FINAL REPORT

Washington State Grape and Wine Research Program

PROJECT TITLE: Influence of cultivar, environment and management on grape yield components and quality (Objective 1: Optimize irrigation strategies for high-quality white wine grape production)

Project Duration: 2014-2017
WRAC Project No.: Unknown

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Cooperator Name:	James F. Harbertson	**Cooperator Name:**	Russell Smithyman
Organization	WSU Tri-Cities	Organization	Ste. Michelle Wine Estates
Description of participation:	Fruit analysis, wine making and evaluation	Description of participation:	Field trial oversight and vineyard management

BUDGET AND OTHER FUNDING SOURCES

FINAL FINANCIAL REPORTING

BUDGET *(LIST COMPLETED BUDGET NUMBERS) – NOT APPLICABLE*

	Year 1 FY	**Year 2 FY**	**Year 3 FY**
	Jul 14 – Jun 15	Jul 15 – Jun 16	Jul 16-Jun 17
Item			
Salaries	19,370	19,370	51,892
Benefits	7,711	7,029	20,740
Wages	2,880	1,920	1,920
Benefits	367	188	192
Equipment			
Supplies	2,731	1,550	1,550
Travel	941	3,943	4,500
Miscellaneous			
Total	34,000	34,000	80,794
Footnotes: This budget lists figures exactly as presented annually under Objective 1 for this continuing project.			

Total Project Funding: $148,794
Project Budget Status: Project funding will be fully expended by June 30, 2017.

OTHER FUNDING SOURCES/SUPPORT

Agency Name: Specialty Crop Block Grant Program
Amount requested: $181,818
Amount awarded: $181,818
Notes: This project ended on 9/28/2016; a final report was submitted to WSDA.

FINAL REPORT

Project Summary:

The Washington wine industry is continuing its rapid expansion phase, yet many wine critics complain that the overall quality of white wines from this state lags behind red wine quality. Two white varieties, Chardonnay and Riesling, account for 75% of all white wine made in Washington, and will continue to be a major component of the industry's expansion. Due to the arid climate in eastern Washington, drip irrigation is the principal management tool to impact yield, quality, and sustainability of premium grape production. However, virtually no research has been conducted to determine optimum irrigation strategies for white varieties. This project used Chardonnay and Riesling to compare three tools to aid irrigation decision making, and to study the impacts of irrigation regimes on grapevine growth, physiology, and fruit composition. The goal of this project was to provide basic information to develop practical recommendations for irrigation decision-aid tools and irrigation strategies to enhance white wine grape production. The project places valuable information in the hands of grape growers, enabling them to make better, science-based decisions regarding application and conservation of limited irrigation water. It also lays the foundation for the development of more effective irrigation strategies for the wine industry, which will permit improvements in fruit and wine quality through the judicious application of deficit irrigation strategies with a focus on white wine grapes.

Project Major Accomplishments:

The objectives of this project were: (1) Evaluate three irrigation scheduling approaches and determine the best approach for directing irrigation of white wine grapes; (2) Investigate the impacts of different irrigation regimes on white wine grape growth, physiology, yield and fruit composition, and optimize irrigation strategies for high-quality white wine grape production. We conducted field trials from 2014 through 2016 in Chardonnay and Riesling vineyards owned and managed by Ste. Michelle Wine Estates (SMWE) near Paterson, WA. Shoot growth, canopy density, fruit exposure, and gas exchange were measured during the growing season. Yield components were estimated at harvest, and berry samples were collected to measure total soluble solids (TSS), titratable acidity (TA), and pH. Pruning weights were measured in winter. Additional fruit was harvested from selected treatments, using 3 of the 4 field replicates, for winemaking in the WSU Wine Science Center research winery (see project by J. Harbertson). Significant results and conclusions:

- Comparison of irrigation decision-aid tools (T0, T1, and T2): Three treatments were implemented in commercial Chardonnay and Riesling vineyards to test three approaches to aid irrigation scheduling. The weekly amount of irrigation water to be applied in T0 (ET-based approach) was based on replacing 100% of crop evapotranspiration (ET_c). The goal for T1 (soil-based approach) was to maintain soil water content (θ_v) near or above non-stress levels ($\theta_v \geq 16\%$ v/v). The goal for T2 (plant-based approach) was to maintain stem water potential (Ψ_s) near or above non-stress levels ($\Psi_s \geq -0.7$ MPa).
    - Chardonnay: As planned, little difference was found in θ_v and Ψ_s among T0, T1, and T2. There was also no difference in leaf gas exchange in all three years. The results for canopy growth and density differed among the three years. In 2014, T0 vines generally had larger and denser canopies (more leaf layers, less light interception in the fruit zone, and more lateral leaves per shoot), compared with T1 and T2. Yet, few differences were found in 2015 and 2016. Minor differences in yield components were found. In 2014, T0 vines had higher yields than T2, and the highest berry weight of all three. In 2015 and 2016, T1 vines had higher yields than T0 and T2; T0 had lower cluster numbers than T1.

In 2016, T0 vines also had lower cluster weights and fewer berries per cluster than T1. The inconsistency in these results may be explained by the variation in irrigation amounts across the three years: in 2014, T0 received the highest amount, but in 2015 and 2016 it had the least. There was little difference in fruit composition at harvest.

- Riesling: In general, T0 had higher θ_v and Ψ_s than T1 and T2, and there was no difference between T1 and T2. Little difference in leaf gas exchange was found among these treatments. Vines of T0 had larger and denser canopies than T1 and T2 across the three years. Few differences were found between T1 and T2. In terms of yield components, T0 had the highest yield in all three years, higher berry weight in 2014 and 2015, and higher cluster weight in 2015 and 2016. More irrigation in T0 may explain the higher vigor and productivity of these vines. The relatively small differences in irrigation amounts between T1 and T2 were apparently insufficient to result in yield differences. Little difference was found in fruit composition in all three years.
- Among these three tools, all the data inputs for irrigation decision-making of T0 were acquired from a nearby AgWeatherNet station. Therefore, this tool required no additional, vineyard-based measurements. However, the accuracy of ET_c relies on the accuracy of reference evapotranspiration (ET_0) and crop coefficient (K_c). If the local conditions of the weather station are rather different from those of the vineyard block, or if the estimate of K_c does not reflect the actual situation of the vineyard, unexpected results may occur when irrigation decisions are made solely based on ET_c. For example, higher θ_v and Ψ_s in T0 than T1 and T2 in the Riesling block indicated that ET_c was overestimated. This led to a 71% greater irrigation water supply in T0 compared with the other decision-aid tools. Scheduling irrigation based on θ_v (T1) or Ψ_s (T2) measured in the vineyard avoided this problem by providing data inputs for decision-making reflecting the local conditions. However, either approach required extra inputs of equipment and labor. This is especially true for T2, because Ψ_s only indicated whether or not irrigation was needed, an additional parameter (in this study θ_v) was needed to determine the amount of irrigation. Also, Ψ_s can be influenced by weather conditions, in particular temperature and humidity.

* Comparison of deficit irrigation regimes (T3, T4, T5, and T6): Four treatments were designed to test method and timing of deficit irrigation. These treatments were applied to impose moderate plant water stress from budbreak through harvest (T3), budbreak through veraison (T4), or fruit set through veraison (T5), or to apply partial rootzone drying (PRD) from budbreak through harvest (T6). For T3, T4, and T5, the target for moderate stress was $12\% < \theta_v < 16\%$, and -1 MPa $< \Psi_s < -0.7$ MPa. The Ψ_s threshold was typically used to decide when to irrigate, while θ_v was used to calculate how much water to apply. For T6, the drying side was irrigated when its $\theta_v \leq 12\%$ to increase θ_v to $\geq 16\%$.
  - Chardonnay: Compared with the no-water-stress treatments (T0, T1, and T2), the deficit irrigation treatments in general had lower θ_v and Ψ_s, which led to less vigorous shoot growth, more open canopies, lower yield, lower berry and cluster weights, and lower titratable acidity. From veraison to harvest, T4 and T5 had higher θ_v and Ψ_s than T3, which indicates that water stress was relieved as planned. In 2014, T6 had more leaf layers than the other three deficit treatments, and more vigor and less light interception in the fruit zone than T5. In 2015, T3 had fewer leaf layers and T6 had higher vigor than the other deficit treatments; T6 also had less light interception than T3 and T4. In 2016, T6 had more canopy growth and denser canopies than T3; T4 and T5 were either

intermediate between, or no different from, T3 and T6. In terms of yield components, T6 generally had higher yield and the highest berry weight among the deficit treatments, even though the amount of irrigation water supplied in T6 was similar to the others. Little difference was found in fruit composition among these treatments in 2014 and 2015, but in 2016 grapes from T6 had higher acidity than those from T3 and T5. Importantly, berry skin phenolics (flavonols and monomeric, oligomeric, and polymeric flavan-3-ols) were not impacted by the irrigation regime per se, but sun exposure led to an eight-fold increase in flavonols, and a fourfold increase in flavan-3-ols compared with shaded berries. This suggests that any potential irrigation effect on bitter or astringent wine phenolics likely occurs via its effect on canopy structure, and thus on light exposure of the fruit.

- Riesling: In general, the deficit treatments resulted in lower θ_v and Ψ_s, and thus led to lower shoot vigor, more open canopies, lower yield, lower berry and cluster weights, and lower titratable acidity than T0. However, growth and yield components in these deficit treatments differed only occasionally from T1 or T2, despite less irrigation in the deficit treatments. Among the deficit treatments, no consistent differences in canopy growth and density were found across the three years, except that T3 vines tended to have fewer leaf layers. From veraison to harvest in both 2015 and 2016, T4 and T5 had higher θ_v, Ψ_s, and leaf gas exchange than T3, which indicates that water stress was relieved as planned. In terms of yield components and fruit composition, few or inconsistent differences were found, except that T6 often had higher berry weights than the other deficit treatments, with similar amounts of irrigation. The results for fruit phenolic compounds were similar to those found in Chardonnay. Overall, Riesling produced much lower amounts of flavan-3-ols than Chardonnay, while flavonol levels were similar.

Practical recommendations:

- It is feasible to schedule irrigation based on either ET_c, θ_v, or Ψ_s. Each approach has its pros and cons, resulting in trade-offs between accuracy and labor/equipment demands, as described above. In order to improve the applicability of the ET-based approach, the current model for estimating K_c based on growing degree days may require adjustments to suit the local conditions of the vineyard. An alternative solution would be to adopt a different method that can estimate K_c locally. If using the ET-based approach, it would be advisable to at least employ either soil- or plant-based measurements to check whether intended irrigation goals are achieved under local conditions.
- Excessive water deficit should be avoided in white wine grape production. Imposing moderate water stress throughout the growing season (T3) tended to result in the smallest canopies that were associated with high sun exposure of the fruit, which may increase bitterness or astringency in wine. Although water stress does not appear to directly impact grape phenolics, an increase in fruit exposure due to water deficit will nevertheless have a detrimental impact on these quality-relevant components. It should be noted that only moderate water stress was applied in the present experiments. More severe stress, which results in leaf abscission in the fruit zone and in sunburn symptoms on the fruit, presumably would worsen the situation.
- With similar or occasionally more canopy growth and little difference in fruit composition compared with conventional deficit irrigation regimes (T3, T4, and T5), PRD (T6) may be beneficial considering its higher yielding with similar irrigation water usage. Also, the irrigation decision was easy to make based on θ_v of two separate

rootzones: irrigation was initiated on the drying side and stopped on the wet side whenever θ_v of the drying side fell below 12%. This threshold could be adapted to different soil types for integration in automated irrigation decision-support tools.

This project has benefited the stakeholders of the Washington state wine industry (both wine grape growers and wine producers). The outputs generated from this project (listed in the following section) have been shared widely with many grower and winery stakeholders, which will enable them to make better, science-based decisions regarding the application and conservation of limited irrigation water, and will lay the foundation for the development of more effective irrigation strategies with a focus on white wine grapes. In the long run, this project will contribute to the long-term economic and environmental sustainability of the wine industry, and will enhance the industry's competitiveness in both domestic and global markets. Moreover, key findings from this project have already been integrated in the PI's classroom teaching materials in the Washington State University viticulture and enology program. This program currently has more than 100 enrolled undergraduate students, most of whom will embark on careers in the wine industry upon graduation.

Information Dissemination, Extension, and Outreach Activities:

Zhang Y., and M. Keller. 2017: Optimize irrigation practice for white wine grape production. Poster presentation. Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA. February 7-9, 2017.

Gohil H., M. Keller, and M. Moyer. 2016: On-farm vineyard trials: A grower's guide. Washington State University Extension Manual EM098e, 23 pp.

Keller M. 2016: The Science of Grapevines: Anatomy and Physiology. Chinese Translation by J. Wang, C.Q. Duan, F. He and B.Q. Zhu. China Science Publishing & Media, Beijing, China, for Elsevier, New York, NY.

Keller M. 2016: 30 years of irrigation research: What's next? Oral presentation. WAVE 2016, Washington Advancements in Viticulture and Enology. Richland, WA, July 14, 2016.

Keller M. 2016: Grape berry ripening: Environmental drivers and spoilers. Keynote presentation. InnoVine International Symposium. Toulouse, France, November 16-17, 2016.

Keller M. 2016: Grape berry ripening: Environmental drivers and spoilers. Oral presentation. Institut des Sciences de la Vigne et du Vin Seminar Series, Université Victor Segalen Bordeaux 2. Villenave d'Ornon, France, November 14, 2016.

Keller M. 2016: Grape berry responses to water stress. Oral presentation. American Society for Enology and Viticulture National Conference. Monterey, CA, June 27-30, 2016.

Keller M. 2016: The time is right: Grape ripening and how to optimize it in the vineyard. Oral presentation. Oregon Wine Symposium. Portland, OR, February 23-24, 2016.

Keller M. 2016: Vineyard irrigation management—grower perspective. Oral presentation. Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA, February 9-11, 2016.

Keller M. 2015: The Science of Grapevines: Anatomy and Physiology. 2nd ed. Elsevier Academic Press, London, U.K.

Rocchi L., Y. Zhang, J. Harbertson and M. Keller. 2016: Physiological responses of white grape berries to sunlight exposure. Oral presentation. Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA. February 9-11, 2016.

Zhang Y., and M. Keller. 2016: Optimize irrigation practice for white wine grape production. Poster presentation. Annual Meeting of Washington State Grape Society. Grandview, WA. November 10-11, 2016.

Zhang Y., L. Rocchi, J.F. Harbertson, and M. Keller. 2016: Irrigation strategies for white winegrape production. Oral presentation. 67th American Society for Enology and Viticulture National Conference. Monterey, CA. June 27-30, 2016.

Zhang Y. 2016: Vineyard irrigation management – vine's perspective: What does the vine think? Oral presentation. Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA. February 9-11, 2016.

Zhang Y. 2016: Understanding water dynamics of the grape berries and irrigation management. Oral presentation. Unified Wine & Grape Symposium. Sacramento, CA. January 25-28, 2016.

Keller M. 2015: Deficit irrigation impacts on viticulture. Oral presentation, Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA, February 10-13, 2015.

Keller M. 2015: Drought impacts on wine grapes. Interview, The New York Times, June 2, 2015.

Keller M. and Y. Zhang. 2015: Grapevine water relations and irrigation management. Oral presentation, American Society for Enology and Viticulture National Conference, Portland, OR, June 15-18, 2015.

Keller M. and Y. Zhang. 2015: Irrigation and mechanization trials, and cold hardiness and grape physiology research. Oral presentation and field tour, National Grape & Wine Initiative Board of Directors. Paterson and Prosser, WA, July 16, 2015.

Rochi L. 2015: Physiological responses of white grape berries to sunlight exposure. PhD thesis, University of Milan, Italy (co-advisor: M. Keller).

Ruiz M.U. 2015: Decision tool comparison based on evapotranspiration, soil, and plant water content to determine vineyard water requirement and improve irrigation strategies for white winegrape production. MS thesis, Geisenheim University, Germany (co-advisor: M. Keller).

Zhang Y. 2015: Irrigation scheduling for Washington's vineyards. Oral presentation. Washington Association of Wine Grape Growers Annual Meeting. Kennewick, WA, February 10-13, 2015.

Zhang Y. and M. Keller. 2015: Irrigation scheduling and management for white wine grape production. Poster presentation. Washington State Grape Society Annual Meeting. Grandview, WA, November 12-12, 2015.

Zhang Y. and M. Keller. 2015: Irrigation scheduling and management for white wine grape production. Proc. 19th International Symposium GiESCO, Gruissan, France. Publications et Actualités Vitivinicoles. pp. 154-158.

Literature Cited:

Not applicable.