Effects of root-zone micro-irrigation on Cabernet Sauvignon

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Abstract. *During 2015, vines receiving season-long drip irrigation delivered into the lower root zone via hard plastic tubes yielded 70 % of commercial production while receiving only 15% of the water as the vines receiving full commercial rates of surface drip irrigation. Vines receiving direct root-zone (DRZ) irrigation at rates reduced to 60, 30, and 15% of commercial drip irrigation (DI) produced individual clusters with higher numbers of berries, yet smaller in size, than did clusters from vines receiving full rates of surface drip irrigation. Preliminary findings suggest that a new form of subsurface micro-irrigation may have potential to not only conserve more water than surface drip irrigation, but may produce grapes of a higher and more desirable quality for producing premium red wines. Relative water use efficiency during 2016 was 1.5, 2.5, and 5.0 times greater for grapes produced by sub-surface irrigation at rates of 60, 30, and 15%, respectively, than for surface drip irrigation. Interrupted irrigation delivery did not provide any advantage over uninterrupted delivery. Treatments were repeated during 2016 and fruit quality at harvest was analyzed for several key factors attributed to high quality wine grapes.*

Keywords: *Subsurface drip irrigation, root-zone, grapevine, water use efficiency, direct root zone irrigation, micro-irrigation, fruit quality, plant stress, deficit irrigation, pulse irrigation, wine quality*

Introduction

Production of wine grapes in the state of Washington has experienced more than 8 percent growth each year for the past decade, accounting for more than 50,000 acres (20,250 ha) currently and placing Washington in second place behind California in U.S. wine grape production. The primary limiting factor to this phenomenal growth is available water for irrigation which is essential in the desert environment in which most grapes are produced. Expansion of wine grape acreage will result either through conversion of other irrigated crops to wine grapes or through the development of more efficient water management and irrigation techniques.

The hot days and cool nights of this desert region have been credited for the production of high quality premium red wines such as Cabernet Sauvignon that have created an increasingly high demand for Washington wines. Irrigation is typically applied to wine grapes as surface drip which is considered an efficient and effective method. However, in the hot, dry region of Washington State, water is lost to both soil surface evaporation and weeds. Additionally, vine root systems become mostly concentrated in the upper 18-20 inches (0.5 m) of the soil profile under current irrigation strategies (Stevens and Douglas, 1994; Bauerle *et al*., 2008; Davenport *et al*., 2008). This condition is compounded by the fact that wine grapes in this region are mostly own-rooted from varieties that typically develop shallow to medium depth root systems (Keller *et al*., 2012). These growth patterns may be more susceptible to both cold intolerance and drought during infrequent, short-term climatic perturbations such as experienced in 2010 and 2015.

Deficit irrigation is known to enhance a number of compounds related to production of premium red wines and substantial literature has been published on this topic that is summarized in detail by Chaves *et al.* (2010). Likewise, subsurface drip irrigation has emerged as an effective water saving strategy in a number of row crops (Lamm *et al*., 2010; 2015).

To investigate opportunities to increase water use efficiency, we initiated a coordinated, trans-disciplinary research effort in 2014 with three broad objectives: 1) determine the potential and feasibility for use of a new form of sub-surface drip irrigation which might improve water conservation while improving the use of deficit irrigation in the production of high quality premium red wine grapes; 2) gain a better understanding of the potential advantages of developing deeper root systems of vines to obtain moisture from the available soil profile in the rhizosphere; and, 3) evaluate the potential of remote sensing to monitor water stress on the whole vineyard scale when applying direct root-zone micro-irrigation at rates much lower than used to meet commercial wine grape production goals.

Methods and Materials

Industry Collaboration. A 4-person stakeholder advisory group was established involving active growers and managers representing leading red wine grape producers in Washington. This group was convened quarterly to confer and advise the project Principal Investigator (PI) and team members on critical industry needs and opportunities. This group also assisted in identifying collaborators to host research experiments in commercial vineyards. These stakeholders also provided letters of support for grant proposals submitted to sponsoring agencies. Additionally, the project PI also became an active member of the National Grape and Wine Initiative and participated in board meetings and education meetings addressing issues of the wine grape industry to both gain knowledge and potential research collaborators.

Research Site Description. Treatments were installed in a commercial block of Cabernet Sauvignon wine grapes located on Kiona Vineyards, Block 2 (46ºl6'59" N, 119º26'33" W) in the Red Mountain American Viticulture Area (AVA) near Benton City, WA in early 2015. Soil on the experimental site is of the Aridisol order and classified as a Hezel loamy fine sand (Xeric Torriorthents) on a terrace landform with parent materials being eolian sands over silty glacio-fluvial sediments deposited at the end of the most recent ice age. These soils are well-drained, subject to wind erosion, and relatively infertile, containing very low amounts of organic matter. Depth to nearest water table is more than 80 inches (>2 m). Normal annual precipitation is 8.83 inches (224 mm) and occurs mainly as rainfall during the dormant growing season. Summer temperatures average 70ºF (21º C) with mid-day temperatures reaching 90ºF (32ºC) or more and cooling during the night, typical of a desert climate. These conditions favor the development of high quality red wine grapes under irrigation. The research site was planted to Cabernet Sauvignon (Clone 2) of own-rooted vines on a spacing of 8' (2.5 m) between rows and 6' (1.8 m) between vines. The vineyard was 8 years old at the beginning of the 2015 growing season.

Experimental Design and Treatments. The experimental design is a randomized complete block with two main effect treatments, irrigation rate and depth of delivery sub-surface. A split plot design was super-imposed to compare pulse irrigation and constant delivery. Each treatment plot involved 15 vines (5 vines x 3 rows) with the center-most 3 vines designated for physiological measurements while being buffered by other vines receiving the same treatment. Each of 18 treatment plots was replicated 3 times (810 vines) and compared with 12 plots (180 vines) receiving full commercial rate of irrigation via surface drip and designate as the control treatment when comparing production and water stress with that of the direct root-zone treatments. Irrigation scheduling was determined by the vineyard manager according to long-standing guidelines used to meet commercial production goals. Irrigations were applied more frequently in 2015 which was the hottest and driest growing season on record. During most of the 2015 growing season, irrigation was applied in a 20 hour set every four days. By contrast, the 2016 growing season was characterized by near normal temperature and precipitation and irrigation sets were more varied in timing and duration, according to the temperature and growing conditions of the vines. Direct root-zone irrigation applications occurred on the same dates as commercial plots during both years, but water amounts were reduced to approximately 60, 30, or 15 percent the amount of the commercial rate through the use of battery powered controllers (Galcon Kfar Blum, type 11000L). Actual water amounts applied to treatment and control plots were quantified by small mechanical water meters (D.L. Jerman Co., Hackensack, NJ) read after each irrigation event. Controllers were programmed to irrigation during the evening hours during the same time schedule every day throughout the growing season. Commercial irrigation sets were scheduled to run throughout the entire evening during each event.

Direct root-zone delivery device. Growers in Washington have attempted to use subsurface micro-irrigation applied through buried lines, but have found this technique generally unacceptable owing to clogging of emitters and damage by burrowing rodents. To achieve direct root-zone irrigation without the use of buried driplines, a 1 inch (25.4 mm) diameter hole was bored vertically to a depth of 1, 2, or 3 foot (0.3, 0.6, and 0.9 m, respectively) about 1.5 foot (ca. 0.5 m) either side from the base of each vine and beneath the trellis wire and suspended irrigation dripline. A length of PVC tube was inserted into each hole. Each section of PVC pipe was previously cut to length to reach the desired depth while extending above ground for a given distance and then split about 6 inches (15 cm) from the lower end with a band saw to allow sufficient water passage to move into the soil to reduce the backing of water up the tube. A PVC cap, previously drilled to allow passage of a one foot (30.5 cm) length of ¼ inch (6.35 mm) diameter micro-tubing through the hole prior to attaching one end to a barbed connector and inserted into the main horizontal water line, and attaching a pressure compensating drip emitter at the other end before placing the emitter snuggly into the top of the PVC tube. The cap was then secured over the end of the tube to prevent dirt or debris to reach the emitter. Emitters were selected to deliver 0.5 gallon (0.6 liter) per hour, thus delivering 1.0 gallon per vine per hour.

Installation of all treatments involving 990 vines was completed prior to beginning of the 2015 growing season. Additionally, soil moisture access tubes were installed in designated plots to monitor soil water dynamics both temporally and spatially across depths within the top 6.5 feet (2.0 meters). Soil moisture content was determined by electronic capacitance probes [SynTek Diviner (spot reading) and SynTek EnviroSCAN (continuous reading), Stepney, S.A., Australia.]. Irrigation events were monitored by data transmitted from the EnviroSCAN probes via cellphone transmitters to a base server (Tuctronics, Walla Walla, WA).

Monitoring of plant water stress. Vine water stress was determined by periodically sampling the center three vines of direct root-zone treatments and control vines by measuring mid-day leaf stem water potential using the pressure bomb method (Scholander *et al.*, 1965). Leaves were selected on the east side of vines (most sun drenched prior to sampling), then covered with a plastic bag inside an aluminum foil exterior envelope and allowed to equilibrate for about an hour prior to sampling. The encased leaf was detached from the vine by severing the petiole with a razor blade, then quickly removed from the bag and inserted into the pressure chamber, while shielding the leaf from direct sunlight, then pressurized with nitrogen gas to the point of water movement from the cut petiole. Pressures were measured in bars then converted to mega-pascals. These data were correlated with multi-spectral digital images obtained through aerial and ground-based platforms during both growing seasons (data not shown). Visual observations of plant condition were documented with digital photos to document phenological impacts on vines from treatments as referenced by Keller (2005)

Determination of grape production and quality. In 2015, grape clusters from designated vines were collected to determine estimates of production, as well as number and size of berries in each treatment and control block. Sampling was executed during two stages of maturity, early-*veraison* and mid-*veraison*. At the 2015 harvest date (September 26), all grapes were harvested from replicated rows of each treatment and weighed by individual vine. In 2016, cluster sampling was not repeated, but all vines in the treatment plots and half of the control plots were harvested on September 24 and weighed. Samples from specific treatments were collected two weeks prior to harvest and submitted to a private commercial laboratory for analytical determination of a number of characteristics associated with quality red wines.

Results and Discussion

Treatments were successfully implemented during both 2015 and 2016 growing seasons. Data presented has not yet been statistically analyzed. Direct root-zone treatments (DRZ) were effective in delivering water to the designated depths. On occasion, we experienced some water backing up in the tube, but this problem was attributed to soil plugging at the time of tube installation, and once dislodged, was not a lingering problem. Water leakage was often observed at the dripline point of insertion by the barbed connector. Sealant was used and provided temporary relief, however this problem persisted for the duration of the study. It is felt that the tool used to punch the initial hole into the dripline was a major source of this problem, as we did not experience it at two other research locations. Operating pressure of the primary pressure pump could also be a source of the problem, but we have not yet addressed this possibility. The electronic controllers worked flawlessly, as did the small mechanical meters. We discovered that the meters performed with most accurately when placed face up rather than to the side, owing to an internal design factor.

Comparison of pulse and constant irrigation delivery revealed no differences in either plant physiological stress or fruit production; therefore, treatment data from this split plot design was pooled. Likewise, depth of water delivery did not produce any consistent advantages across application rates or time (Table 1).

Table 1. Seasonal irrigation delivery and water use efficiency based on grape production during 2015 and 2016 comparing commercial surface drip irrigation with season-long deficit irrigation imposed by direct root-zone micro-irrigation delivered subsurface from 1-3' depths at rates of 60, 30, or 15% the rate of surface drip irrigation.

	Irrigation Treatments			
	Surface Drip (DI)	--------------------------DRZ-------------------------		
	(100 %)	(60 %)	(30%)	(15%)
2015 Water Use (acre ft.)	1.35	0.81	0.40	0.20
Water/vine each event	16.25	9.75	4.88	2.44
Grape production (tons/ac)	4.54	4.08	3.40	3.18
Production Efficiency (lbs./acre inch applied)	560	840	1400	8271
Relative Efficiency	1.0	1.5	2.5	4.7
2016 Water Use (acre ft.)	1.37	0.84	0.43	0.23
Water/vine each event	17.59	10.27	5.13	2.57
Grape production (tons/ac)	6.73	3.79	2.96	2.20
Production Efficiency (lbs./acre inch applied)	818	752	1147	1598
Relative Efficiency	1.0	0.9	1.4	2.0

Our original objective was to ascertain the greatest degree of water conservation that could be achieved while maintaining health and productivity of the vine. For that reason, season-long deficit irrigation was used for all DRZ treatments, although such a strategy is not typically used in commercial grape production. The 2015 growing season was later determined to be the hottest and driest on record for the area. Fruit production at the commercial irrigation rate and applied by surface drip averaged 10 pounds (4.5 kg) per vine, while DRZ irrigation applied 1-3 feet subsurface at reduced rates of ca. 60, 30, and 15% of full commercial rate produced an average of 9.0, 7.6, and 7.2 pounds per vine, respectively (Table 1). Concern was expressed by the grower and members of the stakeholder advisory group that some stress effects from 2015 might be reflected in both fruit production and plant vigor during the following year. These concerns proved valid during 2016 and were reflected in lower overall fruit production in the DRZ treatments than during the previous year, despite the fact that growing conditions were more favorable in 2016 than in 2015, and there was wider disparity in fruit production between the commercial treatment plots and the DRZ plots than occurred during the previous growing season (Table 1). While pruning weights from the 2016 treatment vines have not been obtained at this time, there were visual differences in shoot lengths and condition among the treatments throughout the 2016 growing season.

Plant water stress, as measured by obtaining xylem pressure potentials among the treatment vines, showed obvious differences among the irrigation delivery rates when measured at 3 dates during the growing season (Table 2). Plant water stress increased proportionately with decreasing irrigation rate and progression of the growing season. Similar measurements were made at only one date during 2015 and also showed progressively more stress with lowering rates of irrigation (data not shown).

Table 2. Plant water stress as determined by leaf stem xylem potential during 2016 growing season contrasting commercial surface drip irrigation with season-long deficit irrigation imposed by direct root-zone micro-irrigation delivered subsurface from 1-3' depths at rates of 60, 30, or 15% the rate of surface drip irrigation.

	Irrigation Treatments			
	Surface Drip (DI)	DRZ		
	(100 %)	(60 %)	(30%)	(15%)
Date	Xylem Pressure Potential (-kPa)			
June 3	-528.62	-592.95	-640.66	-781.17
July 7	-635.01	-825.40	-924.59	-1187.96
August 10	-868.74	-1176.93	-1521.67	-1592.69

Water use efficiency, determined as amount of fruit produced per unit of water applied, increased progressively with reduced rates of irrigation in 2015 (Table 3). This trend was repeated in 2016, but was not as pronounced, largely owing to a much higher rate of grape production that occurred from the commercial plots in 2016 than in 2015. Some of this difference may also be attributed to carry-forward effect from the lower water applications during 2015 in the DRZ treatments.

Table 3. Grape production from plots receiving full commercial irrigation applied as surface drip (SD) and applied as direct root-zone micro-irrigation (DRZ) at season-long reduced rates of ca. 60, 30, and 15 % of full commercial rate during 2015 and 2016.

	Irrigation Treatments							
	Surface Drip (DI)		DRZ					
	(100 %)		(60 %)		(30%)		(15%)	
2015	**Wt. per Vine**							
	Lbs.	kg.	Lbs.	kg.	Lbs.	kg.	Lbs.	kg.
Surface Drip	10.0	4.55						
DRZ at -1'			8.6	3.92	6.6	2.98	6.8	3.09
DRZ at -2'			9.1	4.11	7.4	3.36	7.8	3.55
DRZ at -3'			9.3	4.21	8.8	3.99	7.1	3.21
Mean	**10.0**	**4.55**	**9.0**	**4.08**	**7.6**	**3.44**	**7.2**	**3.28**
2016								
	Lbs.	kg.	Lbs.	kg.	Lbs.	kg.	Lbs.	kg.
Surface Drip	14.8	6.73						
DRZ at -1'			8.6	3.90	6.9	3.11	5.4	2.45
DRZ at -2'			8.0	3.62	6.3	2.85	4.6	2.09
DRZ at -3'			8.5	3.84	6.4	2.92	4.5	2.08
Mean	**14.8**	**6.73**	**8.4**	**3.79**	**6.5**	**2.96**	**4.9**	**2.20**

In 2015, cluster samples from the DRZ treatments showed that cluster weights were slightly lower, but grapes were more numerous, yet smaller in size than in the clusters from vines receiving the higher irrigation rate. These findings suggested that the grapes from the lower irrigation rates might have greater potential to produce higher quality red wine, owing to higher concentration of anthocyanins, tannins and sugars. In 2016, similar effects were noted, but not documented, for grapes receiving the DRZ treatments. Replicated cluster samples were obtained from the commercial and DRZ treatment plots and submitted to a private, commercial analytical lab for determination of a dozen components and ratios. Data summarized in Table 4 illustrates four of these components. Acidity became progressively reduced below the 60% irrigation rate, while sugars (Brix), tannins, and anthocyanins all trended higher with decreasing rate of irrigation. These results are in line with the findings of Casassa *et al.* (2015) who noted that efforts to derive benefits in grape quality and water savings through greatly reduced irrigation levels should recognize the potential for yield reductions and/or physiological impacts on vines. Results from our study provides evidence that use of efficient irrigation application such as DRZ could both sustain vines and produce grapes during drought conditions while yielding grapes with potential to produce premium quality red wines in the hands of skilled viticulturists and enologists.

Table 4. Comparison of selected chemical components influencing red wine quality. Analyses of Cabernet Sauvignon grapes grown under full and reduced rates of irrigation season-long during 2016. Reduced irrigation rates were applied via direct root-zone micro-irrigation (DRZ) delivered 2 feet (61 cm) subsurface.

Component	Surface drip (DI)	DRZ		
	Control (100 %)	High (60 %)	Moderate (30%)	Low (15%)
pH	3.41	3.36	3.48	3.55
Brix	25.5	27.1	27.6	28.6
Tannins	403	594	600	741
Anthocyanins	1015	1242	1298	1480

Conclusions

A new form of subsurface micro-irrigation was developed to achieve direct root-zone subsurface delivery or drip irrigation to wine grapes in Washington State. Vines were maintained for production, albeit less than achieved under commercial surface irrigation at full irrigation delivery needed to meet production goals. Rates of 60, 30, and 15% of commercial irrigation produced ca. 90, 75, and 70%, respectively, of the commercial grape production weight. Second year production rates dropped to 57, 44, and 33% that of commercial production at the same rate of irrigation applied the previous year (60, 30, and 15% of commercial irrigation rate, respectively). Carry-forward effects from previous year water stress, improved weather, and longer commercial irrigation sets during 2016 may have contributed to lower second year production ratios. No obvious advantages were found for using pulse irrigation delivery over continuous application sets. No consistent patterns were observed to favor a specific depth among 1, 2, or 3 ft. subsurface delivery points.

Acknowledgements

This research was supported in part by the following: 1) Northwest Center for Small Fruit Research, Agreement No. 59-5358-4-010 and grant # 2072-21000-047-16. 2) Washington State Department of Agriculture – Specialty Crop Block Grant Program – Agreement K1768. The authors also express sincere thanks to Scott Williams, general manager – Kiona Winery and Vineyards, Benton City, WA for providing access to land and resources for this project. We also thank Rick Hamman of Hogue Ranches, Bill Riley of Ste. Michael Wine Estates, Julia Kock of Klipsun Vineyards, and Jim Holmes of Ciel du Cheval Vineyard for serving as advisors to this research project and others. Appreciation is also extended to Drs. Markus Keller and R. Troy Peters for subject matter consultation related to various aspects of this research.

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