MECHANICAL FRUIT ZONE LEAF REMOVAL AND DEFICIT IRRIGATION PRACTICES INTERACT TO AFFECT YIEID AND FRUIT QUALITY OF CABERNET SAUVIGNON GROWN IN A HOT CLIMATE

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Abstract:

Context and purpose of this study – Cabernet Sauvignon is the top red wine cultivar in CA, however, the hot climate in Fresno is not ideal for Cabernet Sauvignon, particularly for berry color development. Fruit-zone leaf removal and irrigation were studied previously to have the significant effect on grape yield performance and berry quality. But the timing of leaf removal and the timing of irrigation are still inconclusive. Also, mechanical fruit-zone leaf removal is relatively new in CA. Our study aims to identify the interactive effect of mechanical fruit-zone leaf removal and irrigation on Cabernet Sauvignon's yield performance and fruit quality and find the ideal timing of leaf removal and irrigation to maximize the berry color while maintaining the sustainable yield level.

Materials and Methods – A two-way (2x3) factorial split block design, replicated in five times, was implemented in Madera for three seasons of 2018 to 2020. Two levels of irrigation were regulated deficit irrigation (RDI) and sustained deficit irrigation (SDI). Irrigation from RDI was maintained at 50% ETc from berry set to veraison and 80% ETc from veraison to harvest and irrigation from SDI was maintained at 80% ETc from berry set to harvest. Three timings of mechanical fruit-zone leaf removal were: 1) bloom, 2) berry set, 3) no leaf removal. Six adjacent vines were used as an experimental unit and a total of 180 vines were included for this experiment. Vine water status, fruit-zone PAR, and leaf gas exchange were collected in the season and yield performance and berry primary and secondary metabolites were measured at harvest.

Results – RDI increased berry anthocyanins by 14% in comparison of SDI and bloom and berry set mechanical fruit-zone leaf removal increased berry anthocyanins by 19% and 13% compared to no leaf removal. However, no interactive effect of leaf removal and irrigation on berry anthocyanins was found in our study. RDI significantly reduced the berry size and led to 15% yield decrease compared to SDI. No yield reduction was caused by either bloom or berry set leaf removal. Both RDI and leaf removal can be applied to improve berry anthocyanins. However, given the significant yield reduction from RDI, leaf removal, particularly at bloom, coupled with SDI should be preferred to increase berry anthocyanins without reducing the yield.

Keywords: Hot climate, Water, Leaf removal, Yield, Anthocyanins

1. Introduction

The San Joaquin Valley (SJV) is a viticultural area in California where $\geq$ 70% of CA wine grapes are grown (California Grape Crush Report 2022). The grapevines must be irrigated due to the arid and hot climate of this area, and the cost of energy to deliver water has increased and the further regulation might restrict the water supply (California Sustainable Groundwater Management Act 2014). In the SJV, deficit irrigation is a pivotal agronomic strategy to reduce applied water use while maximizing yield and fruit quality (Williams 2012, Martinez-Luscher et al., 2017). Sustained deficit irrigation (SDI) of 70%-80% ETc was found to balance economically sustainable yield, fruit quality, and water-savings goals (Williams 2010). Over-irrigation causes grapevines to grow excessively, shading the fruit, which can directly reduce quality and favor the development of fungal diseases (Keller 2015; Mendez-Costabel. et al., 2014). Severe water deficits, pre-veraison, significantly reduces grapevine vegetative and reproductive growth, reduces leaf photosynthesis, and delays fruit maturity by reducing net carbon assimilation (Keller 2015, Levin et al., 2020). Whereas, imposing grapevine a moderate and timely water deficit is desirable to sustain grape production and fruit quality while improving irrigation efficiency and reducing grapevineyard water input in a hot climate (Williams 2014; Levin et al., 2020). But level and timing of moderate water deficit varies on the production goal and climatic conditions.

Besides deficit irrigation, many growers remove leaves in the fruit zone, to increase fruit exposure which may directly improve fruit quality and create a microenvironment that discourages powdery mildew and bunch rots (Austin and Wilcox 2011; Zhuang et al., 2014). Leaf removal is most practiced in cool climates, however, studies on leaf removal in a hot climate also showed similar benefits (William 2012; Cook et al., 2015). Timing and extent of fruit zone leaf removal determines the potential impact on grapevine yield and berry chemical composition at harvest. In a cool climate, basal leaf removal prior to bloom may reduce berry set, thus lowering yield (Acimovic et al., 2016). Effects on berry set depend on the extent of leaf removal (Acimovic et al., 2016), and is also modulated by weather (Frioni et al., 2017). Whereas, in hot climates, mechanical fruit zone leaf removal prior to bloom had no effect on berry set or yield (Cook et al., 2015). In addition to the potential to reduce set, leaf removal prior to bloom can increase berry total soluble solids and anthocyanin content, and other secondary metabolites (Gatti et al., 2012; VanderWeide et al., 2018; Ryona et al., 2008). Recently, mechanical fruit zone leaf removal has gained popularity due to labor shortage and increased labor cost in CA (Kurtural and Fidelibus, 2021; Hed and Centinari, 2018; Zhuang et al., 2019).

A few studies investigated the interactive effects of irrigation and mechanical fruit zone leaf removal on grapevine yield and berry primary and secondary metabolites. According to the previous studies, there was no interactive effect of irrigation and leaf removal on yield and berry primary and secondary metabolites (Cook et al., 2015; Williams 2012). However, currently there is no such information on Cabernet Sauvignon grown in an arid and hot climate. The objective of this trial was to investigate whether irrigation and mechanical fruit zone leaf removal would affect yield and berry chemical composition of Cabernet Sauvignon grown in the SJV.

2. Material and Methods

Vineyard Site: The experiment was conducted in a commercial grapevineyard located in Madera County, CA (37.033984, -120.426657) and grapevines were planted on Pachappa fine sandy loam soil (www.nrcs.usda.gov). The grapevineyard was planted in 2013 with Cabernet Sauvignon (*Vitis vinifera* L.,clone FPS 08) on Freedom (*solonis* × *Othello* × *Dogridge*) rootstock. The grapevine plant spacing was 1.2 m × 3.0 m (grapevine × row) with the rows-oriented Northeast-Southwest. The grapevines were quadrilateral cordon trained, with a 55 cm cross-arm, to 1.2 m height above vineyard floor with a pair of catch wires 30 cm above the cordons. All cultural practices except irrigation and leaf removal were carried out according to University of California Cooperative Extension (Zhuang et al., 2019).

Experimental Design: This experiment was established on a two (deficit irrigation) × three (leaf removal) factorial split-plot design for three seasons: 2018 through 2020. Two adjacent grapevine rows comprised one block with irrigation treatment applied as the main plot, replicated in five times. One block was then split into three sub-plots for leaf removal treatments. There were 6 experimental units per block and each experimental unit comprised of 6 data grapevines. A total of 180 grapevines were used for this field study.

Irrigation treatments: The grapevines were first irrigated when the midday leaf water potential (Ψ) reached -1.0 MPa. Thereafter, irrigation was maintained at 80% of weekly crop evapotranspiration (ETc) for all irrigation treatments before berry set. ETc was calculated using the equation of ETc = ETo × Kc (Williams 2010). Reference evapotranspiration (ET_o) was obtained from the nearby California Irrigation Management Information System (CIMIS) station of Los Banos, Merced County, CA (37.096694, -120.7539) and the crop coefficient (Kc) was calculated using additional grapevines by measuring (weekly at solar noon) the shade cast on the vineyard floor beneath the grapevine canopy irrigated at approximately 120% of weekly ETc (Cook et al. 2015). This irrigation regime was achieved by installing three emitters per grapevine under the same irrigation duration as other irrigation treatment, and weekly midday leaf Ψ was measured to maintain the Ψ < 1.0 MPa. After berry set, sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI) treatments were applied differentially as main plots factors: SDI maintained 80% of weekly ETc from berry set to harvest, and RDI maintained 50% of weekly ETc from berry set to veraison, and after veraison, RDI was switched back to 80% of weekly ETc until harvest.

Leaf Removal: Leaf removal treatments were applied in sub-plots at two different times during the growing season: 1) bloom (Eichhorn-Lorenz 21), 2) berry set (Eichhorn-Lorenz 31), 3) no leaf removal as control (Coombe 1995). Grapevine phenological stages were assessed based on E-L system. Leaf removal was applied to both sides of the canopy using a roll-over leaf plucker with a sickle-bar sprawl clipper adapted for a sprawling-type canopy (Model EL-50, Clemens Vineyard Equipment, Woodland, CA). The leaf plucker defoliated a 60 cm window in the fruiting zone of the canopy to increase photosynthetically active radiation (*PAR*) in the fruiting zone. Midday photosynthetically active radiation (*PAR*) in the fruit-zone was measured per grapevine basis using a line quantum sensor (Li-191R, LI-COR Biosciences, Lincoln, NE). Midday leaf gas exchange was measured bi-weekly selecting a recently fully expanded leaf exposed to the direct sunlight, and two leaves per experimental unit were measured using portable gas exchange analyzer (Li-Cor 6400, LI-COR Biosciences, Lincoln, NE). Total leaf area per grapevine was measured destructively at veraison by defoliating a one-meter section of canopy from the adjacent non-data grapevines for a total of 30 replicates and all the leaves collected in the plastic bag were analyzed in the lab.

Yield Components: When the berry Brix reached approximately 24°, yield components (number of clusters, average cluster weight, average berry weight, and number of berries per cluster) were determined at harvest from each experimental grapevine using methods similar to those described by Fidelibus et al. (2009). Berry Brix, pH, titratable acidity (TA, g/L of tartaric acid), anthocyanins and phenolics were measured in the lab.

Statistical Analysis: All data were tested for normality using Shapiro-Wilk's test. When the normality test failed, data were log or square root transformed to pass the test. Three-way ANOVA (irrigation × leaf removal × year) was run for yield components and four-way ANOVA (irrigation × leaf removal × canopy side × year) was run for harvest fruit chemistry using the PROC MIXED procedure of SAS (v.9.4; SAS Institute, Inc., Cary, NC). Interaction of irrigation × leaf removal on Brix, year × irrigation on pH and TA were tested significant with p <0.05. Differences among treatment means were tested by Tukey's honestly significant difference at p <0.05 using Least Squares Means under the Mixed Procedure.

3. Results and Discussion

3.1 RDI reduced yield by 15% compared to SDI as a summary across three years, and the reduction of yield from RDI was mainly due to smaller berries and clusters (Table 1 and 2). Leaf removal did not significantly affect yield.

3.2 Grapevine primary metabolites were affected mainly by irrigation treatments in our study. RDI consistently reduced Brix at harvest across three years, while leaf removal had no effect on Brix. RDI, when compared to SDI, reduced juice pH at harvest in two out of three years, and no effect of leaf removal on juice pH was found (Table 2). Juice TA at harvest was not affected by either irrigation or leaf removal treatments. There was the significant interactive effect of leaf removal and irrigation on berry Brix (Table 2). Leaf removal either at bloom or berry set significantly increased berry Brix when SDI was applied, whereas leaf removal generally reduced the harvest Brix when RDI was imposed.

3.3 Grape anthocyanins were significantly affected by both leaf removal and irrigation treatments (Table 2). As a summary across three years, RDI increased berry anthocyanins at harvest by 14% in comparison of SDI, and bloom and berry set leaf removal increased anthocyanins by 19% and 13%, respectively compared to no leaf removal control.

4. Conclusion

Irrigation and leaf removal are the main viticultural practices used in the arid warm regions to manage canopy growth, yield formation and fruit quality. In our three years' study, RDI can increase berry anthocyanins at harvest by 14% in comparison of SDI with the sacrifice of 15% yield. Bloom and berry set leaf removal can increase anthocyanins by 19% and 13%, respectively compared to no leaf removal control, with no effect on yield. Given the significant reduction on yield from RDI, bloom leaf removal coupled with SDI should be the preferred practice in the SJV to increase berry color without negatively affecting the yield.

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Table 1. Harvest yield components of Cabernet Sauvignon from 2018, 2019, and 2020

Treatment	**Cluster No./grapevine**	**Yield (kg/grapevine)**	**Cluster weight (g)**	**Berry No./cluster**	**Leaf area (m^2/grapevine)**	**Leaf area:fruit weight ratio (m^2/kg)**	**Pruning weight (kg/grapevine)**	**Shoot No./grapevine**
RDI	89	10.8 b[a]	126 b	125	7.5	0.71 a	1.1 b	59
SDI	96	12.7 a	138 a	124	7.7	0.62 b	1.2 a	58
p value	*0.1173*	*0.0013*	*0.0099*	*0.6861*	*0.3275*	*0.0212*	*0.0443*	*0.4817*
Bloom	92	11.4	130	122	7.4 b	0.66	1.2	59
Berry set	93	11.8	132	126	7.2 b	0.63	1.1	58
No leaf removal	94	12.0	134	125	8.1 a	0.63	1.2	58
p value	*0.5592*	*0.0506*	*0.3240*	*0.4403*	*0.0293*	*0.1680*	*0.5082*	*0.1742*
Year	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Year×irrigation	*0.5487*	*0.3846*	*0.0971*	*0.8876*	*0.3032*	*0.1409*	*0.8933*	*0.3194*
Year×leaf removal	*0.4375*	*0.4873*	*0.5794*	*0.9080*	*0.5771*	*0.4045*	*0.8730*	*0.4109*
Irrigation×leaf removal	*0.3455*	*0.0516*	*0.3265*	*0.5283*	*0.3634*	*0.0515*	*0.3781*	*0.1691*
Year×irrigation×leaf removal	*0.5603*	*0.6012*	*0.8328*	*0.8162*	*0.1563*	*0.2703*	*0.9978*	*0.8254*

[a]Different letters within columns represent the significant differences according to the Tukey's HSD at $p < 0.05$

Table 2. Harvest berry chemistry of Cabernet Sauvignon from 2018, 2019, and 2020

Treatment	**Berry weight (g)**	**Brix**	**pH**	**TA[b] (g/L)**	**Anthocyanins (mg/g of FW[d])**	**Total phenolics (au/g of FW)**
RDI	1.03 b[a]	23.0 b	3.8	4.1	0.74 a	1.02
SDI	1.12 a	23.7 a	3.9	4.1	0.65 b	0.99
p value	*0.0027*	*0.0078*	*0.0699*	*0.9869*	*0.0048*	*0.1410*
Bloom	1.08	23.4	3.8 b	4.1	0.75 a	1.00
Berry set	1.07	23.3	3.9 a	4.1	0.71 b	1.02
No leaf removal	1.07	23.3	3.8 b	4.1	0.63 c	0.99
p value	*0.6324*	*0.5667*	*0.0044*	*0.4859*	*<.0001*	*0.1286*
Southeast side	1.07 b	23.4	3.9 a	4.0 b	0.69	1.01
Northwest side	1.13 a	23.3	3.8 b	4.2 a	0.70	0.99
p value	*<.0001*	*0.1228*	*<.0001*	*<.0001*	*0.7767*	*0.1937*
Year	*0.0002*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Year×irrigation	*0.4630*	*0.2817*	*0.0150*	*0.0200*	*0.5406*	*0.9221*
Year×leaf removal	*0.8682*	*0.9127*	*0.7882*	*0.1861*	*0.2901*	*<.0001*
Irrigation×leaf removal	*0.8794*	*<.0001*	*0.1674*	*0.1481*	*0.4222*	*0.4197*
Year×irrigation×leaf removal×side	*0.5292*	*0.9830*	*0.9307*	*0.8369*	*0.7715*	*0.6422*

[a]Different letters within columns represent the significant differences according to the Tukey's HSD at $p < 0.05$