SHADING OF THE FRUIT ZONE TO REDUCE GRAPE YIELD AND QUALITY LOSSES CAUSED BY SUNBURN

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Abstract

Aim : To test the hypothesis that shading of the fruiting zone of the plants might reduce yield losses caused by excessive exposure to sun while avoiding the most damaging effects associated with reduced radiation.

Methods and results : A number of grapevine rows were shaded with a double layered white plastic netting on their south-facing side, from the ground to about 20 cm above the cluster zone. Data on meteorological conditions, plant growth, plant water availability, yield components and must characteristics were recorded during three growing seasons. Shading significantly increased yield but did not alter significantly the must characteristics.

Conclusion : Partial shading of the grapevine canopy reduced yield losses attributable to excessive radiation. The must obtained from shaded berries had a lower concentration of anthocyanins, and the wines made from these musts had a lighter colour which may be detrimental to their quality.

Significance and impact of the study : The study highlights the effects of solar radiation on the composition of grape musts and suggests a potentially cost-effective method to control excessive radiation in vineyards.

Key words : excessive radiation, *Vitis vinifera*, yield components, must characteristics

Résumé

Objectif : Vérifier l'hypothèse selon laquelle ombrager la zone de fructification des plantes permet de réduire les pertes de rendement causée par les coups de soleil tout en évitant les effets négatifs d'une réduction globale de la radiation.

Méthodes et résultats : Un certain nombre de rangs de vignes ont été ombragées avec une double couche de filet plastique blanc du côté sud, du sol jusqu'à environ 20 cm au-dessus de la zone de fructification. Des données sur les conditions météorologiques, le développement des plantes, l'état hydrique des plantes, les composantes du rendement et les caractéristiques des moûts ont été enregistrées pendant trois saisons de croissance. L'ombrage a augmenté significativement le rendement mais n'a pas changé significativement les caractéristiques des moûts.

Conclusion : L'ombrage partiel du couvert végétal a diminué les pertes de rendement causées par la radiation excessive. Les moûts des baies ombragées avaient une concentration d'anthocyanes plus faible et les vins produits à partir de ces moûts avaient une couleur plus légère, ce qui pourrait dévaloriser leur qualité.

Signification et impact de l'étude : L'étude met en évidence les effets de la radiation solaire sur la composition des moûts et indique une méthode rentable pour contrôler la radiation excessive dans les vignobles.

Mots clés : rayonnement excessif, *Vitis vinifera*, composantes du rendement, caractéristiques des moûts

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INTRODUCTION

The incidence of large numbers of shriveled berries on ripening grape clusters is very high in the Douro wine-producing region of Portugal. Fruits exposed to high radiation and heat are damaged by the sun; many berries desiccate completely (raisining), making the fruit inappropriate for winemaking, thereby reducing yield. This is a common phenomenon in regions with high light intensities and temperatures during the growing period (Cuevas *et al*., 2006; Krasnow *et al*., 2010; Greer and Weedon, 2012). Wine grape growers address this problem by opting for a north-south orientation of rows when slope permits so that fruits on both sides of the canopy achieve a balance in photosynthetic efficiency and exposure to solar radiation (Tarara *et al*., 2005; Cuevas *et al*., 2006). When east-west row orientation is unavoidable, yield loss due to sunburn can be substantial.

Exposure to radiation and heat can be reduced by shading the plants, but this creates an imbalance in the carbon budget, reducing vine biomass and consequently its reproductive allocation (Greer *et al*., 2011). Furthermore, canopy photosynthesis may also be negatively affected (Morandi *et al*., 2011). Faced with elevated doses of solar radiation, higher plants have evolved a number of effective protective mechanisms, one of which is the accumulation of phenolic compounds (Merzlyak *et al*., 2002; Solovchenko and Schmitz-Eiberger, 2003). Phenolic compounds have been the subject of considerable interest in the medical community due to their antioxidant, antimicrobial, antiviral and anticarcinogenic effects found in wine grapes, they are also important contributors to the organoleptic qualities of wine (Jackson, 2000; Cheynier, 2005). The skin of shaded berries displays lower concentrations of flavonol and proanthocyanidins compared to fully exposed berries (Koyama *et al*., 2012). The synthesis of anthocyanins and proanthocyanidins in the berry skin requires a particular combination of light and temperature (Tarara *et al*., 2008), the former being the most abundant class of phenols in grape berries and the latter being responsible for the bitter and astringent properties of red wine (Vidal *et al*., 2003).

Though shading may also influence vine development and must composition, there is no research-based consensus on these effects. Some authors report that shading has little effect on berry ripening and sugar accumulation but increases the pH and titratable acidity of the must (Ristic *et al*., 2007; Matus *et al*., 2009). Others have found that shaded berries ripen later and have a lower total soluble content (Bertamini *et al*., 2007; Marta *et al*., 2008; Abd El-Razek *et al*., 2010). Greer and Weedon (2012) found that irradiance, irrespective of seasonal temperatures, has no effect on the timing of budbreak nor on shoot phenology, stem growth or yield. While shade may slow vine development it may also promote increased leaf size (Greer *et al*., 2010). Nevertheless, the precise response of grapevines to shading is dependent on the grapevine genotype and also on the berry cluster microclimate, something that is influenced by viticultural practices such as vine training, row orientation, leaf canopy density and position of the grape clusters (Pastore *et al*., 2013).

It is not practical or cost-effective to shade entire vines, since it can exacerbate the imbalance between the supply of and demand for carbon and result in greatly reduced vine biomass (Greer *et al*., 2011). However, shading only the fruiting zone of the vines may reduce sunburn-induced yield losses and still avoid the adverse effects of an overall reduction of radiation. To test this hypothesis, a number of east-west oriented rows of a commercial vineyard were shaded either from the onset of fruit setting to maturation or from veraison to maturation over three successive growing seasons. The yield components and the must characteristics were compared with non-shaded vines.

MATERIALS AND METHODS

1. Plant material

The field trial was conducted from 2010 to 2012 on a commercial, 2-hectare, rain-fed vineyard with 27-year-old grapevines (*Vitis vinifera* L., cv. Touriga Nacional) in the Douro Demarcated Region (DRD) in Portugal (41º 08' North, 7º 08' West). The rows were about 70 m long, oriented east-west, and spaced 2 m apart with 1 m between the vines within each row. Once the canopies were fully developed, the rows formed a hedge that was maintained at a height of 1.6 m and width of 0.6 to 0.8 m. Weeds were controlled by mowing from budbreak to harvesting. The soil – sandy-skeletal mixed thermic Udalfic Arent – is the most common for wine production in the DRD (COBA, 1987). Rainfall is about 400 mm a year: while averaging 100 mm from May to September when the canopies are most developed, it can be as low as 7 mm in August. Evaporation from a class A pan is in excess of 1 460 mm a year, with 950 mm from May to September, averaging more than 6 mm a day (Mendes, 1991). An onsite meteorological station (Skye Instruments LTD, www.skyeinstruments.com) provided data on rainfall, air temperature, relative humidity, and total radiation at one-hour intervals.

2. Shading treatments

Thirty rows were chosen randomly. Ten were shaded after fruit setting until maturation (S_f), ten were shaded from veraison to maturation (S_v), and ten were left non-shaded (S_o). On the south-facing side, the lower third of the canopy (i.e., from the ground to about 20 cm above the point of insertion of grape clusters) was covered with a double layer of a white plastic netting (« MOVPROTECT », transparent, highly UV stabilized woven fabric produced from HDPE monofilaments ; COTESI, www.cotesi.com). The netting was attached to iron spikes driven into the ground at 3-m intervals. Measurements of solar radiation taken above and below an identical piece of netting, extended horizontally over the ground, indicated that it could reduce total solar radiation by 23 % and photosynthetic active radiation (PAR) by 27 %.

Total solar radiation, air temperature, relative humidity (Skye Instruments LTD, www.skyeinstruments.com) and PAR (LI-COR LI-250A Light Meter, www.licor.com) were measured above the canopy and inside the canopy (close to the clusters). The temperature of clusters adjacent to the rachis was also measured on two plants, one located in a shaded row (S_f) and the other in a non-shaded row (S_o). All data were logged automatically (Delta-T Devices DL-2 logger, www.delta-t.co.uk) at one-hour intervals. At solar noon, and at random intervals along the rows, an infrared thermometer (RayTemp 8 Infrared Thermometer, www.keison.co.uk) was used to take a total of thirty temperature readings of berries : ten each from plants that had been shaded for the two distinct periods (S_f and S_v) and another ten from non-shaded plants (S_o).

Leaf water potential (Ψ_L) at solar noon was measured with a pressure chamber (Solfranc Tecnologias SL, Tarragona, Spain) on ten randomly-chosen vines that had been subjected to the different shading treatments. Each reading consisted of the average of Ψ_L over two well-lit leaves per plant. The same procedure was used to measure stomatal conductance (g_s), using an AP4 porometer (Delta-T Devices, www.delta-t.co.uk). Both Ψ_L and g_s readings were taken under clear skies on four separate dates : 18 June, 12 July, 30 July and 23 August in 2010 ; 20 June, 14 July, 30 July and 20 August in 2011 ; 22 June, 10 July, 31 July and 22 August in 2012.

3. Yield and quality measurements

When the grapes reached commercial maturity, ten plants from each treatment were randomly chosen for yield measurements. The leaves were collected and total leaf area measured in the laboratory with an area meter (LI-COR LI-3100C, www.licor.com). The grape clusters were harvested in order to quantify the number and weight of the clusters, the number of shriveled berries per cluster, and the weight and volume of the berries. The must obtained from three sub-samples of 500 berries each was used to determine pH, total soluble solids, tartaric and malic acids, glucose and fructose contents, total anthocyanins (*TA*) (OIV, 2005), extractable anthocyanins (*EA*) (Glories and Augustin, 1993) and polyphenol indices (*PI*) (Ribéreau-Gayon *et al.*, 2006).

4. Statistical analysis

The experiment layout was a completely randomized design. The factorial analysis and the mean separations (Tukey's) were performed using the SPSS statistical package (IBM Corp. Released 20.11. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY : IBM Corp.).

RESULTS AND DISCUSSION

The phenological development of the grapevines did not vary much from 2010 to 2012. Flowering occurred between 15 and 20 May, veraison between 10 and 15 July, and commercial maturation between late August and early September. Shading had no effect on the phenological stages of the vines as observed by other authors (e.g., Greer and Weedon, 2012). The meteorological conditions from May to September are summarized in Table 1. The most remarkable feature is the large variability of rainfall, which may be a factor in the yield differences (discussed later).

The highly significant ($P \leq 0.01$) reduction in both total radiation and PAR experienced at the center of the canopy where the clusters form (Table 2) was due to the cumulative effect of (a) the netting itself and (b) the leaves becoming closely pressed together and the shoots being prevented from expanding outwards as the canopy grew. Temperature inside the canopy was significantly ($P \leq 0.05$) higher than in the surrounding atmosphere, due to reduction of air circulation and consequent inhibition of its cooling effect (Whiting and Lang, 2001) ; however, while the netting itself caused no significant difference in temperature, it did reduce radiation significantly.

The shaded berries were approximately 1ºC cooler than non-shaded ones (Figure 1), but no significant difference could be detected between the two shading treatments (S_f and S_v). The temperature difference may be explained by lower incoming radiation reaching the clusters (Bergqvist *et al.*, 2001). While it

Table 1. Monthly total radiation, maximum value of solar radiation, average temperature and rainfall from May to September. DRD 2010 to 2012.

Year	Month	Total radiation (MJm^{-2})	Average daily max. solar radiation ($MJh^{-1}m^{-2}$)	Avg. temp. (ºC)	Rainfall (mm)
2010	May	797.36	3 971	22.4	45.7
	Jun	848.92	4 356	23.1	20.7
	Jul	955.51	4 111	27.5	0.0
	Aug	821.35	3 902	27.1	1.2
	Sep	514.01	3 420	22.3	4.8
2011	May	818.30	4 122	22.2	47.6
	Jun	919.01	4 259	22.7	0.0
	Jul	947.07	4 435	24.4	0.0
	Aug	767.89	3 899	25.2	19.6
	Sep	596.85	3 636	22.3	23.8
2012	May	789.45	4 392	19.2	74.8
	Jun	827.26	4 349	22.6	5.6
	Jul	971.17	4 212	25.0	10.8
	Aug	828.26	3 978	25.1	8.6
	Sep	574.92	3 578	22.7	21.2

is widely accepted that berry temperature affects composition, only differences of 3ºC or above have been reported as causing such changes (Bergqvist *et al.*, 2001 ; Pieri and Fermaud, 2005 ; Tarara *et al.*, 2008).

The vines' water status, evaluated by Ψ_L at solar noon, displayed the usual pattern, i.e., becoming more negative as the season progresses (Figures 2 and 3). In a hot climate where rainfall is scarce during the growing season, soil water is depleted as the canopy grows larger and maturing berries compete for water (Williams and Araujo, 2002 ; Intrigliolo and Castel, 2007 ; Williams *et al.*, 2012), the loss of hydration of the plant tissues being reflected in Ψ_L values. Ψ_L is positively correlated with net photosynthesis (Baeza *et al.*, 2007) because the plants respond to mild water stress by regulating g_s and reducing CO_2 assimilation, with higher degrees of water stress inducing non-stomatal regulation related to limited ribulose biphosphate regeneration, reduced carboxylation efficiency and impairment of photochemical reactions (Escalona *et al.*, 1999 ; Santos *et al.*, 2009). The plant decreases the g_s to limit water loss, thus, g_s has a curvilinear direct relationship with Ψ_L (Hochberg *et al.*, 2013).

The results obtained for g_s (Figures 4 and 5) showed neither a significant relationship with Ψ_L nor a clear pattern over the growing season. It must be noted, however, that there are too few pairs of data to establish a significant correlation between the two variables and that g_s is more sensitive than Ψ_L to particular atmospheric conditions at the time of the readings, such as vapor pressure deficit, solar radiation and wind speed (Sousa *et al.*, 2006 ; Gerosa *et al.*, 2012).

From these results it can be reasonably assumed that there was no significant difference in plant water status and g_s between the three shading treatments (S_o, S_f and S_v), and that these parameters did not affect the net photosynthesis per unit of leaf area.

Yield components were significantly lower in 2012 than in 2010 and 2011 (Table 3). For a given season and in the absence of significant influences of either

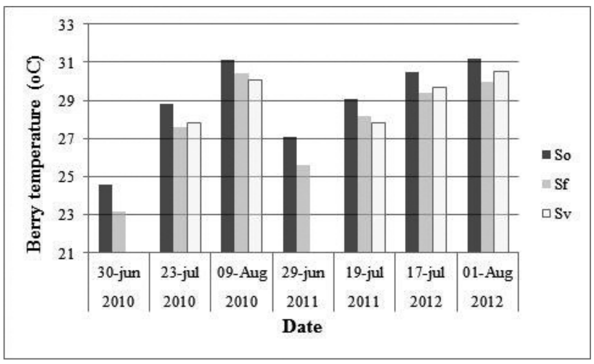

Figure 1. Average berry temperature at solar noon at random intervals with each treatment. Different letters above bars indicate a significant difference between treatments (Tukey´s$_{\alpha \leq 0.05}$). So, no shading; Sf, shading after fruit setting until maturation; Sv, shading from veraison to maturation. DRD 2010 to 2012.

Table 2. Averages for air temperature, relative humidity, solar radiation and photosynthetic active radiation (PAR) during day time from 15 July to 31 August above the canopy and inside the canopy at cluster level. DRD 2010 to 2012.

	Above canopy	S_o	S_f
Average air temperature (°C)	25.5	27.4^a	27.5^a
Average relative humidity (%)	43.0	37.8^a	36.8^a
Air temperature inside the cluster (°C)		26.1^a	26.9^a
Average solar radiation (MJh^{-1} m^{-2})	4140	0.745^a	0.367^b
Average PAR (mmol m^{-2} s^{-1})	1.31	0.20^a	0.14^b

Different superscript letters indicate a significant difference between treatments (Tukey´s$_{\alpha \leq 0.05}$)

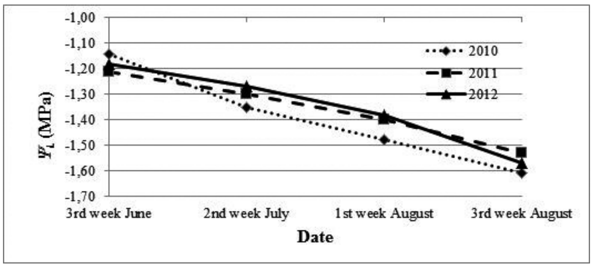

Figure 2. Leaf water potential (ΨL) on four dates during the grapevine growing season in three consecutive years, displaying no significant differences between years (Tukey´s$_{\alpha \leq 0.05}$). Interaction year x shading treatment was not significant. DRD 2010 to 2012.

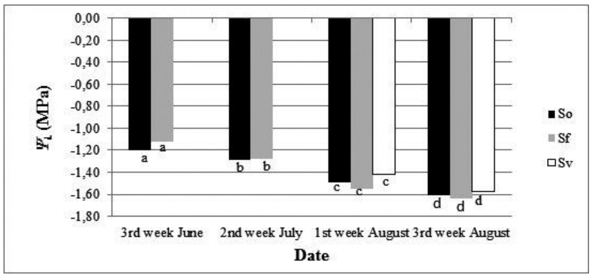

Figure 3. Leaf water potential (ΨL) on four dates during the grapevine growing season with each treatment. Different letters below each bar indicate a significant difference (Tukey´s$_{\alpha \leq 0.05}$). Interaction year x shading treatment was not significant. DRD 2010 to 2012.

diseases or pests, climate is the single most important factor determining yield (van Leeuwen *et al.*, 2004; Girona *et al.*, 2006). Poor fruit setting and a consequent loss of yield can be attributed to higher than usual rainfall in 2012 during the flowering stage (May). The shade netting was always placed after fruit setting and, thus, had no influence on this phenomenon. In 2012, both the larger number of sunburnt berries and the smaller size of the remaining berries compared to previous years contributed to yield reduction; however, there was no climatic data that correlated with this occurrence and there was no record of higher incidence of either diseases or pests.

Non-shaded vines consistently had a significantly lower yield than shaded ones. There was no significant difference in the number of clusters per vine (data not shown) between the two shading treatments and the lower yield for vines with no shading (S_o) can be attributed to the larger number of shriveled berries per cluster (twice as high as the levels experienced with shaded vines), while no significant yield differences between S_f and S_v were detected. Shading does not totally prevent raisining because this phenomenon is also caused by factors other than high radiation, mainly water stress (Bondada and Shutthanandan, 2012).

It was observed that leaf senescence started in the shaded part of the canopy soon after veraison, almost three weeks sooner than in non-shaded plants, and progressed much faster. At harvest, S_o had a significantly higher total leaf area than S_f and S_v. The reduction of available light results in leaf senescence (Lers, 2007) and it is the probable cause of the loss of leaf area. Total leaf area over the measured range appears to have no significant influence on yield.

The must characteristics (Table 4) were consistent with values reported for the same region (Guerra and Abade, 2008) and were typical for hot climate vineyards, especially the high total soluble solids and low acid contents (Pereira *et al.*, 2006; López *et al.*, 2007). Overall, shading had no significant influence on those parameters.

The results presented in Tables 3 and 4 suggest that photosynthetic carbon acquisition, which provides the substrates for structural carbon sequestered into biomass of the partially shaded grapevines, was not significantly different from the non-shaded plants.

Table 3. Mean separations of yield, percentage of shriveled berries per cluster, total leaf area at harvest, weight and volume of 200 berries for each shading treatment and year. DRD 2010 to 2012.

	Yield (g plant^{-1})	% Shriveled berries per cluster	Total leaf area (cm^2)	Weight of 200 berries (g)	Volume of 200 berries (cm^3)
Year					
2010	2403.6^a	7.3^a	32999.9^a	321.6^a	167.6^a
2011	2258.6^a	6.5^a	35043.3^a	307.9^a	149.1^a
2012	1095.0^b	12.3^b	32335.5^a	210.5^b	109.1^b
Treatment					
S_o	1503.5^a	13.7^a	43401.9^a	269.5^a	136.0^a
S_f	2172.0^b	5.8^b	31157.5^b	256.6^a	130.8^a
S_v	2075.6^b	6.7^b	26097.9^b	256.3^a	131.4^a

Different superscript letters indicate a significant difference between treatments (Tukey´s$_{\alpha\leq 0.05}$)

Table 4. Mean separations of pH, total soluble solids (TSS), concentrations of tartaric and malic acids, glucose and fructose for each shading treatment and year. DRD 2010 to 2012.

	pH	TSS (ºBrix)	Tartaric acid (g L^{-1})	Malic acid (g L^{-1})	Glucose (g L^{-1})	Fructose (g L^{-1})
Year						
2010	3.96^a	23.54^a	4.73^a	2.83^a	111.11^a	80.47^a
2011	4.16^b	25.26^b	3.24^b	1.28^b	111.56^a	80.83^a
2012	3.61^c	24.22^{ab}	4.72^a	1.38^b	124.56^a	127.96^b
Treatment						
S_o	3.90^a	24.15^a	4.48^a	1.71^a	123.36^a	103.37^a
S_f	3.78^b	24.20^a	4.32^a	1.91^a	120.92^{ab}	112.90^a
S_v	3.81^b	24.52^a	4.14^a	1.60^a	106.07^b	92.30^a

Different superscript letters indicate a significant difference between treatments (Tukey´s$_{\alpha\leq 0.05}$). Interaction year x shading treatment was not significant.

The concentrations of *TA* and *ET*, the phenolic compounds responsible for the red and purple colours that accumulate during ripening in berry skins of red grape varieties, and the *PI* are shown in Table 5. These were significantly higher in 2012 (lowest yield) than in previous years, but there is no data available that can be associated with this phenomenon.

Shading treatments clearly caused a significant reduction in both *TA* and *EA*, but had no significant effect on *PI*. The biosynthesis of phenolic compounds is sensitive to light environments, reflecting the role of these compounds for photoprotection in plants (Downey *et al*., 2006; Koyama *et al*., 2012), thus, the phenol content in berry skin increases with light intensity (Pollastrini *et al*., 2011). S_f and S_v berries received a much lower intensity of radiation than S_o berries and this is the very probable cause of the significant difference in *TA* and *EA* between shaded and non-shaded berries. Anthocyanins accumulate after veraison during ripening in berry skins of red grape varieties (Downey *et al*., 2006; Fujita *et al*., 2006), a very likely explanation for there being no significant difference in *TA* and *EA* between S_f and S_v.

PI is a colour parameter that measures the potential of a red wine for aging and hence its colour stability (Pérez-Lamela *et al*., 2007). According to the results for *PI*, the colour stability of wine made from shaded berries is not affected; however, the wine colour might be lighter due to a lower concentration of anthocyanins. For some types of wines and some specific wine markets, a light-coloured red wine is considered a quality defect.

With regard to the costs of canopy shading, it would cost 3 000 euros to shade 1 hectare with the netting used in this research, and the netting could be expected to last at least 10 years. Installing and removing the netting each year would cost about 150 euros per hectare. Thus, shading may increase yield by 2 500 kg ha^{-1}, which corresponds to 4 325 euros, assuming a price of 1.73 euros per kilo of grapes (IVDP, 2012).

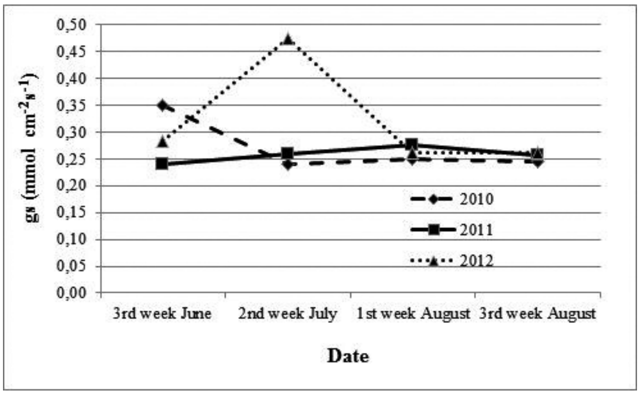

Figure 4. Stomatal conductance (gs) on four dates during the grapevine growing season in three consecutive years, displaying significant differences between readings on the first two dates (Tukey´s$_{\alpha\leq0.05}$). Interaction year x shading treatment was not significant. DRD 2010 to 2012.

CONCLUSIONS

Partial shading of grapevine canopies susceptible to large yield losses due to excessive radiation can increase yield up to 2 500 kg per hectare. The musts from shaded berries are not significantly different from those of non-shaded berries, except in the concentration of anthocyanins, which shading significantly reduces. Wines made from musts with lower anthocyanin contents have a lighter colour which might be considered detrimental to their quality. The added value of larger yields may permit growers to offset the cost of the netting and its installation and even increase their returns.

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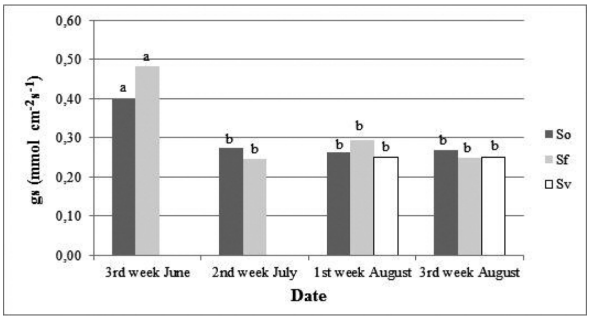

Figure 5. Stomatal conductance (gs) on four dates during the grapevine growing season with each treatment. Different letters above each bar indicate a significant difference (Tukey´s$_{\alpha\leq0.05}$). Interaction year x shading treatment was not significant. DRD 2010 to 2012.

Table 5. Mean separations of total anthocyanins (TA), extractable anthocyanins (EA) and polyphenol index (PI) for each shading treatment and year. DRD 2010 to 2012.

	TA (mg L^{-1})	EA (mg L^{-1})	PI
Year			
2010	688.18^{a}	532.93^{a}	45.59^{a}
2011	815.89^{a}	597.32^{a}	50.56^{a}
2012	1946.25^{b}	963.75^{b}	69.61^{b}
Treatment			
S_o	1534.11^{a}	824.98^{a}	59.82^{a}
S_f	990.10^{b}	678.60^{b}	55.46^{a}
S_v	1239.81^{b}	725.66^{b}	58.70^{a}

Different superscript letters indicate a significant difference between treatments (Tukey´s$_{\alpha\leq0.05}$). Interaction year x shading treatment was not significant.

REFERENCES

Abd El-Razek E., Treutter D., Saleh M.M.S., El-Shammaa M., Fouad A.A., Abdel-Hamid N. and Abou-Rawash M., 2010. Effect of defoliation and fruit thinning on fruit quality of ‘Crimson Seedless’ grape. *Res. J. Agric. Biol. Sci.*, **6**, 289-295.

Baeza P., Sánchez-de-Miguel P., Centeno A., Junquera P., Linares R. and Lissarrague J.R., 2007. Water relations between leaf water potential, photosynthesis and agronomic vine response as a tool for establishing thresholds in irrigation scheduling. *Sci. Hortic.*, **114**, 151-158.

Bergqvist J., Dokoozlian N. and Ebisuda N., 2001. Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. *Am. J. Enol. Vitic.*, **52**, 1-7.

Bertamini M., Zulini L., Zorer R., Muthuchelian K. and Nedunchezhian N., 2007. Photoinhibition of photosynthesis in water deficit leaves of grapevine (*Vitis vinifera* L.) plants. *Photosynthetica*, **45**, 426-432.

Bondada B. and Shutthanandan J., 2012. Understanding differential responses of grapevine (*Vitis vinifera* L.) leaf and fruit to water stress and recovery following re-watering. *Am. J. Plant Sci.*, **3**, 1232-1240.

Cheynier V., 2005. Polyphenols in foods are more complex than often thought. *Am. J. Clin. Nutr.*, **81**, 223S-229S.

COBA, 1987. *Carta de Solos e Carta de Utilização Actual do Solo do Nordeste de Portugal*. Universidade de Trás os Montes e Alto Douro, Vila Real, Portugal.

Cuevas E., Baeza P. and Lissarrague J.R., 2006. Variation in stomatal behaviour and gas exchange between mid-morning and mid-afternoon of north–south oriented grapevines (*Vitis vinifera* L. cv. Tempranillo) at different levels of soil water availability. *Sci. Hortic.*, **108**, 173-180.

Downey M.O., Dokoozlian N.K. and Krstic M.P., 2006. Cultural practice and environmental impacts on the flavonoid composition of grapes and wine : a review of recent research. *Am. J. Enol. Vitic.*, **57**, 257-268.

Escalona J.M., Flexas J. and Medrano H., 1999. Stomatal and non-stomatal limitations of photosynthesis under water stress in field-grown grapevines. *Aust. J. Plant Physiol.*, **26**, 421-433.

Fujita A., Goto-Yamamoto N., Aramaki I. and Hashizume K., 2006. Organ-specific transcription of putative flavonol synthase genes of grapevine and effects of plant hormones and shading on flavonol biosynthesis in grape berry skins. *Biosci. Biotechnol. Biochem.*, **70**, 632-638.

Gerosa G., Mereu S., Finco A. and Marzuoli R., 2012. Stomatal conductance modeling to estimate the evapotranspiration of natural and agricultural ecosystems. *In : Evapotranspiration - Remote Sensing and Modeling*. Irmak A. (ed.), InTech, available from http://www.intechopen.com/books/evapotranspiration-remote-sensing-and-modeling/stomatal-conductance-modeling-to-estimate-the-evapotranspiration-of-natural-and-agricultural-ecosyst.

Girona J., Mata M., del Campo J., Arbonés A., Bartra E. and Marsal J., 2006. The use of midday leaf water potential for scheduling deficit irrigation in vineyards. *Irrig. Sci.*, **24**, 115-127.

Glories Y. and Augustin M., 1993. Maturité phénolique du raisin, conséquences technologiques : application aux millésimes 1991 et 1992, pp. 56-61. *In : Actes du Colloque « Journée Technique du* CIVB », CIVB, Bordeaux.

Greer D.H., Weston C. and Weedon M., 2010. Shoot architecture, growth and development dynamics of *Vitis vinifera* cv. Semillon vines grown in an irrigated vineyard with and without shade covering. *Funct. Plant Biol.*, **37**, 1061-1070.

Greer D.H., Weedon M.M. and Weston C., 2011. Reductions in biomass accumulation, photosynthesis *in situ* and net carbon balance are the costs of protecting *Vitis vinifera* 'Semillon' grapevines from heat stress with shade covering. *AoB PLANTS*, doi : 10.1093/aobpla/plr023. Available from www.aobplants.oxfordjournals.org.

Greer D.H. and Weedon M.M., 2012. Interactions between light and growing season temperatures on, growth and development and gas exchange of Semillon (*Vitis vinifera* L.) vines grown in an irrigated vineyard. *Plant Physiol. Biochem.*, **54**, 59-69.

Guerra J. and Abade E., 2008. *Caracterização Enológica de Castas Autóctones da Região do Douro*. DRAPN, Lisboa. Available from http://www.drapn.min-agricultura.pt/drapn/conteudos/fil_trab/Trabalho % 20Castas % 20Brancas % 20e%20Tintas % 20do % 20Douro.pdf.

Hochberg U., Degu A., Fait A. and Rachmilevitch S., 2013. Near isohydric grapevine cultivar displays higher photosynthetic efficiency and photorespiration rates under drought stress as compared with near anisohydric grapevine cultivar. *Physiol. Plant.*, **147**, 443-452.

Intrigliolo D.S. and Castel J.R., 2007. Evaluation of grapevine water status from trunk diameter variations. *Irrig. Sci.*, **26**, 49-59.

IVDP (Instituto dos Vinhos do Douro e do Porto), 2012. *Comunicado de Vindima 2011*. Available from http://www.ivdp.pt/pt/docs/CVindima/Comunicado % 20Vindima % 202011.pdf.

Jackson R.S., 2000. Wine, health, and food, pp. 591-607. *In : Wine Science : Principles, Practice, Perception*. Taylor S. (ed.), Academic Press, San Diego.

Koyama K., Ikeda H., Poudel P.R. and Goto-Yamamoto N., 2012. Light quality affects flavonoid biosynthesis in young berries of Cabernet Sauvignon grape. *Phytochemistry*, **78**, 54-64.

Krasnow M.N., Matthews M.A., Smith R.J., Benz J., Weber E. and Shackel K.A., 2010. Distinctive symptoms differentiate four common types of berry shrivel disorder in grape. *Calif. Agric.*, **64**, 155-159.

Lers A., 2007. Environmental regulation of leaf senescence, pp. 108-144. *In : Senescence Processes in Plants - Annual Plant Reviews Vol. 26*. Gan S. (ed.), Blackwell Publishing Ltd., Oxford..

López M.I., Sánchez M.T., Díaz A., Ramírez P. and Morales J., 2007. Influence of a deficit irrigation regime during ripening on berry composition in grapevines (*Vitis vinifera* L.) grown in semi-arid areas. *Int. J. Food Sci. Nutr.*, **58**, 491-507.

Marta A., Di Stefano V., Cerovic Z., Agati G. and Orlandini S., 2008. Solar radiation affects grapevine susceptibility to *Plasmopara viticola*. *Sci. Agric. (Piracicaba, Braz.)*, **65**, 65-70.

Matus J.T., Loyola R., Vega A., Peña-Neira A., Bordeu E., Arce-Johnson P. and Alcalde J.A., 2009. Post-veraison sunlight exposure induces MYB-mediated transcriptional regulation of anthocyanin and flavonol synthesis in berry skins of *Vitis vinifera*. *J. Exp. Bot.*, **60**, 853-867.

Mendes J.C., 1991. *Normas Climatológicas da Região de Tras os Montes e Alto Douro e Beira Interior*. Instituto Nacional de Meteorologia e Geofísica, Lisboa, Portugal.

Merzlyak M.N., Solovchenko A.E. and Chivkunova O.B., 2002. Patterns of pigment changes in apple fruits during adaptation to high sunlight and sunscald development. *Plant Physiol. Biochem.*, **40**, 679-684.

Morandi B., Zibordi M., Losciale P., Manfrini L., Pierpaoli E. and Grappadelli L.C., 2011. Shading decreases the growth rate of young apple fruit by reducing their phloem import. *Sci. Hortic.*, **127**, 347-352.

OIV (International Organisation of Vine and Wine), 2005. *International Oenological Codex*. OIV, Paris.

Pastore C., Zenoni S., Fasoli M., Pezzotti M., Tornielli G.B. and Filippetti I., 2013. Selective defoliation affects plant growth, fruit transcriptional ripening program and flavonoid metabolism in grapevine. *BMC Plant Biol.*, **13**, 30.

Pereira G.E., Gaudillere J.P., Pieri P., Hilbert G., Maucourt M., Deborde C., Moing A. and Rolin D., 2006. Microclimate influence on mineral and metabolic profiles of grape berries. *J. Agric. Food Chem.*, **54**, 6765-6775.

Pérez-Lamela C., García-Falcón M.S., Simal-Gándara J. and Orriols-Fernández I., 2007. Influence of grape variety, vine system and enological treatments on the colour stability of young red wines. *Food Chem.*, **101**, 601-606.

Pieri P. and Fermaud M., 2005. Effects of defoliation on temperature and wetness of grapevine berries. *Acta Hort. (ISHS)*, **689**, 109-116.

Pollastrini M., Di Stefano V., Ferretti M., Agati G., Grifoni D., Zipoli G., Orlandini S. and Bussotti F., 2011. Influence of different light intensity regimes on leaf features of *Vitis vinifera* L. in ultraviolet radiation filtered condition. *Environ. Exp. Bot.*, **73**, 108-115.

Ribéreau-Gayon P., Glories Y., Maujean A. and Dubourdieu D., 2006. *Handbook of Enology Vol. 2 - The Chemistry of Wine Stabilization and Treatments*. John Wiley & Sons, England.

Ristic R., Downey M.O., Iland P.G., Bindon K., Francis I.L., Herderich M. and Robinson S.P., 2007. Exclusion of sunlight from Shiraz grapes alters wine colour, tannin and sensory properties. *Aust. J. Grape Wine Res.*, **13**, 53-65.

Santos M.G., Ribeiro R.V., Machado E.C. and Pimentel C., 2009. Photosynthetic parameters and leaf water potential of five common bean genotypes under mild water deficit. *Biol. Plant.*, **53**, 229-236.

Solovchenko A. and Schmitz-Eiberger M., 2003. Significance of skin flavonoids for UV-B-protection in apple fruits. *J. Exp. Bot.*, **54**, 1977-1984.

Sousa T.A., Oliveira M.T. and Pereira J.M., 2006. Physiological indicators of plant water status of irrigated and non-irrigated grapevines grown in a low rainfall area of Portugal. *Plant Soil*, **282**, 127-134.

Tarara J.M., Ferguson J.C., Hoheisel G.A. and Perez-Peña J.E., 2005. Asymmetrical canopy architecture due to prevailing wind direction and row orientation creates an imbalance in irradiance at the fruiting zone of grapevines. *Agric. Forest Meteorol.*, **135**, 144-155.

Tarara J.M., Lee J., Spayd S.E. and Scagel C.F., 2008. Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. *Am. J. Enol. Vitic.*, **59**, 235-247.

Vidal S., Francis L., Guyot S., Marnet N., Kwiatkowski M., Gawel R., Cheynier V. and Waters E.J., 2003. The mouth-feel properties of grape and apple proanthocyanidins in a wine-like medium. *J. Sci. Food Agric.*, **83**, 564-573.

van Leeuwen C., Friant P., Choné X., Tregoat O., Koundouras S. and Dubourdieu D., 2004. Influence of climate, soil and cultivar on terroir. *Am. J. Enol. Vitic.*, **55**, 207-217.

Whiting M.D. and Lang G.A., 2001. Canopy architecture and cuvette flow patterns influence whole-canopy net CO_2 exchange and temperature in sweet cherry. *HortScience*, **36**, 691-698.

Williams L.E. and Araujo F.J., 2002. Correlations among predawn leaf, midday leaf, and midday stem water potential and their correlations with other measures of soil and plant water status in *Vitis vinifera*. *J. Amer. Soc. Hort. Sci.*, **127**, 448-454.

Williams L.E., Baeza P. and Vaughn P., 2012. Midday measurements of leaf water potential and stomatal conductance are highly correlated with daily water use of Thompson Seedless grapevines. *Irrig. Sci.*, **30**, 201-212.