FINAL REPORT

Washington State Grape and Wine Research Program

DUE June 30, 2019
by email to: ARCGrants@wsu.edu

PROJECT TITLE: USE OF DIRECT ROOT-ZONE MICRO-IRRIGATION TO CONSERVE WATER AND ENHANCE GRAPE QUALITY

Project Duration: ***(2017-2019)***
WRAC Project No.: 3019-6818

PI Name:	**PETE W. JACOBY**
Organization	WASHINGTON STATE UNIVERSITY
Address	P.O. BOX 646420, PULLMAN, WA 99164-6420
Telephone	509-335-3495
Email	JACOBY@WSU.EDU

Cooperator Name:	**SCOTT WILLIAMS**	**Cooperator Name:**	**RICK HAMMAN**
Organization	KIONA WINERY	Organization	HOGUE RANCHES
Description of participation:	PROVIDED VINES & MANAGEMENT	Description of participation:	PROVIDED VINES & MANAGEMENT

FINAL REPORT

FINAL FINANCIAL REPORTING
BUDGET *(LIST COMPLETED BUDGET NUMBERS)*

	Year 1 FY	**Year 2 FY**	**Year 3 FY**
	Jul 2016 – Jun 2017	Jul 2017 – Jun 2018	Jul 2018 - Jun 2019
Total	$ 11,000	$ 11,000	$ 15,000
Footnotes:			

Total Project Funding: $ 37,000

Project Budget Status: Project has been completed without unforeseen delays.

Project Summary:

Non-technical, 1 - 3 succinct paragraphs that cover the following points. These will be used for public descriptions of the project.

- What is the current issue and why did it need to be researched?

Improvement of crop water use efficiency was needed to ensure sufficient water availability for continued growth of the WA grape based industries. A new method of delivering subsurface drip irrigation was hypothesized to be a means of conserving water while sustaining grape yields and quality. Industry funding and grower participation were needed to conduct a proof of concept trial in commercial production vineyards.

- What were the basic methods and approaches used to collect data that will be used to inform the target audience?

Treatments included 3 rates of water applied at three depths of water under continuous and pulsed delivery schedules during 2016. In 2017, rates of direct root-zone (DRZ) delivery were adjusted to 80, 60, and 40 percent of surface drip applied at a depth of 2-feet below soil surface. DRZ was compared with equal rates of water applied at full commercial rate and also 80, 60, and 40 percent of full commercial rate delivered by surface drip. Grapes from plots were harvested in fall, and total vine grape yields were weighed. Cluster samples from each treatment plot were submitted for a full phenolic panel analysis by ETS in Walla Walla, WA. Statistical analyses of data were performed in Pullman, WA.

- What ultimate goals did the project hope to achieve?

The overarch goal of this project was to determine the potential of DRZ micro-irrigation to conserve water. Secondary goals were to: 1) determine the impacts on grape yields and quality from applying less than the commercial surface drip rate; and, 2) determine the extent of water savings by using DRZ rather than surface drip for the portion of the growing season from fruit set until harvest.

FINAL REPORT

Project Major Accomplishments: *(No page limit)*

- Describe specific objectives that were met.

DRZ micro-irrigation was equally effective at all depths, but most consistent at 2-feet below soil surface in conserving water while sustaining grape production. Greatest benefit derived from use of DRZ is to improve crop water use efficiency (quantity of fruit per unit of water) during the growing season following fruit set. DRZ allows for implementing deficit irrigation by maintaining a more consistent level of soil water availability than achieved with surface drip systems. DRZ is seen as a complementary irrigation technique to existing surface drip irrigation systems for achieving high quality grapes, especially for red wine grapes grown in regions with limited water availability. Irrigation delivery at two feet or more below soil surface reduced root biomass in the upper foot of the soil profile.

- Describe significant results achieved and any conclusions (both positive and negative)

Initial rates of reduced irrigation (30 or 15 percent of commercial rate) were deemed too low, with the lowest two rates impacting grape yields below 90 percent of commercial goals. When adjusted upwards to 80, 60, and 40 percent of commercial goals, acceptable yields were achieved, with DRZ outperforming surface drip in crop water use efficiency.

- Discuss key outcomes realized from this project.

DRZ micro-irrigation has shown the potential for reducing water use during the major portion of the growing season to about half the amount applied currently to meet commercial wine grape production. These results were achieved during 2017 and 2018, years that experienced high amounts of soil water recharge prior to the initiation of the growing season. We expect that DRZ would far exceed surface drip irrigation in water use efficiency based on results that were observed in 2015, the driest and hottest growing season recorded during our studies to date. When applied below two feet under the soil surface, DRZ reduced vine stress as measured by mid-day stem water potential. Vines receiving DRZ were observed to develop deeper roots and reduce overall root biomass in the upper two feet of the soil profile when observed via mini-rhizotrons (Fig. 1). Data obtained from soil water capacitance probes suggest vine stress levels can be achieved and held more constant under DRZ than by surface drip application. This may partially explain why grapes receiving DRZ were higher in anthocyanins, tannins, and Brix than those grown under surface drip application.

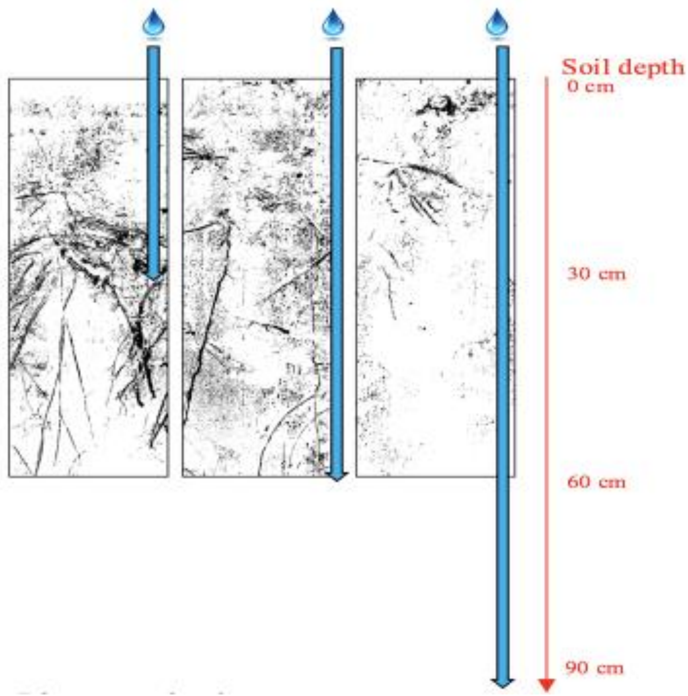
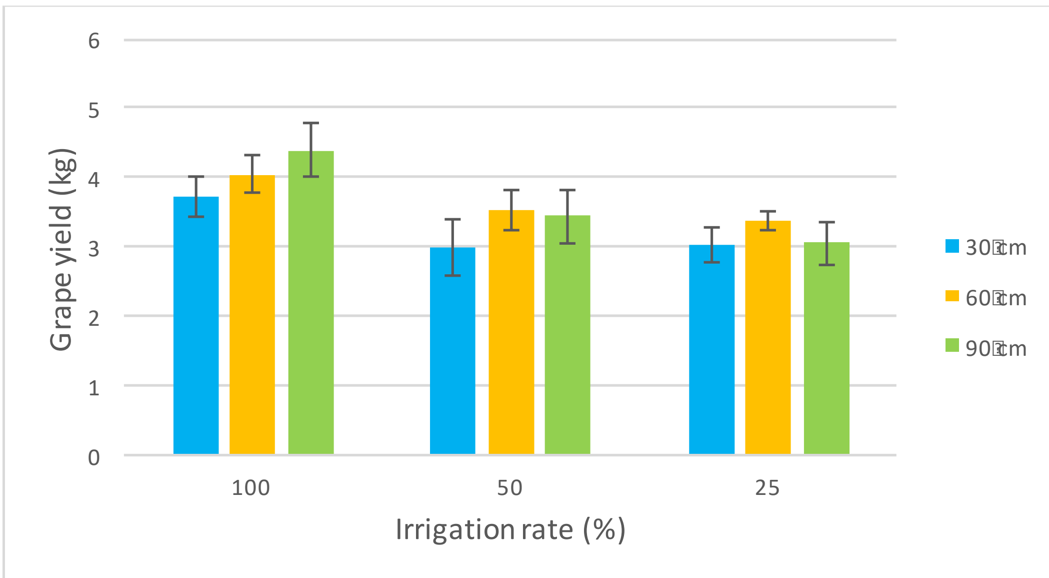


Figure 1. In first panel, water is applied via DRZ tube to the 1-ft. depth and root biomass is abundant in that zone. In the second panel, water is applied deeper at the 2-ft. depth and root biomass is less abundant in the upper 2 feet of the soil profile than in the first panel. In the third panel, water is delivered at the 3-ft. depth, and root biomass is much less abundant in the top 2 feet than in the other two panels. This data suggests that roots become most abundant in the zone closest to the point of water delivery. This also helps explain why roots become mostly concentrated in the upper 45 cm (18 inches) under surface drip systems. Deeper root development may offer some resistance to vine damage from extremes in temperatures and will be determined in future studies.

Initial proof-of-concept studies focused on whether or not DZR subsurface drip irrigation would impact vine health and maintain production levels while conserving water. Three rates of DRZ delivery at three depths were compared during 2015-2016 (Fig. 2). Rates were adjusted during 2017 and 2018 and direct measurements of yield were made using both surface drip (SD) and subsurface drip (DRZ) delivery at the 2-ft depth (Table 1).



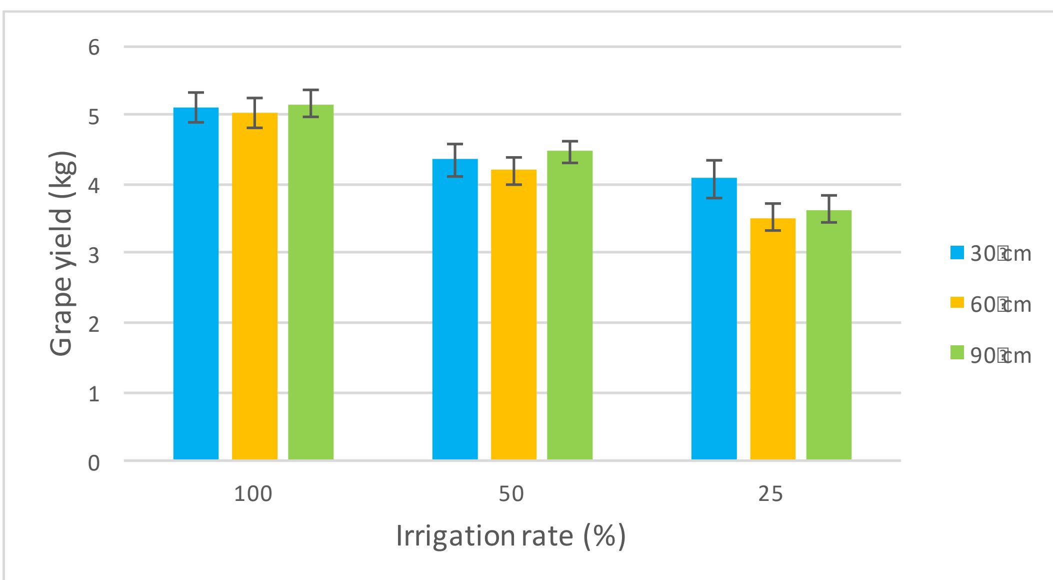


Figure 2. Grape yield per vine (kg/vine) under different irrigation rates (100%, 50%, and 25%) and depths (30 cm, 60 cm, and 90 cm) in **2015 (top)** and **2016 (bottom)**. Error bars represent standard errors (SE).

		Commercial		Irrigation Treatments		
		100%		80%	60%	40%
2017 Water Use (ac. ft.)		1.24		1.04	0.74	0.46
Grape yield (tons/ac.)		4.64	**SD**	4.91 ab	4.41 ab	4.23 b
			DRZ*	5.01 a	4.82 ab	4.73 ab
2018 Water Use (ac. ft.)		1.26		1.10	0.81	0.52
Grape yield (tons/ac.)		4.76	**SD**	4.87 ab	4.45 ab	4.29 b
			DRZ*	5.16 a	5.04 ab	4.89 ab

[*DRZ delivered at the 2' (60 cm) depth]

Table 1. Grape yield under commercial rates (100%) of surface drip delivery and equal rates of both surface drip (SD) and subsurface drip (DRZ) reduced to 80, 60, and 40 % of the full commercial rate. Mean values not followed by the same letter are significantly different at the 95% level of confidence.

Influence on grape quality from reducing water rate through DRZ subsurface delivery is demonstrated in Fig. 3. Generally, grape quality was enhanced for producing higher quality premium wines when water rate was reduced through DRZ delivery. Acidity levels were reduced by reducing amount of water applied, while levels of Brix, tannins and total anthocyanins were found to increase with lowering the rates of water applied.

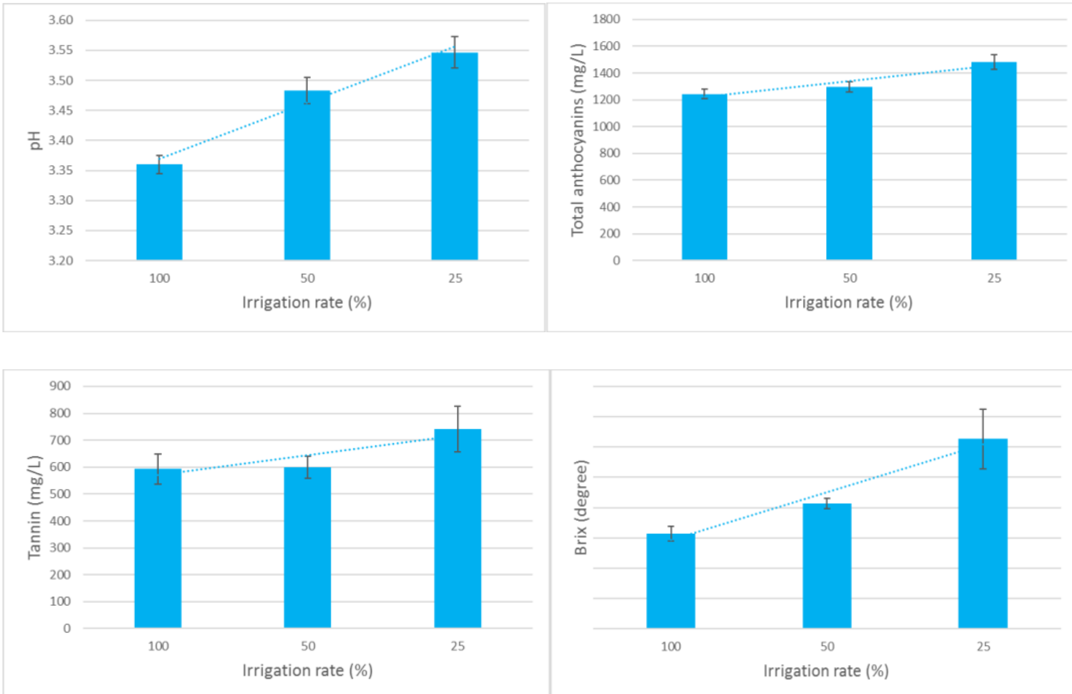


Figure 3. Grape quality in response to irrigation rates applied as DRZ averaged over all depths in 2016.

One explanation for the improvement in grape quality under reduced rates of water delivery is that water stress has been related to improvements in grape quality. This fact is basic to the use of deficit irrigation during a portion of the growing season, particularly in certain red wine varietals. Fig. 4 (below) illustrates the increase in vine water stress among the three rates of subsurface irrigation and among the dates when measures were taken during the advancement of the growing season.

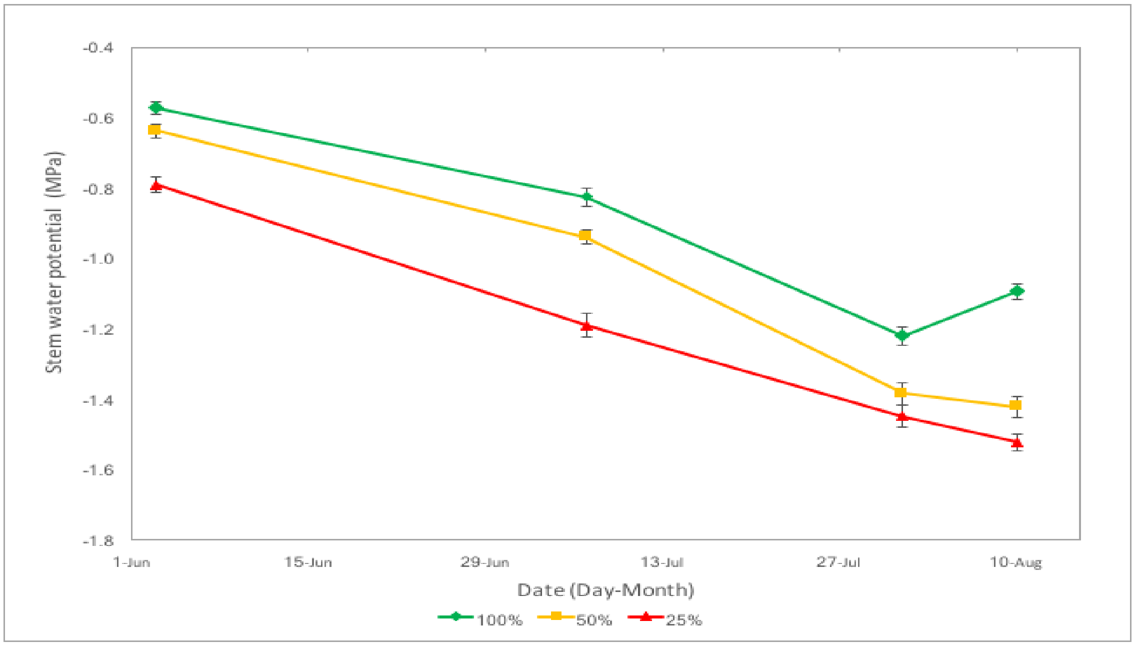


Figure 4. Vine water stress as imposed by reducing rates of DRZ subsurface irrigation in 2016. Stress is represented as mid-day stem water pressure potential.

Other physiological indicators of vine water stress are shown in Fig. 5 (Photosynthetic rate) and Fig. 6 (Stomatal gas exchange or conductance). In both measures, vines receiving lower rates of water exhibit lower rates of activity which results from increased stress levels. In each case, vines receiving water via the subsurface (DRZ) delivery exhibits greater activity while being under more stress than are vines receiving more water. The vines receiving lower rates of water delivered as surface drip (SD) are less active (more stressed) than DRZ owing the less efficient water use because of water loss to evaporation and use by non-crop species (weeds).

In Fig. 6, stomatal conductance follows the same trends as shown in Fig. 5 (Photosynthesis) and these trends are also indicative of lower efficiency of water use by the vines grown under higher rates of water delivery.

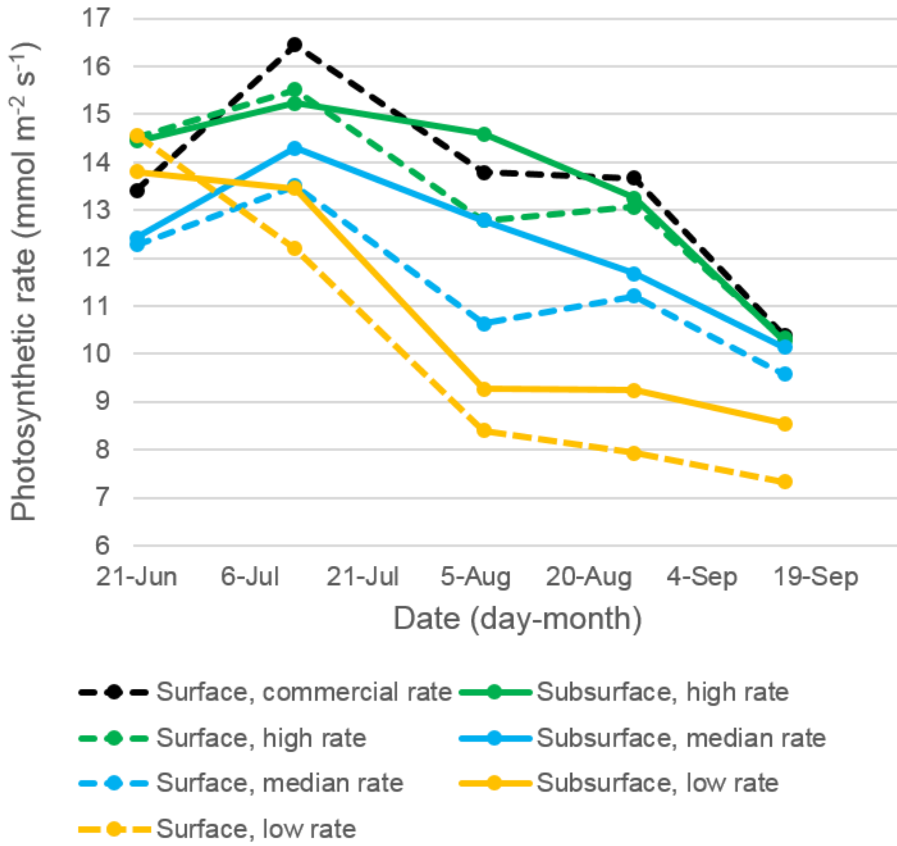


Figure 5. Changes of photosynthetic rate under surface and subsurface irrigation strategies with different irrigation rates (water use amounts). Solid lines represent subsurface irrigation, and dash lines represent surface irrigation. Different colors represent different irrigation rates: black-commercial rate (depends on soil moisture content, and decided by vineyard manager), green-high rate (80% of commercial rate), blue-median rate (60% of commercial rate), and yellow-low rate (40% of commercial rate). Data were taken triweekly from three central vines under each treatment plot in each of 3 blocks (n=3) at sunny mid-days by using LCi-SD Photosynthetic system.

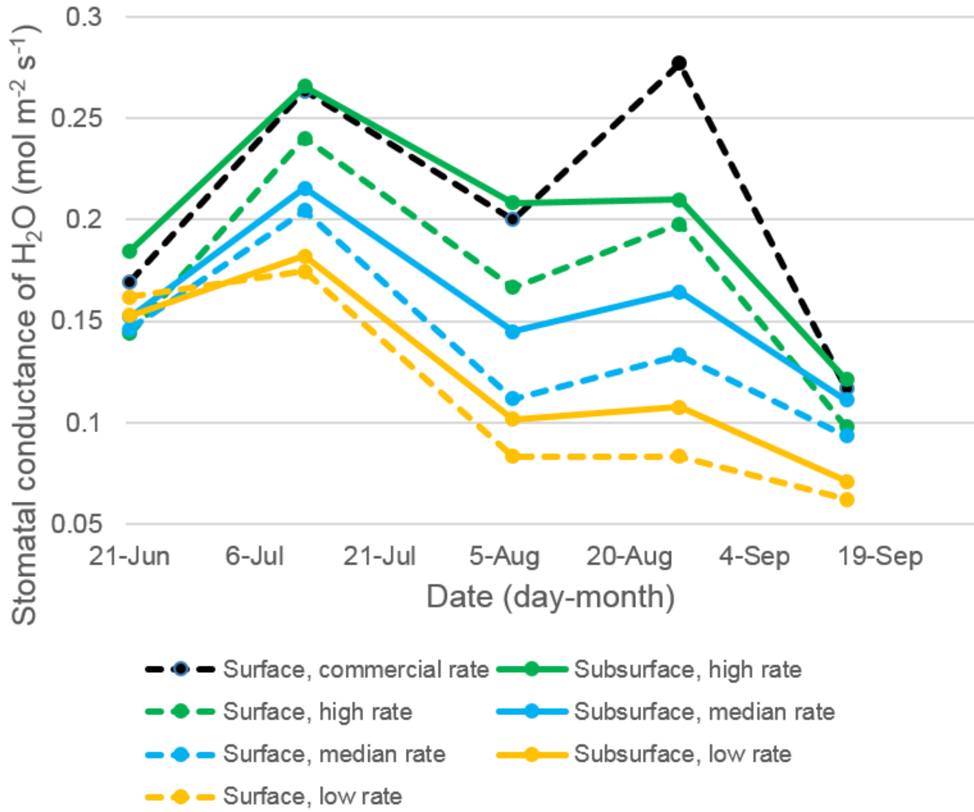
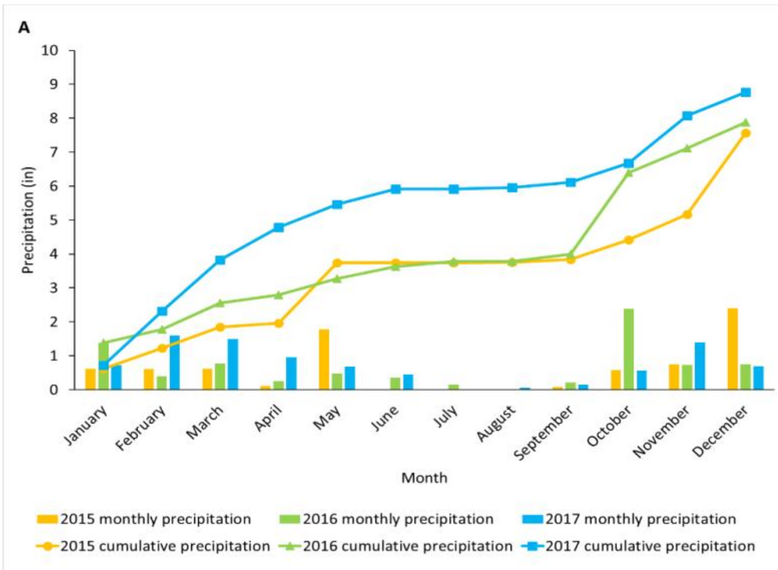
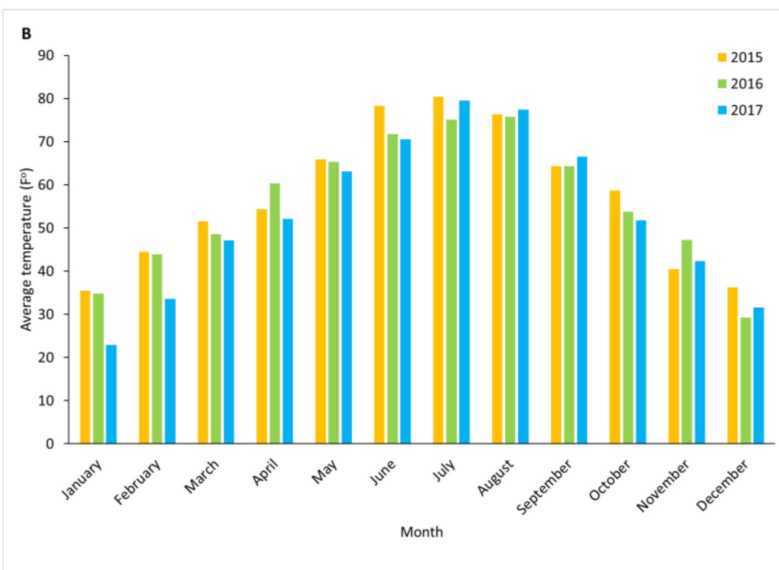


Figure 6. Changes of stomatal conductance under surface and subsurface irrigation strategies with different irrigation rates (water use amounts). Solid lines represent subsurface irrigation, and dash lines represent surface irrigation. Different colors represent different irrigation rates: black-commercial rate (depends on soil moisture content, and decided by vineyard manager), green-high rate (80% of commercial rate), blue-median rate (60% of commercial rate), and yellow-low rate (40% of commercial rate). Data were taken triweekly from three central vines under each treatment plot in each of 3 blocks (n=3) at sunny mid-days by using LCi-SD Photosynthetic system.

Growing conditions have varied over the 4-year period of study since implementation in 2015. Use of DRZ at greatly reduced irrigation rates has consistently produced yields near or greater than those produced under surface drip irrigation rates used to meet commercial production.





No particular depth of DRZ was determined to be more advantageous among the ones used (1, 2, or 3-foot depths). Applications by DRZ at only 0.5 ac.ft. of water exceeded yields from plots receiving either similar or greater rates of those produced under surface drip irrigation during both 2017 and 2018, when direct comparisons were made between the two delivery methods

On-plant measurements of plant water stress (negative xylem pressure potential) found a consistent pattern of higher stress occurring with decreasing irrigation amount. Overall stress increased as daily temperatures increased during advancement of the growing season.
Analyses of grapes during 2016 and subsequent years found that grape quality, as determined by brix, acidity, tannins, and anthocyanin levels, was improved under DRZ drip irrigation; however, this improvement was related to ability of the vines to produce under more stress that occurred with less water being applied than to the vines receiving surface drip irrigation. We were able to quantify the development of deeper roots throughout the vertical soil profile by vines under DRZ irrigation compared with surface drip irrigated vines. We hypothesize that this response of the vines may allow them to deal with water stress more effectively than vines irrigated with surface drip irrigation, under which the root systems became more concentrated in the top 18 inches of the soil profile. Verification of this response will be the topic of future research in order to better manage grape quality through more efficient and cost effective use of deficit irrigation to produce grapes for the production of premium quality red wines.

- Discuss the value and benefits of this research to industry (growers/winemakers).

DRZ micro-irrigation may provide growers the opportunity to achieve superior quality wine grapes while conserving water resources and reducing the energy costs associated with the delivery of pressurized irrigation on a frequent schedule. Wine grapes appear to be capable of obtaining water from deeper depths in the soil profile when conditioned to do so. This ability could lengthen intervals between irrigation events and enhance the ability of growers to use deficit irrigation. By avoiding surface application, water loss from surface evaporation could be greatly reduced and water use by shallow rooted weed species could be reduced or eliminated.

Information Dissemination, Extension, and Outreach Activities:

Peer-reviewed Journal Articles

Ma, X.C., K.A. Sanguinet, **P.W. Jacoby**. 2019. Direct root-zone irrigation outperforms surface drip irrigation on grape yield and water use efficiency while restricting shallow root growth in a semi-arid climate. *Agric. Water Manage.* (in review)

Ma, X.C., K.A. Sanguinet, **P.W. Jacoby**. 2019. Performance of direct root-zone deficit irrigation on *Vitis vinifera* L. *cv.* Cabernet Sauvignon production and water use efficiency in semi-arid south-central Washington. *Agric. Water Manage.* 221:47-57. [See copy attached to this report] (Impact Factor: 3.565)

Chakraborty, M., L.R. Khot, S. Sankaran, and **P.W. Jacoby**. 2019. Evaluation of mobile 3D light detection and ranging-based canopy mapping system for tree fruit crops. *Computer and Electronics in Agriculture* https://doi.org/10.1016/j.compag.2019.02.012/ (Impact Factor: 2.761)

Espinosa, C.Z., A. P. Rathnayake, M. Chakraborty, S. Sankaran, **P.W. Jacoby**, and L.R. Khot. 2018. Applicability of time-of-flight-based ground and multispectral aerial imaging for grapevine canopy vigour monitoring under direct root-zone deficit irrigation. *Int'l. J. Remote Sensing*. DOI: 10.1080/01431161.2018.1500047 (Impact Factor: 1.724).

Espinosa, C.Z., L.R. Khot, S. Sankaran, and **P.W. Jacoby**. 2017. High resolution multispectral and thermal remote sensing based water stress assessment in grapevines to evaluate subsurface irrigation technique effects. *Remote Sensing* 9(9):961-976; http://www.mdpi.com/2072-4292/9/9/961/htm DOI: 10.3390/rs9090961. [(ISSN 2072-4292) Impact Factor 3.244].

Internal Professional Society Publication

Jacoby, P.W., and X.C. Ma. 2018. Introducing direct root-zone deficit irrigation to conserve water and enhance grape quality in the Pacific Northwest. *Crop and Soils Magazine* Sept.- Oct.: pp. 34-37, 58. doi:10.2134/cs2018.51.0510 [See copy attached to this report]

Symposium and Conference Proceedings (includes published abstracts)

Jacoby, P.W., and X.C. Ma. 2019. Impacts of subsurface deficit irrigation on wine grape yield and quality. Am. Soc. Enology and Viticulture, Napa, CA. June 17-20,

Jacoby, P.W., and X.C. Ma. 2018. Direct root-zone delivery to enhance deficit irrigation application. Ann. Meet., Irrigation Association Technical Program, Long Beach, CA. Dec. 2-6.

https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/2018IrrigationShowTechnicalPapers.pdf (see pp. 143-152)

Ma, X.C., A.P. Smertenko, M. Keller, **P.W. Jacoby**, and K.A. Sanguinet. 2018. Enhancing crop production and water conservation through Direct Root-Zone irrigation strategy. ASA Section, Am. Soc. Agron. Ann. Meeting, Baltimore, MD. Nov. 4-7.

Chakraborty, M., L. R. Khot, S. Sankaran and **P.W. Jacoby**. 2018. Evaluation of mobile 3D time of flight based canopy mapping system for tree fruit crops. Paper No. 1801540, ASABE 2018 Annual International Meeting, Detroit, MI, July 29- Aug 1.

National Professional Society Poster Presentations with Published Abstracts

Ma, X.C., K.A. Sanguinet, and **P.W. Jacoby**. 2018. Comparing effects of different irrigation rates and depths on wine grape production, grapevine growth, and root development through direct root-zone irrigation strategy. Our Farms – Our Future National Conference, Sustainable Agricultural Research and Education (SARE) and USDA, NIFA. April 3-5, St. Louis, MO (invited oral paper w/poster).

Jacoby, P.W., and X.C. Ma. 2018. Conserving water while increasing grape production through direct root-zone (DRZ) deficit irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.

Hawkins, G., **P.W. Jacoby**, and X.C. Ma. 2018. Cabernet Sauvignon berry quality from vines irrigated through direct root-zone irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.

Ma, X.C., K. Sanguinet, and **P.W. Jacoby**. 2018. Performance of Cabernet Sauvignon under direct root-zone deficit irrigation. Ann. Meeting, Amer. Soc. Enology and Viticulture, Monterey, CA. June 18-21.

Ma, X.C., **P.W. Jacoby**, and K. Sanquinet. 2017. Influences of direct root-zone deficit irrigation on wine grape production, grapevine growth, and root distribution in Pacific Northwest. *In:* Tech. Abs., Ann. Meeting, ASA-CSSA-SSSA. Oct. 6-10. Tampa, FL.

Ma, X.C., **P.W. Jacoby**, A. Torp, G. Hawkins, and L. Mongan. 2017. Effects of root- zone deficit irrigation on crop growth, fruit yield, and agroecosystem stability: using the wine grapevine *Cabernet Sauvignon* as a model. Ecological Society of America Annual Meeting. August 6-11. Portland, OR.

Rathnayake, A.P., C.Z. Espinosa, L.R. Khot, S. Sankaran, and **P.W. Jacoby**. 2017. Application of 3D imaging for measuring grapevine plant growth under subsurface drip irrigation. Paper No. 1701180, Amer. Soc. Agric. Biol. Engin. Ann. Int'l. Meeting. July 16-19, Spokane WA.

Jacoby, P.W., X.C. Ma, and J.R. Thompson. 2017. Maintaining vineyard production with season-long deficit irrigation. ASEV Annual Meeting. June 26-29. Bellevue, WA.

Jacoby, P.W., X.C. Ma, and J.R. Thompson. 2016. Effects of root-zone micro-irrigation on Cabernet Sauvignon. *Proceedings*: Technical Education Conference on Use of Micro-irrigation in Agricultural Cropping Systems, Irrigation Association Annual Meeting. (full-length paper and oral presentation). December 5-9, 2016. Las Vegas, NV

Espinosa, C.Z., L.R. Khot, **P.W. Jacoby**, and S. Sankaran. 2016. Remote sensing based water-use efficiency evaluation in sub-surface irrigated wine grape vines. Proc. SPIE 9866, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping. http://dx.dpi.org/10.1117/12.2228791/.

Bartoshevich, R., J. Chi, S.N. Pressley, H. Liu, B.K. Lamb, P. O'Keeffe, **P.W. Jacoby**, and S.H. Sadeghi. 2016. Quantifying the influence of irrigation and meteorology on water use efficiency at a vineyard in Washington. 15th Annual Amer. Meteorological Society Student Conf. *Beyond the Weather – Embracing the interface of science and society.* Jan. 9-10, New Orleans, LA.

Sadeghi, S.H., **P. Jacoby**, B. Lamb, J. Chi, P. O'Keeffe, and H. Liu. 2016. Application of eddy covariance technique to improve water use efficiency and grape quality in Washington. An. Meeting of ASABE, July 17-20. Orlando, FL.

Jacoby, P.W. 2015. Deep subsurface micro-irrigation for increasing vineyard water use efficiency. p. 125 In: *Science – a platform for progress*. Technical Abstracts. 66th National Conference of the American Society of Enology and Viticulture. June 15-18, 2015. Portland, OR. 176 p.

Jacoby, P.W., R.T Peters, S. Sankaran, and L.R. Khot. 2015. Advancing water use efficiency in vineyards with subsurface micro-irrigation. Proceedings: *Emerging Technologies for Sustainable Irrigation, Joint ASABE/ Irrigation Association Symposium.* (full length manuscript with accompanying poster presentation). Nov. 10-12, 2015. Long Beach, CA

Poster Presentations at State and Local Grower Meetings

Jacoby, P.W., and X.C. Ma. 2019. Impacts of subsurface deficit irrigation on wine grape yield and quality. Ann. Meeting, WA Winegrowers, Kennewick, Feb. 12.

Jacoby, P.W., and X.C. Ma. 2019. Impacts of subsurface deficit irrigation on wine grape yield and quality. WSU Academic Showcase. (System-wide poster presentations) – Pullman, WA. Mar. 28.

Ma, X.C., **P.W. Jacoby**, and K. Sanguinet. 2018. Comparing effects of different irrigation rates and depths on wine grape production, grapevine growth, and root development through direct root-zone irrigation strategy. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7.

Espinosa, C.Z.., **P.W. Jacoby**, S. Sankaran, and L.R. Khot. 2018. Proximal and remote sensing methods to evaluate vine water status in subsurface and deficit Cabernet Sauvignon grapevines. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7.

Hawkins, G., **P.W. Jacoby**, M.C. Ma, and J.R. Thompson. 2018. Cabernet Sauvignon berry quality in vines watered through direct root zone irrigation. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7. (Third place undergraduate poster contest)

Ma, X.C., J.R. Thompson, and **P.W. Jacoby**. 2017. Direct root-zone deficit irrigation: a strategy to enhance water conservation and sustain grape production in Pacific Northwest. Center for Precision & Automated Agricultural Systems (CPAAS) Technology Day. July 31. Prosser, WA.

Extension & Outreach Papers/Presentations/Posters/Press Releases

Truscott, Seth. 2019. Scientist's involvement helps sensors send water to crops, right when they need it. WSU *CAHNRS News* and *WSU Insider*. On-line press releases by staff reporter. March 8. http://news.cahnrs.wsu.edu/scientists-involvement-helps-sensors-send-water-to-crops-right-when-they-need-it/

Jacoby, P.W., and X.C. Ma. 2018. Direct root-zone delivery to enhance deficit irrigation application. Ann. Meet., Irrigation Association Technical Program, Long Beach, CA. Dec. 2-6. https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/DRZ_Drip-Irrigation_JACOBY.pdf/

Ma, X.C., **P.W. Jacoby**, and K.A. Sanguinet. 2018. Comparing effects of different irrigation rates and depths on wine grape production, grapevine growth, and root development through direct root-zone irrigation strategy. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7.

Hawkins, G., **P.W. Jacoby**, X.C. Ma, and J.R. Thompson. 2018. Cabernet Sauvignon berry quality in vines watered through direct root zone irrigation. Ann. Meeting, WA Winegrowers, Kennewick, WA. Feb. 6-7. (Third place undergraduate poster contest)

Jacoby, P.W. 2017. Micro-irrigation team wins national award for water conservation. http://news.cahnrs.wsu.edu/blog.2017/10/18/jacoby-micro-irrigation-team-wins-national-award/

Ma, X.C., J.R. Thompson, and **P.W. Jacoby**. 2017. Direct Root-zone Deficit Irrigation: A Strategy to Enhance Water Conservation and Sustain Grape Production in Pacific Northwest. Poster presentation at annual open house, Center for Precision and Automated Agricultural Systems (**CPAAS**), July 31, Prosser, WA.

Prengaman, Kate. 2017. Study pushes limits of deficit irrigation. ***Good Fruit Grower***, July 2017 issue. (based on phone interview with **P.W. Jacoby,** June 8). https://www.goodfruit.com/study-pushes-limits-of-**deficit-irrigation**-trials/

Jacoby, P.W. 2017. Use of DRZ subsurface drip irrigation to save water and enhance quality of wine grapes. WA Advancements in Viticulture and Enology (**WAVE**), Radio Program interview, May 2, Richland, WA.

Jacoby, P.W. 2017. Conserving Water through Subsurface Delivery and Precision Irrigation Scheduling. Oral presentation to ***Masters of Wine*** group, WSU St. Michael Wine Science Center, May 2, Richland, WA.

Jacoby, P.W. 2017. Direct Root-zone (DRZ) Micro-irrigation for Sustaining Vineyards during Drought. Oral presentation to WA Advancements in Viticulture and Enology (**WAVE**), Annual Event, Walter Clore Wine and Culinary Center. April 19, Prosser, WA.

Jacoby, P.W. 2016. Direct root-zone irrigation in vineyards. *In*: WSU Viticulture and Enology Extension News, p. 8, spring ed. http://www.wine.wsu.edu/research-extension.