CUMULATIVE EFFECT (6 YEARS) OF DEFICIT IRRIGATION IN TWO IMPORTANT CULTIVARS OF DOURO REGION, PORTUGAL

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Abstract:

Context and purpose of the study - Numerous studies have demonstrated the importance of irrigation in improving the grape yield and quality in areas with arid and semiarid climates, particularly in the context of ongoing climate changes. However, the introduction of irrigation in vineyards of the Mediterranean basin is a matter of debate, in particular in those of the Douro Demarcated Region (DDR), due to the limited number of available studies in this region. The present study aimed to evaluate how different irrigation deficits for 6 years would influence production and must quality in Touriga Francesa (TF) and Touriga Nacional (TN) varieties.

Material and methods – Field grown plants of cultivars TF and TN, were tested in a commercial vineyard, at Douro Superior sub-region, between 2015 and 2020. Vineyards are planted in a steep slope area (slope of 45%), in terraces of two rows, in a schistic and acidic soil. Three irrigation regimes were compared to a rain-fed treatment, R0, based on the estimated crop evapotranspiration (ETc): R25 (25% ETc), R50 (50% ETc), R75 (75% ETc). Irrigation was performed every 15 days, based on weather parameters recorded at the meteorological station located in the plot.

Results – Regarding the production, the number of clusters/vine in TN at different irrigation debts were as follows: R0 = R25 = R50 < R75 (11% higher). In turn, the yield was as follows: R75 > R0/R50 > R25. In TF variety, the lowest number of clusters/vine was registered at R0 (24% lower than at R75), and the yield at all irrigation debts were higher than at R0. Considering the composition of the must of both varieties, evaluated during the six years of the trial, results showed that all irrigation debts did not change the sugar amount, pH and acidity (titratable and malic acid), nor phenolic compounds. In TN, values of pruning mass were higher at R75, while in TF the pruning mass was higher at R50. These results showed that irrigation in DDR did not significantly change berry quality traits and its effect in vine performance was inconsistent, thus suggesting that this agricultural practice should be implemented in a case-by-case scenario, depending on the cultivar, orientation, water holding capacity of the soil, microclimatic conditions, among others.

Keywords: Climate change, evapotranspiration, grapevine, must composition, yield.

1. Introduction

Several projections predict that climate change will significantly affect the hydrological cycle, leading in many agricultural areas of the planet, to more frequent droughts and heat waves, to alteration of the spatial and temporal patterns of precipitation, to an increase in crop evapotranspiration and to a general reduction of the available water for agriculture (IPCC, 2014). In Mediterranean regions, as in Douro, water deficits during the summer, associated with high temperature and irradiance stress, which depending on the time that occur and length, give rise to photosynthesis limitations (Moutinho-Pereira et al., 2004).

Water stress periods caused by unfavorable patterns of precipitation may reduce yield as well as compromise berry quality. Deficit irrigation is applied, generally, at advanced stages of berry development (II and III) to produce high value wines, since drought stress increases sugar accumulation, color and aroma intensity in berries (Bravdo et al., 1985). In Douro Demarcated Region, water stress levels can be severe during summer, though irrigation is often not recommended or even not allowed, as it can alter yield and quality attributes. Projections of future warming at this region, reveal more frequent higher growing season temperatures, and higher heat stress events, and reduction on precipitation, which will impact the ability to properly grow grapes and produce premium wines (Jones and Alves, 2012).
The aim of the present work was to test different irrigation deficits and compare to a non-irrigated treatment in two important varieties cultivated in Douro Region. Results were compared in terms of ecophysiological traits, vegetative development, yield and must quality.

2. Material and methods

Plant material and growing conditions

Plant material - Fourteen-years-old *Vitis vinifera* L. of cultivars Touriga Nacional (TN) and Touriga Francesa (TF) grapevines, grafted onto 110 Richter rootstocks and a plant density of 4546 vines/ha (2.2 m × 1.0 m), were used for the present study. Vines were spur-pruned, Royat single cordon, with a bud load of 10 buds per vine, in a hillside with 45% of slope and an average altitude of 180 m in Touriga Nacional and 240 m in Touriga Francesa. The trial was conducted in a randomized block experiment, with four treatments and three replicates (blocks) per treatment. Treatments corresponded to 25% ETc (R25), 50% ETc (R50), 75% ETc (R75), and control, a rainfed modality (R0). Drip-irrigation was applied bi-weekly (I15), from 2015-2020. Each experimental unit included 10 plants (4 treatments × 3 replicates × 10 vines).

Plant measurements - Reference evapotranspiration (ET_0) was estimated from weather parameters recorded at the meteorological station located in the plot (METOS®. Pssl Instruments, Weiz, Austria). ET_0 along with constant crop coefficient (Kc = 0.8) were used to calculate the amount of water required by the plants (ETc) using the equation $ETc = Kc \times ET_0$. The constant Kc was chosen from previous studies, considering the months where irrigation occurred, the vineyard characteristics, and the values described in the literature (Prichard, et al., 2004). The decision on starting irrigation was based on data provided by a soil probe (Aquagri, Oeiras, Portugal) installed in the field and when the value of predawn leaf water potential (Ψ_{PD}) is lower than -0.4 MPa. Ψ_{PD} was measured using a Schölander pressure chamber (PMS Instruments Co., Model 600, Corvallis, OR, USA), on eight plants per treatment (using one well exposed and fully expanded leaf per plant), every 15 days, before irrigation.
In each season, the number of buds and inflorescences per vine were registered. Total leaf area was assessed at maturation on 12 shoots (fruitful shoots of average length) per treatment (4 per replicate), according to Lopes and Pinto (2005) method. Fertility index and budburst rate were calculated. In winter, pruning mass per vine were recorded.
Quality of grapes were assessed using a sample of 200 berries per plot. Berry weight, probable alcohol (%), pH, titratable acidity (g/L), malic acid (g/L) and polyphenols (mg/L) were determined using Miura One® (ISE, Italy) following the Organisation Internationale de la Vigne et du Vin procedures (OIV, 2021). At harvest yield, berry weight and the number of clusters per vine, were collected.

Statistical analysis - One-way ANOVA analysis was performed, followed by Tukey HSD test at $p > 0.05$ using GraphPad Prism version 8.0 for Windows (GraphPad Software, La Jolla, CA, USA). Data are presented as mean value ± standard deviation.

3. Results and discussion

3.1. *Vegetative growth was mainly affected by irrigation*

Figure 1 presents the values of pre-dawn leaf water potential, measured each 15 days after irrigation. No major differences between treatments were registered, except in 2017 with R0 having much more negative values and all modalities, including the irrigated presented a weak to moderate water deficit (van Leeuwen et al, 2009).

Total leaf area, at maturation, demonstrated no differences in TN cultivar, whereas TF showed significant differences between R0 when compared with R25 and R75, with irrigated plants (R25 and R75) presenting a value about 43% higher than R0 (Table 1). Although water stress has little to no effect on shoot growth during post veraison stage, during ripening it can significantly diminish leaf area due to early senescence (O'Neill, 1983).
In terms of pruning weight in TN, the modality R75 registered the higher value (Table 1) and in TF, R50 presented a value 13% higher than R0, with R25 and R75 presenting intermediate values. Number of shoots also registered significant differences on both cultivars. In TN, R50 registered the higher amount, which was 1.06 times higher, compared to R25. For TF, plants that weren't irrigated registered the lowest value. As observed in table 1, fertility index, and budburst rate had not been influenced by irrigation.

3.2. *For 6 years, cumulative effects of irrigation were observed in yield parameters*

Berry weight is an important yield component, and it is often the most important factor in yield differences in deficit irrigation studies (Prichard, et al., 2004). This component registered significant differences in TN, with R75 and R50 registering the higher weight (Table 2), but no differences were registered in TF. The differences in TN can be explained by the lower values of soil water content during the growing season, and the higher temperatures on berry cell elongation period, leading to a reduction in cell division in pericarp tissue (McCarthy, 1999), and to a shrinkage of berries during advanced stages of ripening (Crippen and Morrison, 1986).
For number of clusters per vine, both varieties showed significant differences, with R25 presenting the lower value in TN and R25 and R75 presenting the higher value and R0 the lower in TF (Table 2). This trend was also observed in yield. In this case, TN presented the higher yield in R75 and the lower in R25. Regarding TF, it showed highest values in the three irrigated modalities (Table 2). Timing, severity, duration of water stress, seasonal variations, type of cultivar and interaction of genotype with environment can influence the response of vines to water stress, and this way, explaining the discrepancies seen in the results of different studies (Baeza et al., 2019).

3.3. *Berry composition was not affected by drip irrigation*

Irrigation treatments did not have significant impact in berry quality, including probable alcohol, pH, titratable acidity, anthocyanins, polyphenols and malic acid, either in TN or TF (Table 3). Irrigation did not influence sugar in TN, and also with no statistical meaning in TF. Girona et al. (2009) showed that only moderate water stress at post-veraison on Tempranillo vines (stem water potential < -1.0 MPa) can have positive effects on grape composition.

4. Conclusions

Grapevines can respond and adapt to both short- and long-term changes in environmental conditions such as soil water deficits through mechanisms such as stomatal closure (Chaves et al., 2010), osmotic adjustment with compatible solutes such as proline and sorbitol (Rodrigues, et al., 1993). Despite the influence of irrigation that is observed throughout the years, vintage effect can have an important effect on the growth and vegetative and productive development. Water regime did not affect the stability of phenolic compounds, as well as most of quality parameters, revealing that deficit irrigation can be an interesting management tool. However, irrigation treatments produced an increase in productive yield, compared to non-irrigated plants.
In the present study, despite considerable variation in growing season climate conditions from year to year, the irrigation treatment effects were consistent among years. There were some differences in vine physiology, growth and yield when irrigation with 75%, 50%, 25% of ETc is applicate between fruitset and harvest. Rainfed treatment, however, led to a reduction on yield, with the RDI regimes originating similar yields in TF variety.
Differences observed between Touriga Nacional and Touriga Francesa, resulted essentially from a tendency for higher vigour of TN and also from the fact that this variety is planted in a more fertile part of the field.
In conclusion, irrigation might be an adequate option for minimizing the effects of climate change as it increases fruit yield without major deviations in the quality of gapes.

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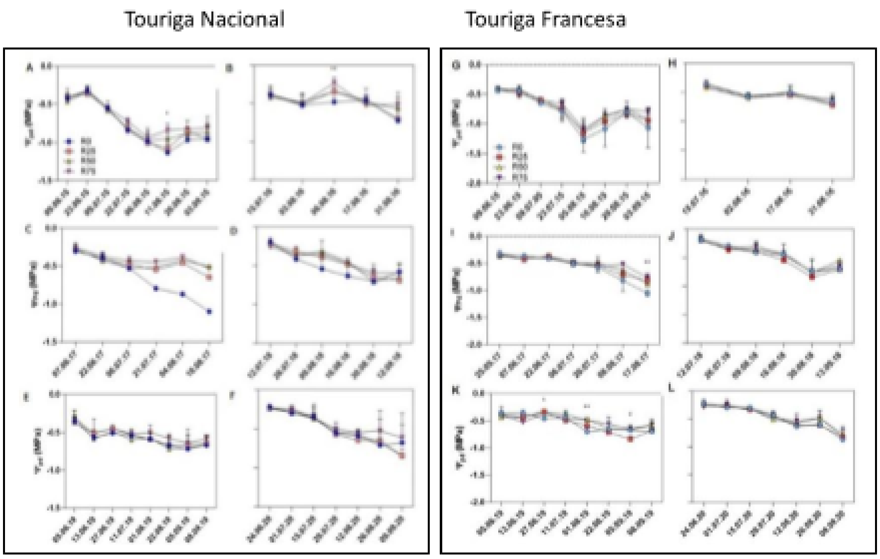

Figure 1: Pre-dawn leaf water potential in Touriga Nacional (A-F) and Touriga Francesa (G-L) (2015-2020). Each symbol represents the average of 8 measurements. Asterisks represent significant differences, with $p < 0.05$: R0 – rain-fed plants; R25 - irrigation at 25% ETc; R50 - 50% ETc; R75 - 75% ETc. Values are represented as mean ± standard deviation.

Table 1: Total leaf area, pruning weight, number of shoots, fertility index and budburst rate in cvs. Touriga Nacional and Touriga Francesa (2015-2020). Irrigation conditions: R0 - rain-fed plants; R25 - irrigation at 25% ETc; R50 - 50% ETc; R75 - 75% ETc. Values are represented as mean ± standard deviation. In each column, values with different letters present a statistical significance at $p < 0.05$ by Tukey HSD test.

Year / Treatment	Total LA (m^2/vine)	Pruning mass (kg/vine)	N°. shoots	Fertility Index	Budburst rate (%)
			Touriga Nacional		
R0	3.43±2.19	0.85±0.34 b	11.21±2.59 ab	1.21±0.38	111.6±21.6
R25	3.61±2.38	0.84±0.32 b	10.77±2.40 b	1.18±0.37	111.9±20.3
R50	3.71±1.85	0.88±0.33 b	11.39±2.14 a	1.18±0.39	112.9±17.6
R75	3.79±2.24	0.97±0.40 a	11.22±2.73 ab	1.21±0.38	111.9±18.9
***P* - value**	0.86	0.001	0.02	0.76	0.87
			Touriga Francesa		
R0	2.20±1.29 b	0.52±0.21 b	9.94±2.04 b	0.90±0.50	107.2±17.5
R25	3.09±1.98 a	0.55±0.23 ab	10.04±2.35 a	0.93±0.38	105.7±16.3
R50	2.92±1.55 ab	0.59±0.24 a	10.34±2.34 a	0.90±0.40	107.9±18.6
R75	3.18±1.86 a	0.56±0.22 ab	10.32±2.17 a	0.92±0.38	104.6±17.6
***P* - value**	0.007	0.001	0.04	0.69	0.05

Table 2: Berry weight, number of clusters per vine and yield in cvs. Touriga Nacional and Touriga Francesa (2015-2020). Irrigation conditions: R0 - rain-fed plants; R25 - irrigation at 25% ETc; R50 - 50% ETc; R75 - 75% ETc. Values are represented as mean ± standard deviation. In each column, values with different letters present a statistical significance at $p < 0.05$ by Tukey HSD test.

Year / Treatment	Berry Weight (g)	Clusters/vine	Yield (kg/vine)
	Touriga Nacional		
R0	1.26±0.14 b	16.07±5.56 ab	1.64±0.82 bc
R25	1.27±0.14 b	15.08±5.37 b	1.58±0.79 c
R50	1.32±0.15 ab	16.03±5.59 ab	1.79±0.82 b
R75	1.38±0.17 a	16.58±5.53 a	2.00±0.96 a
***P* - value**	0.01	0.01	0.001
	Touriga Francesa		
R0	1.66±0.22	8.72±3.66 b	1.62±0.93 b
R25	1.71±0.24	9.48±4.03 a	1.95±1.19 a
R50	1.78±0.21	9.38±3.86 ab	1.98±1.09 a
R75	1.77±0.16	9.89±4.16 a	2.01±1.13 a
***P* - value**	0.07	0.001	0.001

Table 3: Probable alcohol, pH, titratable acidity, anthocyanin, polyphenols content and malic acid in cvs. Touriga Nacional and Touriga Francesa (2015-2020). Irrigation conditions: R0 - rain-fed plants; R25 - irrigation at 25% ETc; R50 - 50% ETc; R75 - 75% ETc. Values are represented as mean ± standard deviation.

Year / Treatment	Probable Alcohol (%)	pH	Titratable Acidity (g/L)	Anthocyanins (mg/L)	Polyphenols (mg/L)	Malic Acid (g/L)
			Touriga Nacional			
R0	14.42±0.62	3.79±0.13	4.33±0.50	116.60±37.70	756.5±173.4	1.74±0.39
R25	14.59±0.51	3.80±0.12	4.49±0.47	123.00±40.23	801.9±206.3	1.72±0.27
R50	14.54±0.56	3.82±0.11	4.41±0.35	119.60±29.99	777.1±178.3	1.79±0.40
R75	14.49±0.55	3.82±0.12	4.52±0.37	111.20±27.49	766.7±161.3	1.91±0.28
***P* - value**	0.74	0.66	0.37	0.64	0.82	0.17
			Touriga Francesa			
R0	12.91±1.46	3.95±0.15	4.29±0.42	119.60±43.95	681.0±204.7	1.58±0.30
R25	13.44±1.79	3.99±0.17	4.20±0.43	121.20±42.09	703.7±216.9	1.80±0.42
R50	13.52±1.36	3.94±0.20	4.28±0.44	134.10±55.48	722.1±212.0	1.65±0.38
R75	13.67±1.48	3.97±0.16	4.29±0.47	142.60±49.21	737.1±209.9	1.65±0.36
***P* - value**	0.23	0.65	0.81	0.17	0.73	0.11