Washington State Grape and Wine Research Program

FINAL REPORT
2023-24 FUNDING CYCLE

1. Summary:

Project Title: Dissecting the relative importance of grape variety versus environment for irrigation management

Principal Investigator: Markus Keller

Irrigation management strategies have not evolved in parallel with the varietal diversification of Washington's wine industry. The main approach for water application is a regulated deficit irrigation program that is more-or-less customized to fit either red or white varieties. However, growers often report that some varieties tend to show peculiar behaviors, making irrigation management somewhat ambiguous. In the past, grape varieties have been grouped into "pessimists" (called isohydric) and "optimists (called anisohydric), but our recent research has shown that this categorization is overly simplistic. This challenges the current one-size-fits-all approach to deficit irrigation, and partly explains why irrigation management can sometimes have unpredictable outcomes. The present study addresses these knowledge gaps by comparing varietal behavior across regions with disparate climates and soils, namely Washington's Yakima Valley and Red Mountain AVAs and France's Bordeaux region. This will help us to determine the extent to which differences in behavior are driven by genotype (variety) versus environment (vineyard site and growing season). Such information is essential to develop variety- and site-specific irrigation management strategies. Thus, the research outcome will provide growers with a pathway to improve grape quality using enhanced knowledge-based irrigation scheduling.

2. **Annual Report**: Year 4 of 4 (one-year, no-cost extension).

3. **Project Title**: **Dissecting the relative importance of grape variety versus environment for irrigation management**

4. **Principal Investigator/Cooperator(s)**:
PI: Markus Keller, Washington State University, Irrigated Agriculture Research and Extension Center (IAREC), Prosser, WA, (509) 786 9263, mkeller@wsu.edu
Co-PI: Joelle Martinez (*until July 2020*), Charles Obiero (*from May 2021*) Washington State University, IAREC, Prosser, WA
Cooperators: Gregory Gambetta, University of Bordeaux, France
Jim Holmes, Ciel du Cheval Vineyard, Benton City, WA

5. **Objective(s) and Experiments Conducted to Meet Stated Objective(s)**:
Note: This project is mostly funded by the Specialty Crop Block Grant Program (SCBGP). Due to the SCBGP funding cycle (9/30/2019 – 9/29/2022), field measurements started in 2020 and continued through 2022. A postdoctoral research associate (Co-PI Joelle Martinez) was hired at WSU-IAREC in September 2019 but resigned in July 2020. Hiring another postdoc (Co-PI Charles Obiero) was delayed due to the ongoing COVID-19 pandemic until May 2021. An MS student (Marc Plantevin) conducted the measurements in Bordeaux.

Objective 1: Measure seasonal changes in vine water status and stomatal conductance of grape varieties under well-watered and water-deficit conditions in Washington (Prosser) and France (Bordeaux).
A replicated field trial was established in the WSU-IAREC research vineyard in 2020 to evaluate the responses to imposed water deficit of 30 wine grape varieties grown in the same vineyard. Novel plant sensors (FloraPulse stem water potential probes), which had not been available at the time this project proposal was submitted, were installed in 2021 on three replicate vines each of Cabernet Sauvignon, Grenache, Malbec, and Sémillon. These varieties were chosen for their differences in responses to water deficit in preliminary experiments. The sensors provide continuous measurements of stem water potential (Ψ_s) in real time. Their output was compared to midday leaf water potential (Ψ_l) measurements taken with a pressure chamber on the same vines. In addition, novel sap flow sensors (Treetoscope T2S) were installed in 2022 on Cabernet Sauvignon, Grenache, Durif, and Tempranillo, which differ in plant vigor.

In 2020, preliminary data (soil moisture and Ψ_l) were collected in Cabernet Sauvignon, Grenache, Malbec, and Sémillon. In 2021 and 2022, all varieties were fully irrigated through fruit set, and then the soil was allowed to dry down to create an increasingly severe soil water deficit through veraison. Following a full irrigation to field capacity at veraison, a second drydown cycle was imposed through postharvest. Approximately biweekly measurements of predawn and midday Ψ_l and midday stomatal conductance (g_s) were collected from fruit set through harvest. Complementing the measurements collected at IAREC, the Bordeaux team compared six varieties (Cabernet Sauvignon, Grenache, Merlot, Tempranillo, Sémillon and Ugni blanc), five of which (all but Ugni blanc) are also included in the IAREC trial. A coordination meeting between the two groups took place on January 31, 2022, to compare results and discuss how the two datasets can be integrated and used to develop practical recommendations. However, the Bordeaux group subsequently decided to publish their data independently (Plantevin et al., 2022; see under 7. below).

Objective 2: Measure changes in soil moisture and canopy development as for Objective 1.
Soil moisture access tubes for neutron probe measurements were installed in 2020 in all replicates of all 30 varieties. In addition, soil sensors (Green Shield capacitance probes) were installed to a depth of 3 ft under some of the same vines (Cabernet Sauvignon and Grenache only due to funding restrictions) on which the FloraPulse Ψ_s sensors were installed. The Green Shield sensors provide continuous measurements of soil moisture and soil temperature in real time. All data were collected throughout each growing season. Volumetric soil water content (VWC) was converted to extractable soil water (ESW), defined as the relative water content normalized to field capacity (FC) and permanent wilting point (PWP): ESW = (VWC – PWP)/(FC – PWP). The dimensionless ESW normalizes the influence of soil texture on VWC (ESW = 0 at PWP and ESW = 1 at FC), which permits comparison of soil water deficit across different soil types. Shoot growth was measured at fruit set and veraison, and pruning weights were determined after the 2021 season but have yet to be measured for the 2022 season. These measurements were coupled with canopy photographs to estimate the canopy size of each variety.

Objective 3: Collect and analyze soil moisture and vine water status data from Red Mountain.
The PI and Co-PI (Joelle Martinez) met with cooperator Jim Holmes in December 2019 to discuss the overall approach, and the "new" Co-PI (Charles Obiero) also met with Jim in 2021. Jim continues to share the soil moisture and Ψ_s data from Ciel du Cheval Vineyard. In addition, he is also conducting his own analysis to model Ψ_s from soil moisture measurements. Following the formation of the new federally-funded WSU Artificial Intelligence (AI) Institute (https://agaid.org) in 2021, it was agreed that all data would be shared with computer scientists from that institute to employ machine-learning approaches for enhanced data analysis and model development. Data analysis is in progress.

Objective 4: Integrate all measurements to develop irrigation scheduling recommendations.
This objective is currently being addressed through the end of this project and beyond. The ultimate goal of the modeling work conducted by the WSU AI Institute is to fully automate irrigation scheduling by grape variety.

6. **Summary of Major Research Accomplishments and Results by Objective:**
Objective 1: Measure seasonal changes in vine water status and stomatal conductance of grape varieties under well-watered and water-deficit conditions in Washington (Prosser) and France (Bordeaux).
Though significant, the correlation between the FloraPulse Ψ_s sensor measurements and the "standard" pressure chamber Ψ_l measurements was rather low ($r = 0.49$, $p < 0.001$, across varieties). Measurements of trunk diameter suggest that the reliability of the sensors increases as trunks become thicker. Grenache has the thickest trunks in our vineyard and showed the best correlation. Based on our feedback, FloraPulse is now developing a smaller sensor designed specifically for the relatively slender trunks of grapevines, a problem that is compounded by the dual-trunk approach in many vineyards in Washington. By contrast, the data obtained with the Green Shield soil moisture sensors were highly correlated with the "standard" neutron probe measurements ($r = 0.83$, $p < 0.001$).

During the first (preveraison) drydown cycle in 2021 and 2022, all varieties were virtually isohydric above 15% VWC (ESW = 0.35) and anisohydric as the water deficit became more severe below that threshold. This means that the Ψ_l essentially remained constant as the soil moisture decreased from above field capacity (ESW > 1.0) down to 15% and then declined relatively rapidly as the soil dried further (ESW < 0.35). Also, there was a rather consistent difference of about 0.4–0.5 MPa between predawn Ψ_l and midday Ψ_l across the soil moisture spectrum. Nevertheless, so-called anisohydric varieties (e.g. Sémillon) or varieties with a large canopy (e.g. Tempranillo) reached a seasonal minimum midday Ψ_l around -1.6 MPa, whereas so-called isohydric varieties (e.g. Grenache) or varieties with a small canopy (e.g. Durif) only decreased their midday Ψ_l to about -1.3 MPa. In terms of water stress experienced by grapevines, a Ψ_l of -1.3 MPa is considered moderately severe, and a Ψ_l of -1.6 MPa is considered severe stress (Rienth and Scholasch, 2019). The general response of g_s to declining soil moisture was similar to that of Ψ_l across the 30 varieties. During the second (postveraison) drydown cycle in 2021, all varieties again responded similarly to the decline in soil moisture, though some varieties (e.g. Grenache, Tempranillo) seemed even more isohydric than previously. While the predawn Ψ_l was similar to or slightly higher than during the first cycle, the midday Ψ_l was generally about 0.2 MPa higher at the same level of soil moisture, possibly as a result of lower VPD and shorter daylength. Thus, the postveraison difference between the predawn Ψ_l and midday Ψ_l ranged from 0.2 to 0.4 across the soil moisture spectrum. Unlike in 2021, only one round of measurements was taken during the second (postveraison) drydown cycle in 2022 due to the lateness of the season. Nonetheless, the predawn Ψ_l was similar to the first drydown while the midday Ψ_l was higher.

Despite their differences in canopy size (see Objective 2), all varieties responded similarly to soil drying, in the sense that they did not begin to "feel" water-stress until the soil reached an ESW threshold of about 0.35. Consequently, irrigating to maintain substantially higher soil moisture levels (i.e., ESW > 0.35) unnecessarily wastes water resources. However, the varieties differed when considering the ESW at midday Ψ_l of -1 MPa (transition from mild to moderate water stress). Some varieties (e.g. Chardonnay, Sémillon, Melon, Cabernet Sauvignon, Durif) had ESW values between 0.15 and 0.2 at that threshold, while the ESW of others (e.g. Aligoté, Albariño, Riesling, Sauvignon blanc, Merlot, Nebbiolo, Grenache, Tempranillo) was between 0.1 and 0.15, and that of Malbec was below 0.1 (the permanent wilting point is at ESW = 0.0). Varieties with lower ESW at midday Ψ_l = -1 MPa did not experience water stress until the soil had dried down to lower levels compared with varieties with higher ESW numbers. For example, varieties such as Malbec may require significant soil drydown to achieve the benefits associated with moderate water stress imposed by regulated deficit irrigation. There was no clear indication that these ESW thresholds were related to shoot length, except that Melon stands out as experiencing moderate water stress at the highest soil moisture, which may explain why it was the least vigorous variety in our study. A more detailed data analysis is currently in progress.

The Bordeaux group ranked the six varieties included in their measurements in terms of their apparent drought sensitivity based on changes in Ψ_{pd} and Ψ_l (Plantevin et al., 2022): Grenache (least sensitive) < Ugni blanc < Cabernet Sauvignon < Merlot < Tempranillo < Sémillon (most sensitive). However, they did not estimate canopy size in their field trial. Though their results differ from ours, they, like us, found Tempranillo to be among the first varieties to show leaf wilting under drought stress. At this point we do not know whether the differences between our results and the Bordeaux results are due to rootstock use (our vines are own-rooted, theirs are grafted on SO4), differences in climate (summers in eastern Washington are somewhat warmer and have greater diurnal temperature differences than in Bordeaux), soil properties (our soil is a silt loam, theirs is a mix of gravel and sand), or vineyard management including planting density (our vines are spaced at 6' × 9', theirs at 3.3' × 6'), training and pruning (our vines are spur-pruned at 38" height, theirs are cane pruned at 20" and hedged in summer), irrigation (their vineyard is dry-farmed), or floor management (we have a summer-dormant cover crop with under-vine herbicide strip, they have a mowed cover crop with under-vine tilling). Vine age and virus status are unlikely to be significant issues; our vineyard was planted in 2010, the Bordeaux vineyard was planted in 2009, and both used virus-tested, clean planting material.

Plantevin M., M. Gowdy, A. Destrac-Irvine, E. Marguerit, G.A. Gambetta and C. van Leeuwen. 2022. Using $\delta^{13}C$ and hydroscapes for discriminating cultivar specific drought responses. OENO One 56: 239-250.

Rienth M. and T. Scholasch. 2019. State-of-the-art of tools and methods to assess vine water status. OENO One 4: 619-637.

Objective 2: Measure changes in soil moisture and canopy development as for Objective 1.

Shoot growth measurements indicated that the canopy size varied considerably across varieties. Vigorous varieties (e.g. Nebbiolo, Tempranillo, Albariño) had an approximately two-fold larger canopy than the least vigorous varieties (e.g. Durif, Aligoté, Melon). The varietal differences in canopy size were rather consistent between 2021 and 2022, indicating that vigor differences have a significant genetic component. The canopy data suggest that differences in the response to water deficit among grape varieties, if they exist, cannot simply be explained by differences in vigor and hence canopy size. However, varieties with bigger canopies dried the soil more quickly compared to those with smaller canopies, thus more vigorous varieties may require more frequent irrigation to maintain a desirable plant water status. Full statistical data analysis is currently in progress.

Objective 3: Collect and analyze soil moisture and vine water status data from Red Mountain.

A large and ongoing soil moisture and leaf water potential dataset is being provided to the project by the industry cooperator (Jim Holmes). Data sharing and analysis are in progress and an initial statistical analysis suggests that it may be possible to model (i.e., predict) Ψ_l values from continuous measurements of soil moisture.

Objective 4: Integrate all measurements to develop irrigation scheduling recommendations.

Though data collection is nearly complete (safe for pruning weights), full integration cannot be achieved before all data have been analyzed statistically. Nevertheless, we have developed the following preliminary recommendations and irrigation decision support tools:

(1) Among the 30 wine grape varieties tested in our study, differences in responses to soil water deficit appear to be associated more with varietal differences in canopy size rather than with inherent physiological variables. All varieties maintained their water status (i.e., behaved isohydrically) at higher soil moisture levels (ESW > 0.35), and plant water status began to decline (i.e., behaved anisohydrically) below a common soil moisture threshold (ESW < 0.35). A recommendation that follows directly from this result is for growers to refrain from irrigating to soil moisture levels that are substantially higher than the 0.35 ESW threshold.

(2) Wine grape varieties may have different soil moisture thresholds at which plant water deficit transitions from mild to moderate stress. There are those with higher (0.15–0.2), medium (0.1–0.15), and lower (below 0.1) ESW thresholds. Though the type of wine grape variety (i.e., red or white) is unimportant with respect to these thresholds, moderate water stress is generally desirable for fruit quality of most red winegrapes, whereas mild stress is preferable for white winegrapes. Growers may thus customize deficit irrigation goals and scheduling depending on specific wine styles and quality parameters.

(3) Canopy measurements may be used in irrigation scheduling for different wine grape varieties. Vigorous varieties dry the soil faster and should be irrigated more frequently once control of shoot growth has been achieved, especially during heat waves. To use this vigor-based tool, growers need to compare shoot growth or pruning weight of their different varieties.

(4) In principle, Ψ_s sensors embedded in the vine trunk could eliminate the need for frequent manual measurements to determine vine water status. However, in their current form they seem not well correlated with the standard pressure chamber measurements. It appears that the sensor size is too big for many vine trunks; the data correlate better in vines with larger trunks. The manufacturer has been made aware of this issue and is currently developing a smaller sensor that may work better for grapevines, which have much slimmer trunks than fruit trees.

(5) Since (1) and (2) above recommend irrigation tools based on soil moisture, growers need to know the field capacity (ESW = 1) and permanent wilting point (ESW = 0) of their vineyard soils to use these tools. Growers could benefit from continuous soil moisture measurements through probes that are permanently installed in the soil, but such probes also should be calibrated against field capacity and permanent wilting point.

7. **Outreach and Education Efforts - Presentations of Research**:

We are disseminating our results to the industry during and after this project, taking advantage of existing outreach and education programs, and collaborating with industry organizations (e.g. Washington Wine Commission, Washington Winegrowers Association, Washington State Grape Society). We are currently integrating the knowledge gained in established guidelines to provide recommendations to the industry. Key findings will also be used in the PI's classroom and certificate program teaching materials. Novel scientific knowledge will be published in peer-reviewed journals. During 2022, results were shared with industry and other stakeholders as follows:

- Obiero C. and M. Keller. 2022: Vigor and canopy size are key to irrigation scheduling for different winegrape varieties. Poster, American Society for Enology and Viticulture National Conference. San Diego, CA, June 19-22, 2022.
- Obiero C. and M. Keller. 2022: Optimizing vineyard irrigation management by wine grape variety. Poster, WineVit by Washington Winegrowers Association, Kennewick, WA, February 7-10, 2022.
- Obiero C. and M. Keller. 2022: Irrigation scheduling by wine grape variety: hints from research. WSU Viticulture and Enology Extension News, Fall 2022: 3-5.
- Plantevin M., M. Gowdy, A. Destrac-Irvine, E. Marguerit, G.A. Gambetta and C. van Leeuwen. 2022. Using $\delta^{13}C$ and hydroscapes for discriminating cultivar specific drought responses. OENO One 56: 239-250. (Separate report by the Bordeaux group)

8. **Research Success Statements**:

The outputs generated from this project will help growers and other wine industry members to tailor irrigation management by cultivar and vineyard site as required, thereby optimizing water use efficiency. Also, growers will have science-based information to assess and monitor water stress on each variety, which will be especially useful for those varieties that are reportedly difficult to irrigate. Results will be shared widely with industry stakeholders as outlined above.

9. **Funds Status**:

Funds are expected to be fully expended by June 2023. They were originally intended to be used for travel by the Co-PI, but all out-of-state travel was canceled in year 1 due to pregnancy and childbirth, and in year 2 due to the COVID-19 pandemic. Consequently, funding was used to purchase novel plant sensors (https://www.florapulse.com) that were permanently installed in vine trunks in spring of 2021 and 2022 for continuous measurements of stem water potential. These sensors had not been available at the time the project was originally submitted.