EXTENDED ABSTRACT

Drip irrigation and precision cooling reduce impact of extreme heat events during berry ripening

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INTRODUCTION

Intensified frequency and severity of heat events are a major concern for the production of wine grapes. The analysis of historical weather data series has highlighted increasing trajectories for average and maximum temperature in the growing season across several viticultural regions worldwide (Jones and Webb 2010). Future climate projections have also been examined, showing that the maximum temperature and the number of days reaching critical temperatures for grape production (often identified as 35 or 38°C) are likely to continue increasing (Forrestel 2022). The impact of elevated temperature on vine performance has been thoroughly studied. Heat affects vine physiological processes both directly, through the inhibition of photosynthesis-related enzymes occurring over 35 °C (Greer and Weston 2010), and indirectly due to the frequent coupling between heat and water stress. Peaks in vapor pressure deficit (VPD) cause vines to modulate stomatal activity, a phenomenon that occurs in a genotype-specific manner. Yield formation is largely responsive to elevated temperatures and the degree of impact is dependent on the intensity and timing of heat, with a consensus that yield is negatively affected by supra-optimal temperatures (Fraga et al. 2020). The development of organic acids, phenolic and aroma compounds has been shown to be impaired by elevated temperatures, a phenomenon described as the decoupling between sugars and secondary metabolites (Previtali et al. 2021, Sadras and Moran 2012, Sweetman et al. 2014).

Given these considerations, the study of heatwave mitigation techniques has gained unprecedented importance. Irrigation is an essential tool to modulate plant water status, which directly influences yield and quality outcomes in wine grapes. In previous studies, increasing irrigation during heatwaves successfully reduced negative effects of heat spikes on vine physiology, yield and quality (Forrestel 2022). To optimize efficacy and sustainability of irrigation practices, the relative importance of irrigation amount and timing of supplemental irrigation prior to the heat event has also been characterized (Previtali et al. 2023). Another use of irrigation for heat mitigation is to provide cooling to vines, as widely experimented in California and Australia (Caravia et al. 2017, Kliewer and Schultz 1973), but concerns often remain as water is delivered directly on vine foliage or fruit which creating favorable conditions for fungal diseases. In this study, we tested novel technologies for precision vine cooling and drip irrigation treatments side by side, to compare the efficacy of these strategies for heatwave mitigation.

RESEARCH OBJECTIVES

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MATERIAL AND METHODS

Plant materials

The experiment was conducted in 2024 in a commercial vineyard located in the Alexander Valley (38°45'21''N, 122°59'3''W) American Viticultural Area of California. At the trial site, Cabernet Sauvignon (clone FPS 5 on 1103 Paulsen rootstock) was planted in 2010 and trained as a high-wire bilateral cordon with 1.8 and 3.0 m vine and row spacings. Standard growing practices were applied uniformly across the block throughout the season except for drip irrigation and vine cooling treatments described below.

Experimental treatments

Treatments were applied at each heatwave occurrence both pre- and post-veraison. Heatwaves were defined as two or more days with $T_{max} \geq 38$ °C based on the forecast temperature according to the National Oceanic and Atmospheric Administration National Weather Services. Six drip irrigation treatments were compared to a control that received baseline irrigation (80 % ET). The experimental treatments included two irrigation levels, 1.5x (+ 50% irrigation, 120 % ET) and 2x (double irrigation, 160 % ET), and three timings: 2 days prior (2dp), 1 day prior (1dp) or the first day of the heatwave (0dp). Variable irrigation was maintained throughout the heatwave and stopped on the first day with T_{max} < 38 °C. Different irrigation amounts were achieved by changing the irrigation duration (i.e. number of irrigation hours). Each treatment was applied to four replicates of 180 vines each. Four systems were utilized for vine cooling: COOL1 (CoolNet Pro, fogger), COOL2 (StripNet X, precision micro sprinkler), COOL3 (GyroNet, micro sprinkler) and COOL4 (MegaNet, full coverage sprinkler). All systems were provided by Netafim (Israel). COOL1 to COOL3 were equipped with Pulsar pulsating tube technology (Netafim, Israel), while COOL4 was operated in cycles of 10 min on/off. Precision cooling treatments were installed so that the drip and cooling systems could be operated independently. Drip irrigation for cooling treatments was applied in equal amounts and at the same time as the drip control. Cooling lines were triggered automatically when ambient temperature in the fruit zone exceeded 35 °C.

Plant measurements

Air temperature and relative humidity (RH) in the fruit zone was monitored using MX2301A HOBO sensors (Onset, Bourne, MA) installed in each treatment and replicate and on both sides of the canopy. VPD was calculated from temperature and RH data. Fine T-type thermocouple wires (DwyerOmega, Michigan City, IN) were inserted in six berries per treatment (two canopy sides, and top-middle-bottom positions) post-veraison and data were logged using a portable datalogger (DwyerOmega, Michigan City, IN). At the end of the season, yield components were measured on two vines per treatment and replicate. Samples for fruit composition were collected and analyzed following the procedure described in Previtali et al. (2021).

Statistical analysis

Treatments were compared using linear mixed models with irrigation treatments fitted as a fixed effect and block as random factor. Statistical analyses were conducted in R (R4.2.2, Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Heatwave characterization at the vineyard site

Temperatures recorded at the experimental sites indicated the occurrence of several heat events in 2024. With 76 and 39 days with Tmax exceeding 35 and 38 °C, the 2024 season was exceptionally hot when compared to average values for the previous decade (32 and 11 days respectively). The highest temperature recorded at the site was 45.1 °C on July 11. Two major heatwaves occurred in July, followed by shorter or less severe ones in August and September.

Effect of variable drip irrigation and precision cooling on fruit zone microclimate and berry temperature

Diurnal changes in fruit zone microclimate variables measured for each treatment are shown in **Fig 1A-C**. Changes in fruit zone T_{air}, RH and VPD were negligible under treatments with increased drip irrigation. All precision cooling systems significantly improved fruit zone microclimate, lowering temperature and VPD, however only two systems were able to continuously avoid fruit exposure to critical temperatures (≥ 38 °C), namely COOL2 and COOL4 (**Fig 1A**). Concurrently, VPD (**Fig 1C**) was reduced the most under these two treatments (VPD_{max} = 4.7 kPa in COOL2 and 4.3 kPa in COOL4) when compared to the high VPD of the control (6.1 kPa). Across the entire season, cooling systems significantly reduced the fruit exposure to critical temperatures, on average 78 hours with T > 38 °C in COOL4 compared to 160 hours in the control. Changes in berry temperature under the treatments investigated are shown in **Fig 1D** and reflected the differential cooling capacity measured using temperature sensors in the fruit zone.

Effect of variable drip irrigation and precision cooling during heatwaves on yield and fruit composition

Yield components and fruit composition parameters were significantly affected by the treatments applied (**Table 1**). Berry weight at harvest was maximized under the heaviest drip irrigation treatments (+100% irrigation applied 1 or 2 days prior to the heatwave), leading to berries on average 20-23 % heavier than the control. These results agree with previous studies on irrigation rates for heatwave mitigation (Previtali et al., 2023). Berry weights were slightly improved across the precision cooling treatments, but to a lesser extent and due to their lower contribution in terms of adding soil moisture. Yield data corroborated trends observed for berry weights, with a significant increase in vine yield (+50 %) obtained with the highest irrigation rate and earliest initiation (+100% irrigation, 2 days prior) and intermediate effects for the other drip irrigation and cooling treatments.

The efficacy of the treatments against heat effects was evident in TSS and moisture data, where treatment variation reflected different rates of berry dehydration. There were large significant effects under the heaviest heatwave irrigation and precision cooling treatments, where fruit displayed lower (up to -4 °Brix) and more on target TSS levels (25-26 °Brix) and significantly higher berry moisture. Anthocyanins displayed a positive trend with increasing drip irrigation during heatwaves, however the effect became not significant with in the 2dp irrigation treatments. The highest color was measured in cooling treatments, especially in COOL2 and COOL4 where the highest degree of cooling was observed. These findings add to previous reports on sprinkler cooling in vines, and larger effects observed in our study are to be attributed to technological advancements in cooling systems and precisely timed application of cooling allowed by automated systems.

CONCLUSION

Negative effects on yield and quality have been associated with heat exposure of grapevines. The present study shows adjusting vineyard irrigation during heatwaves and/or applying precision cooling techniques as heatwave mitigation techniques. Both approaches led to improved yield and quality overall, with primary effects on yield for increased drip irrigation during heatwaves and large quality enhancement under vine cooling.

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FIGURE

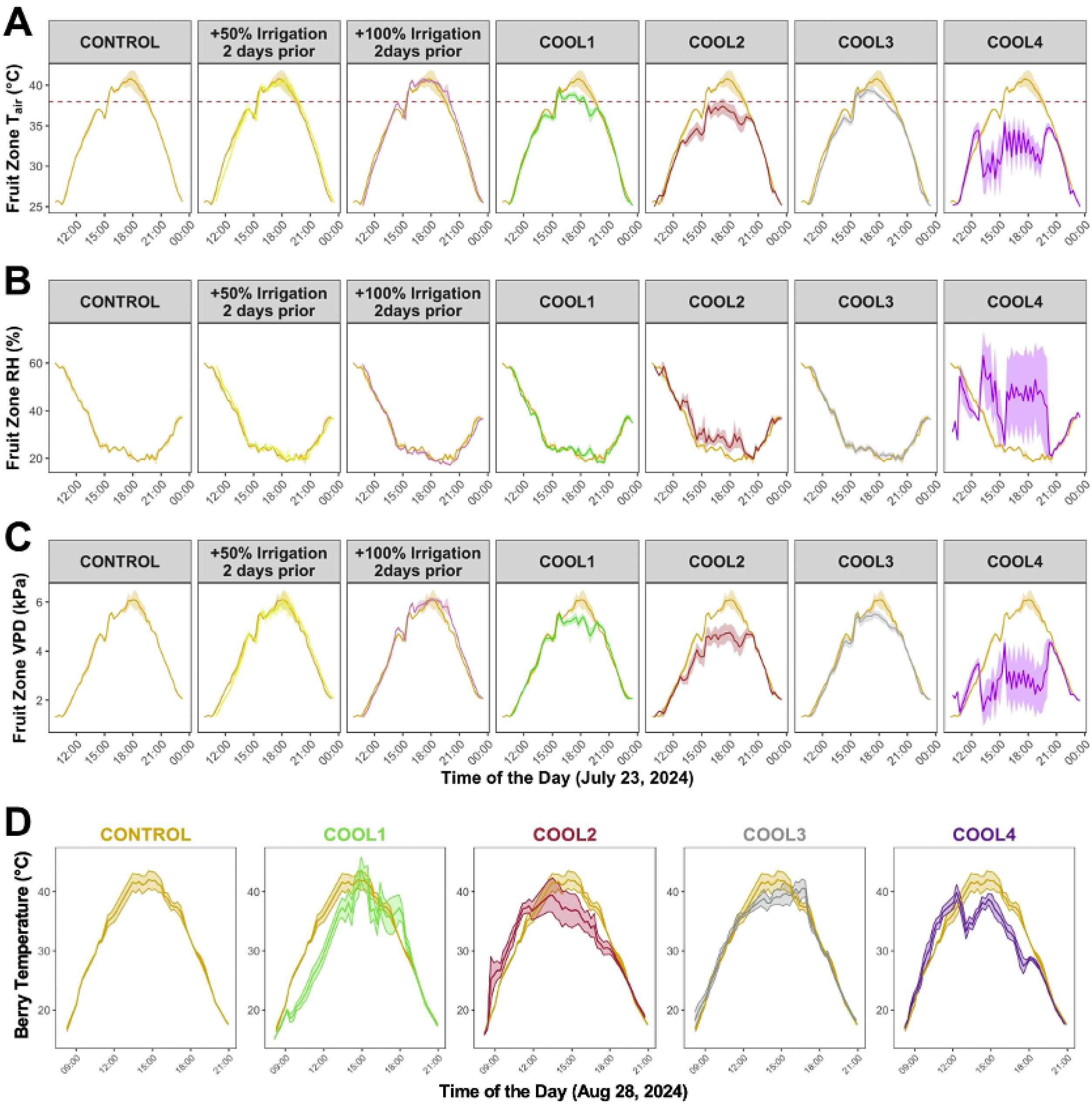

Figure 1. Effect of drip irrigation and precision cooling treatments on fruit zone microclimate and berry temperature: A) air temperature (Tair, °C); B) relative humidity (RH, %); C) vapor pressure deficit (VPD, kPa) and D) berry temperature (°C). Curves in A-C represent diurnal trends for July 23, 2024. Diurnal trends in internal berry temperature (D) are shown for Aug 28, 2024 (Ambient Tmax = 42.1 °C). Lines and ribbons represent means ± SE by treatment (4 replicates and 2 canopy sides). Colors differentiate between treatments and the control line (orange) is repeated in each panel as a point of comparison with each experimental treatment.