011.

Year	GST (Mar-Sep) (ºC)	GDD (Mar-Sep) (Cº units)	nº days (Mar-Sep) T>30 (ºC)	nº days (Mar-Sep) T>35 (ºC)	% days (J-J-A) T> 35 (ºC)	Ψpd (veraison) (MPa)	Ψpd (ripening) (MPa)	Winkler (Region)
2005	20.9	2372	92	46	50%	-1.34 c	-1.25 b	V
2009	20.2	2189	81	33	28%	-0.90 b	-1.19 b	IV
2007	19.3	1882	72	12	12%	-0.44 a	-0.67 a	III
2002-2011	*20.2*	*2179*	*86*	*33*	*32%*	*-0.91*	*-0.87*	*IV*

The results showed that vineyards in the Douro region frequently experience a severe water stress with predawn water potential levels below the general reference to different types of the wines [3], which reduce photosynthetic activity, mainly at midday, due to both stomatal and non-stomatal limitations, as can be seen by g_s and C_i/C_a values. Thus, irrigation has positive effects on leaf gas exchange rates and even in intrinsic water use efficiency by late August (Table 2).

Table 2 – Net photosynthesis (A, µmol m^{-2} s^{-1}), transpiration rate (E, mmol m^{-2} s^{-1}), stomatal conductance (g_s, mmol m^{-2} s^{-1}), intercellular CO_2 concentration/ambient CO_2 ratio (C_i/C_a), intrinsic water use efficiency (A/g_s, µmol mol^{-1}) and leaf water potential determined in 2009 at morning (except Ψ that was measured at predawn) and midday period for cv. Touriga Nacional under three water regimes. Values represent the mean (n=10). Within one diurnal period and parameter, means followed with different letters are significantly different at *P*<0.05.

Data	Diurnal period	WR	A	E	g_s	C_i/C_a	A/g_s	Ψ
29 Jul	Morning	NI	3.09 a	1.64 a	101.6 a	0.81 b	37.7 a	-0.94 a
(2009)		WR1	8.97 b	3.34 b	215.9 b	0.75 a	47.3 a	-0.58 b
		WR2	13.16 c	4.30 c	324.2 c	0.76 a	41.4 a	-0.34 c
	Midday	NI	0.64 a	0.54 a	18.7 a	0.84 b	37.7 a	-1.57 a
		WR1	8.74 b	2.44 b	123.8 b	0.61 a	41.4 a	-1.45 b
		WR2	11.70 c	3.34 c	187.6 c	0.64 a	42.0 a	-1.31 c
27 Aug	Morning	NI	3.56 a	1.67 a	136.6 a	0.87 b	25.8 a	-1.18 a
(2009)		WR1	11.26 b	2.69 b	225.0 b	0.73 a	49.8 b	-0.61 b
		WR2	13.54 b	2.88 b	254.6 b	0.69 a	55.6 b	-0.36 c
	Midday	NI	0.53 a	0.89 a	24.6 a	0.86 b	24.1 a	-1.54 a
		WR1	5.11 b	1.86 b	105.5 b	0.77 b	45.9 a	-1.21 b
		WR2	11.49 c	1.61 b	101.2 b	0.42 a	115.6 b	-1.19 b

The values for yield components, vigour and fruit composition are strongly affected by the year characteristics, with a significant yield reduction in 2005, mostly due to a decrease in cluster and berry weight, and also a reduction in sugar content and acidity (Table 3). Also in the NI vines, the leaf surface tends to decrease by scorching reaching 50% in years with severe water stress (data not shown). Both irrigation levels have a positive significant effect on yield due to an increase in clusters, number and weight, and berry weight. Irrigation also increases shoot weight and better balanced vigour (Ravaz index). Fruit quality changed with irrigation treatments, with an increase in sugar content and a reduction in acidity, although no significant effect was registered on pH. During the ripening period, a regular increase of sugar was observed during 2007 (data not shown), while sugar accumulation slowed or even stopped during the ripening period in 2009 and mainly in 2005.

Table 3 - Yield attributes, vigour, and fruit composition at harvest, determined in the 2005, 2007 and 2009 experiments for cv. Touriga Nacional under three water regimes. Values represent the mean (n=80 for yield and vigour; n=4 for fruit composition, 200 berry per sample). Means followed with different letters are significantly different at *P*<0.05. (*na* - data not available).

	Year			Water Regime (WR)			Interaction
	2005	**2007**	**2009**	**NI**	**WR1**	**WR2**	**Year x WR**
Clusters per vine (nº)	19.3b	19.9ab	20.8ab	18.8b	20.3a	20.9a	***
Yield per vine (kg)	1.35c	2.84a	1.74b	1.36c	2.15b	2.41a	*ns*
Cluster weight (kg)	0.07c	0.14a	0.08b	0.08c	0.10b	0.11a	***
Shoot weight (g)	29.2b	33.7a	33.8a	29.2b	32.4a	35.1a	*
Ravaz index	3.59b	4.80a	3.23b	3.03b	4.18a	4.40a	*
Berry weight (g)	0.9c	1.6a	1.3b	1.0b	1.3a	1.4a	*
ºBrix	21.3b	23.3a	24.0a	21.8b	23.4ab	23.5a	*ns*
Acidity (TA) (g/L)	2.83c	3.98b	4.39a	3.97a	3.59b	3.65b	**
pH	4.19a	3.66b	3.57b	3.85a	3.80a	3.77a	*ns*
Phenols (IPT)	*na*	55.1a	49.8a	55.4a	50.4a	51.8a	*ns*
Anthocyanins (mg/L)	*na*	1313.3a	1007.4a	1151.2a	1193.6a	1136.2a	*ns*

4 CONCLUSIONS

Grapevines experienced a severe heat and water stress with low levels of water potential and strong negative effects on physiology, yield and quality. Moderate levels of irrigation had a significant impact on yield and on berry sugar concentration. On the other hand, a variable behaviour regarding the interaction between climate conditions and water management, as a tool to regulate the "terroir" characteristics to achieve the better potential quality of the grapevines, was showed. Further work is needed to modeling the water stress management with climate variability in order to improve grapevine quality.

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