CORDON HEIGHT AND DEFICIT IRRIGATION PRACTICES INTERACT TO AFFECT YIELD AND FRUIT QUALITY OF CABERNET SAUVIGNON AND PETITE SIRAH GROWN IN A HOT CLIMATE

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Abstract:

Context and purpose of this study – Cabernet Sauvignon and Petite Sirah are the top red wine cultivars in CA, however, the hot climate in Fresno is not ideal for red *Vitis Vinifera*, particularly for berry color development. Mechanical pruning and irrigation were studied previously to significantly affect grapevine yield performance and berry quality. But there is lack of studies on cordon height and irrigation on mechanical pruned vineyard system. Recently, mechanical pruning started to gain growers' interests in CA due to the vineyard labor shortage. Our study aims to identify the interactive effect of cordon height and irrigation on two wine cultivars' yield performance and fruit quality and find the ideal cordon height and irrigation to maximize the berry color while maintaining the sustainable yield level.

Materials and Methods – A two-way (2x2) factorial split block design, replicated in three times, was implemented in Fresno for two seasons of 2021 and 2022, and the same experimental design was applied for both Cabernet Sauvignon and Petite Sirah. Six years' old field grown vines were trained in bilateral cordon and spur pruned system with no catch wire. Two cordon heights were 1.3 m and 1.7 m above the vineyard floor. Two irrigation treatments were regulated deficit irrigation (RDI) and sustained deficit irrigation (SDI). RDI was maintained at 60% ETc from berry set to veraison and 80% ETc from veraison to harvest and SDI was maintained at 80% ETc from berry set to harvest. Five adjacent vines were used as an experimental unit and a total of 120 vines were included for this experiment. Vines were hand pruned in the first three years and box pruned with 10 cm spur height in the following three years. Temperature dataloggers were located at the fruit-zone and fruit-zone PAR were measured monthly. Vine water status and leaf gas exchange were measured in the season and yield performance and berry primary and secondary metabolites were measured at harvest.

Results – RDI reduced Cabernet Sauvignon berry weight and Petite Shira cluster weight compared to SDI as a summary across two years. But neither cordon heights nor irrigation treatments significantly affected the yield. High cordon increased leaf area per vine by 24% for Cabernet Sauvignon but not for Petite Shira, whereas high cordon increased leaf area to fruit ratio for Petite Shira but not for Cabernet Sauvignon. High cordon might offer benefits on cooler fruit-zone, higher Brix and berry anthocyanins compared to low cordon in the hot climate.

Keywords: Hot climate, Mechanical pruning, Cordon, Irrigation, Yield, Anthocyanins

1. Introduction

The San Joaquin Valley (SJV) is a viticultural area in California where ≥ 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 fruit quality and favor the development of fungal diseases (Keller 2015; Mendez-Costabel. et al., 2014). Severe water deficit, 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.

Vineyard mechanization recently has gained the popularity due to the labor shortage and increasing labor cost in CA (Kurtural and Fidelibus 2021). Nearly all wine grapes in the SJV have been mechanical harvested. Mechanical leaf removal and shoot thinning were also utilized in some wine programs (Kurtural and Fidelibus 2021). The last vineyard practice to be mechanized is pruning and currently there are lots of interests among growers to adopt mechanical pruning in their vineyard systems. Bilateral or quadrilateral cordons, spur pruned training is the most common trellising system for mechanical pruning. However, the cordon height remained a question and the wide variation on cordon height has been observed in the field with the range from 120 cm to 173 cm above the vineyard floor. Recent studies have shown that higher cordon produces more berry anthocyanins with cooler fruit-zone and becomes more resilient to drought and heat waves (Yu et al. 2022; Resseguier et al. 2023). However, currently there is no such information to compare different cordon heights on mechanical pruned vineyard system in an arid and hot climate. The objective of this research was to investigate whether cordon height and irrigation would affect yield and berry chemical composition of mechanical pruned Cabernet Sauvignon and Petite Shira grown in the SJV.

2. Material and Methods

Vineyard Site: The experiment was conducted in a commercial grapevineyard located in Fresno County, CA (36.669312, -119.935368) and grapevines were planted on El Peco fine sandy loam soil. The grapevine was planted in 2017 with Cabernet Sauvignon (*Vitis vinifera* L.,clone FPS 07) and Petite Shira (*Vitis vinifera* L.,clone FPS 03) on 1103 Paulsen (*berlandieri* × *rupestris*) rootstock. The grapevine plant spacing was 1.8 m × 3.0 m (grapevine × row) with the rows-oriented East-West. The grapevines were bilateral cordon trained, to 1.3 m or 1.7 m height above vineyard floor. Grapevines were two-budded at the first year and vine trunks and cordons were trained in the second year. Vines were slick pruned by hand in the third year, and box pruned with 10 cm spur height in the following years. The grapevine was drip-irrigated with pressure-compensating emitters spaced at 91 cm delivering 1.89 liter/hr. All cultural practices except irrigation were carried out according to University of California Cooperative Extension (Zhuang et al., 2019).

Experimental Design: This experiment was established on a two (irrigation) × two (cordon height) factorial split-plot design for two varieties and two seasons: 2022 through 2023. Two adjacent grapevine rows comprised one block with cordon height as the main plot, replicated in three times. Cordon height was set at 1.3 m or 1.7 m above the vineyard floor. One experimental block was then split into two sub-plots for irrigation treatments. There were 4 experimental units per block and each experimental unit comprised of 5 data grapevines. A total of 120 grapevines were used for this field study.

Fruit-zone Microclimate and Leaf Area: Fruit-zone temperature were collected hourly in 2022 using temperature sensor and datalogger (Pendant MX temperature/light data logger; Onset Co., Bourne, MA). 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 grapevine for a total of 24 replicates and all the leaves collected in the plastic bag were stored in the cooler and leaf area was measured using the leaf area meter (LI-3100C Area Meter, LI-COR Biosciences, Lincoln, NE) and the total leaf area per grapevine was calculated as reported by Cook, et al. (2015).

Plant Water Status: The midday leaf Ψ was assessed after each weekly irrigation cycle between 12:30 PM to 2:30 PM (solar noon) on a recently fully expanded leaf exposed to the sun and showing no sign of disease or damage. A zip-top plastic bag was placed over a single leaf and sealed around the petiole before it was severed. Then midday leaf Ψ was directly determined using a pressure chamber (Model 610 Pressure Chamber Instrument; PMS Instrument Co., Corvallis, OR). Two leaves per experimental unit were measured weekly during the growing season as described by Terry and Kurtural (2011).

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 Fresno State, Fresno County, CA (36.820833, -119.74231) 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). Those grapevines were not water stressed, and therefore were suitable for use to develop a non-stressed baseline Kc (Williams 2010). 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.

Yield components and berry composition: When the Brix reached at 25°, yield components were recorded such as cluster number, total weight, and berry weight. Harvest berry primary metabolites, such as Brix, pH, and TA, were measured in the lab using 100 berry samples. Harvest berry secondary metabolites, such as anthocyanins and phenolics, were quantified as well.

Statistical Analysis: All data were tested for normality using Shapiro-Wilk's test before ANOVA. When the normality test failed, data were log or square root transformed to pass the test. Two-way ANOVA (irrigation × cordon height) was run for yield components and berry primary and secondary metabolites using the PROC MIXED procedure of SAS (v.9.4; SAS Institute, Inc., Cary, NC). Only means were presented unless the interaction was 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 Cabernet Sauvignon berry weight and Petite Shira cluster weight compared to SDI as a summary across two years (Table 1 and 2). But neither cordon height nor irrigation treatments significantly affect the yield.

3.2 High cordon increased leaf area per vine by 24% for Cabernet Sauvignon but not for Petite Shira, whereas high cordon increased leaf area to fruit ratio for Petite Shira but not for Cabernet Sauvignon (Table 1 and 2). High cordon can also offer the benefit of cooler fruit-zone which can receive excessive heat in the hot climate.

3.3 Grapevine primary metabolites were affected neither by cordon height nor irrigation treatments in our study.

4. Conclusion

Mechanical pruning becomes the standard grapevine practice due to the labor shortage and cost in CA. In our two years' study, RDI can be adopted to reduce berry and cluster size on the mechanical pruned grapevineyard system, and the smaller berry and cluster size can be preferred for certain rot prone varieties. High cordon can provide cooler fruit-zone and more leaf area per vine on certain varieties that can benefit from higher berry Brix and anthocyanins in the hot climate.

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Table 1. Harvest yield components and berry primary metabolites of Cabernet Sauvignon in 2021 and 2022

Treatment	**Cluster No./grapevine**	**Yield (kg/grapevine)**	**Cluster weight (g)**	**Berry wt (g)**	**Berry No./cluster**	**Leaf area (m^2/grapevine)**	**Leaf area:fruit weight ratio (m^2/kg)**	**Shoot No./grapevine**	**Brix**	**pH**	**TA (g/L)**
High cordon	142	18.8	141	1.11	125	18.9 a[a]	1.01	76	24.8	3.8	4.0
Low cordon	150	19.7	137	1.19	113	15.3 b	0.78	78	23.3	3.7	4.5
p value	*0.2629*	*0.3892*	*0.5077*	*0.1921*	*0.0749*	*0.0480*	*0.1122*	*0.4312*	*0.2056*	*0.1933*	*0.1670*
RDI	145	19.0	138	1.09 b	124 a	17.2	0.91	79	24.1	3.7	4.2
SDI	147	19.5	140	1.21 a	114 b	17.0	0.88	76	24.1	3.8	4.2
p value	*0.6628*	*0.5249*	*0.6708*	*0.0059*	*0.0486*	*0.8716*	*0.6407*	*0.2545*	*0.9559*	*0.1726*	*0.9397*
Cordon×irrigation	*0.7607*	*0.7947*	*0.7348*	*0.6505*	*0.4880*	*0.7942*	*0.7551*	*0.3996*	*0.0647*	*0.2459*	*0.5333*
Year	*<.0001*	*0.6896*	*<.0001*	*0.0002*	*<.0001*	*0.0423*	*0.0208*	*0.0001*	*<.0001*	*0.0033*	*0.0746*
Year×cordon	*0.1518*	*0.2216*	*0.4088*	*0.6505*	*0.4557*	*0.9623*	*0.5024*	*0.4712*	*0.0870*	*0.0252*	*0.2869*
Year×irrigation	*0.2512*	*0.4519*	*0.6366*	*0.8455*	*0.5742*	*0.8716*	*0.5693*	*0.5503*	*0.1273*	*0.2140*	*0.3205*
Year×irrigation×cordon	*0.1330*	*0.7042*	*0.2356*	*0.6816*	*0.4177*	*0.7942*	*0.9584*	*0.6363*	*0.1677*	*0.1490*	*0.6382*

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

Table 2. Harvest yield components and berry primary metabolites of Petite Shira in 2021 and 2022

Treatment	**Cluster No./grapevine**	**Yield (kg/grapevine)**	**Cluster weight (g)**	**Berry wt (g)**	**Berry No./cluster**	**Leaf area (m^2/grapevine)**	**Leaf area:fruit weight ratio (m^2/kg)**	**Shoot No./grapevine**	**Brix**	**pH**	**TA (g/L)**
High cordon	85	15.7	185	1.23	157	10.9	0.71 a[a]	52	23.5	3.7	3.9
Low cordon	90	16.2	182	1.18	160	10.3	0.65 b	55	22.7	3.7	4.1
p value	*0.6186*	*0.7419*	*0.7963*	*0.6486*	*0.6402*	*0.4739*	*0.0192*	*0.0875*	*0.5898*	*0.5610*	*0.0819*
RDI	89	15.3	175 b	1.16	158	10.4	0.69	54	23.0	3.7	3.9
SDI	86	16.6	193 a	1.25	159	10.8	0.67	52	23.1	3.7	4.1
p value	*0.6757*	*0.3755*	*0.0431*	*0.2253*	*0.8194*	*0.6607*	*0.7937*	*0.2395*	*0.7778*	*0.7636*	*0.3083*
Cordon×irrigation	*0.5932*	*0.8456*	*0.1723*	*0.8609*	*0.3876*	*0.7673*	*0.4246*	*0.8744*	*0.7639*	*0.5558*	*0.1992*
Year	*0.8410*	*0.2330*	*0.0313*	*0.0005*	*<.0001*	*0.6955*	*0.1401*	*0.0017*	*0.0445*	*<.0001*	*0.0002*
Year×cordon	*0.1197*	*0.1460*	*0.6987*	*0.7642*	*0.6749*	*0.1193*	*0.8865*	*0.5649*	*0.0416*	*0.0751*	*0.7697*
Year×irrigation	*0.2051*	*0.2120*	*0.8137*	*0.8025*	*0.3171*	*0.6607*	*0.5090*	*0.8744*	*0.3475*	*0.8055*	*0.3758*
Year×irrigation×cordon	*0.9919*	*0.4556*	*0.3695*	*0.7453*	*0.3282*	*0.7673*	*0.5547*	*0.6369*	*0.2262*	*0.6301*	*0.6312*

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