Irrigation Strategies
Maintain Natural Grapevine Mechanisms Through a Drought

Thibaut Scholasch

Co-founder of Fruition Sciences, **Thibaut Scholasch** brings his technical and scientific expertise in viticulture and enology to the company. He conceived the conceptual framework for 360viti (ex Fruition Analytics) and selected the tools to be connected to the vineyard. Throughout this experience, he became an expert in controlling the effects of environmental stresses on vine physiology, fruit and wine quality, such as light, temperatures, nitrogen or water stresses on grape composition. He has worked as a winemaker and consulted for wineries all around the world (France, Chile, California, Australia, Argentina, Israel). Scholasch has a Ph.D. in vine physiology and a passion for understanding what drives vine health to make good wines.

THIS ARTICLE SHARES DATA and field observations along with scientific findings to discuss the effect of irrigation frequency on vineyard water use regulation. It is suggested that imposing high irrigation frequency is not always the most desirable strategy to reduce water deficit. High frequency irrigation can lead to more severe yield loss and increase sugar concentration before harvest due to fruit ripening disorders or heightened fruit sensitivity to shriveling. Such fruit responses related to water deficit management should be avoided particularly in a context of higher temperatures. The discussion leverages historical vineyard performances using continuous vine water status measurements in response to high irrigation frequency. Thanks to technological advances, new and more precise source of information can be used to improve future irrigation practices. Combined with recent scientific knowledge on vine water use regulation alongside field observations, it is possible to adopt irrigation strategies more respectful of grapevine natural mechanisms to cope with drought.

Abstract

We discuss how irrigation frequency affects root architecture, vine water use regulation and ultimately fruit ripening dynamics. We report results from continuous vine water use measurements by using sap flow and obtained over various vineyards and multiple years to illustrate how irrigation frequency can impact water deficit profile between two watering events and during the season. Our data suggests that under more frequent irrigations, vine water use tends to drop more substantially once the effect of water applied disappears. However, under the same growing conditions, applying larger volumes less frequently leads to a more moderate vine water deficit profile over the season. In turn, applying longer intervals between irrigations can have positive effects on berry volume and berry sugar accumulation rate. We discuss some practical consequences related to irrigation volume and frequency and the need to systematically relate irrigation strategies to their effects on plant water use and fruit indices.

Introduction

In semi-arid regions and with warmer temperatures, irrigation is increasingly becoming a part of vineyard management practices. Whether in a newly developed vineyard or in an older vineyard that used to be dry-farmed, implementing irrigation will have a major effect on vineyard performances.

The main effect of any irrigation is to increase vine water use. If there is a water deficit prior to irrigation, the vine water deficit level decreases after irrigation because of an increase in water use. The magnitude of the decrease in vine water deficit is proportional to climatic demand and to the rise in the amount of water use.

However, irrigation also modifies root architecture while water deficit variations impact fruit composition and yield levels (Guilpart et al., 2014). Thus, monitoring irrigation effect on vine water use variations is critical to define an irrigation strategy adapted to production goals, climate and soil conditions, as well as plant material and architecture. Irrigation effects on vine water use can be measured either directly with sap flow sensors or indirectly with different methods, including water potential readings or environmental readings (like eddy covariance or surface renewal).

By analyzing vine water use variations in response to different irrigation strategies, useful information can emerge to design an irrigation program adapted to vineyard-specific properties, particularly regarding the volume and frequency of water application. By comparing fruit ripening profile with yield obtained under contrasted irrigation strategies, vineyard managers and winemakers can improve vineyard performance. For more than 10 years and across vineyards located in semi-arid climates, we collected sap flow data to precisely evaluate irrigation effects on vine water use (Scholasch, 2018). Thus, leveraging sap flow data, we propose to shed a new light on the benefits that a moderate drought period imposed between two successive irrigations can have on vine production.

We will first discuss irrigation effect on root profile before analyzing short-term and long-term effects of irrigation frequency on seasonal vine water deficit variations. Second, we will discuss the consequences of irrigation frequency on fruit ripening profile and berry volume loss before harvesting by using case studies. Practical consequences of imposing longer intervals between two irrigations and moderate drought periods during the season are discussed to define an irrigation strategy that improves vineyard production.

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1. Irrigation Modifies Root Architecture

Edwards et al., (2013) investigated the effect of different irrigation volumes on root dry mass over 75 cm of soil depth. They found that total root dry mass is the highest under well-watered conditions and lowest under the prolonged drought treatment where less water was applied. However, the fraction of total root mass within the first 25 cm represented more than 55 percent in the well-watered treatment and 30 percent in the treatment where prolonged drought was imposed pre-veraison. Figure 1 shows the total amount of root dry mass measured in the top 25 cm of soil (estimated from a grid of nine soil cores per unit area).

FIGURE 1

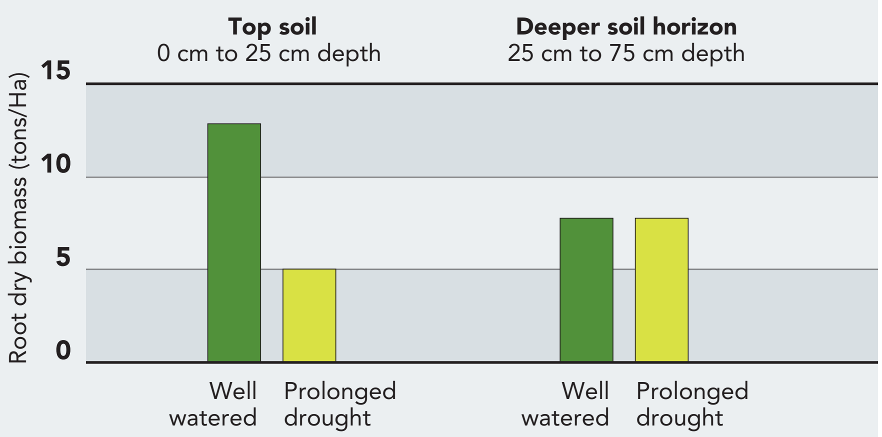

FIGURE 1: Trends in root dry mass distribution along soil profile in response to irrigation: Left, in the top soil horizon (0-25 cm); Right, in the 25 to 75 cm soil horizon (adapted from Edwards et al, 2013)

FIGURE 1 left and right show that the root distribution along the root profile is more uniform when less water is applied. Under the well-watered treatment, as soil is more abundantly rewetted, a larger and shallower root system develops.

Conclusion:
Root architecture can be modified in response to the frequency and volume of irrigation. Thus, irrigation strategy affects the size and distribution of root absorption sites along the soil profile. When root mass and root absorption sites are more concentrated in the topsoil (below the irrigation dripper), vine water supply becomes more dependent upon soil moisture content variations that occur in the topsoil layer. To understand how the modification of root absorption site distribution along the soil profile affects vine water use, we compared the effect of short and long intervals between irrigations on vine water use and berry ripening.

2. Short Intervals Between Irrigation Can Induce More Severe Water Deficit

To investigate the effect of water application distribution on vine water use, we analyzed the effects of different drought intervals imposed between irrigations. Using sap flow sensors, we monitored vine transpiration response to short and large irrigation intervals between two irrigations and over the season.

A) RESPONSE BETWEEN TWO IRRIGATIONS

Over the same season, a same volume of water is applied via one irrigation (18 mm) or via three smaller irrigations (6 mm each) in the same vineyard. Figure 2 shows vine water use profiles obtained during an irrigation study in Napa Valley, with Cabernet Sauvignon. After the same total amount of water was applied, the vine transpiration level is 50 percent lower (0.6 mm per day) in the treatment with small irrigations compared to one large irrigation (1.2 mm per day). The steepness of vine water use decline after irrigation is more pronounced when small irrigations are applied. After a 6 mm water application, transpiration is reduced substantially only a few days after irrigation After an 18 mm water application, transpiration is reduced gradually over the course of more than 10 days.

FIGURE 2

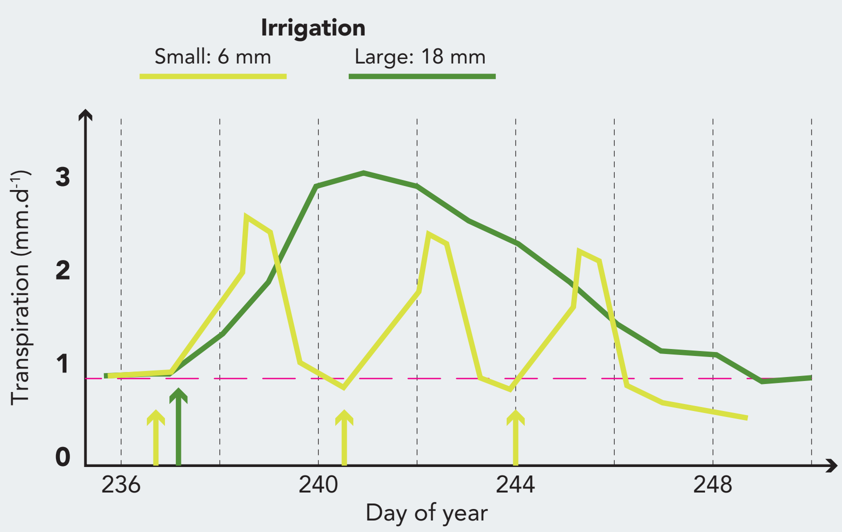

FIGURE 2: Vine transpiration in response to large and small irrigations (adapted from Scholasch et al., 2009)

Conclusion:
In the conditions of the experiment, following a small irrigation, vine water use declines rapidly. However, following a large irrigation, vine water use declines slowly. After 11 days, the vine transpiration rate is reduced when irrigation is more frequent, even if the same total amount of water is applied over the period.

When longer periods of drought are imposed between irrigations, vine water use efficiency is improved, and the irrigation effect can last longer.

B) SEASONAL RESPONSE

Because changing irrigation strategy can modify root mass distribution, the effects of converting irrigation strategy from short to longer drought intervals can span several years. We investigated the effect of imposing a longer drought period over three consecutive years in the same vineyard located in Napa Valley, with cv. Cabernet Sauvignon. The treatment objective is to change irrigation strategy from frequent (every three to seven days) to less frequent irrigations. To ensure increased intervals between two irrigations, we did not increase the severity of water deficit in between, and sap flow and water deficit index variations were continuously monitored in real time and collected over the same vines for three seasons.

To analyze vine water use variations in response to changing environmental conditions, a water deficit index (WDI) is created:

$$WDI = T / K_{cb} * ET_{ref}$$

T is actual vine transpiration from sap flow sensors; ET_{ref} is computed from a nearby weather station by using **Penman Monteith**'s equation. K_{cb} is the basal crop coefficient according to the nomenclature of the dual coefficient approach, reported by Allen, et al. (1998). The basal crop coefficient is computed as:

$$K_{cb} = T_m / ET_{ref}$$

where T_m is maximal transpiration measured under cultural conditions. Models that simulate seasonal changes in basal crop coefficient are used and adjusted according to site-specific data. In practice, when WDI is at 100 percent, a vine is transpiring at its maximal level whereas when WDI is at 0 percent, the vine is no longer transpiring.

Time intervals between two irrigations were increased by adding larger amounts of water and tracking sap flow and WDI to determine when the next irrigation should be triggered. The amount of water applied was gradually increased from 5 mm per irrigation (year 1), to 8 mm (year 2), to 8 to 12 mm (year 3). The total amount of water applied over the season was 75 mm for year 1, 72 mm for year 2 and 76 mm for year 3.

A same WDI threshold of 40 percent was used to trigger irrigation in years 1 and 2. A higher threshold level was used (55 percent) in year 3 to further decreases the water deficit intensity. As larger water volumes are applied, intervals between irrigations became larger.

FIGURE 3 shows seasonal WDI profile recorded in year 1 and 2. During year 1, irrigation is applied every three to seven days and, during year 2, every 10 to 15 days. As a result, in year 2, WDI reaches higher values after each irrigation, the irrigation effect duration increases, and the seasonal water deficit is less severe compared to year 1. Between June and September, the average WDI is under 50 percent in year 1 and around 55 percent in year 2.

FIGURE 4 compares the WDI seasonal dynamics recorded in year 1 and year 3. While the same amount of water is applied for both seasons, the lowest level of water deficit is recorded in year 3 with the average seasonal WDI higher than 60 percent. Applying larger irrigation volumes for two consecutive years improved vine water use regulation, and the seasonal water deficit is more moderate. A larger water volume applied less frequently extended the period length with moderate water use. It may also have increased the depth of root absorption sites. These changes in vine water use regulation and root architecture may contribute to maintaining a lower water deficit (i.e., a higher seasonal WDI value).

Conclusions

Applying water less frequently reduces the severity of seasonal water deficit

Increasing the drought period between irrigations contributes to improving vine water deficit regulation. As a result, when irrigation intervals increase, seasonal water deficit gets less severe.

FIGURE 3

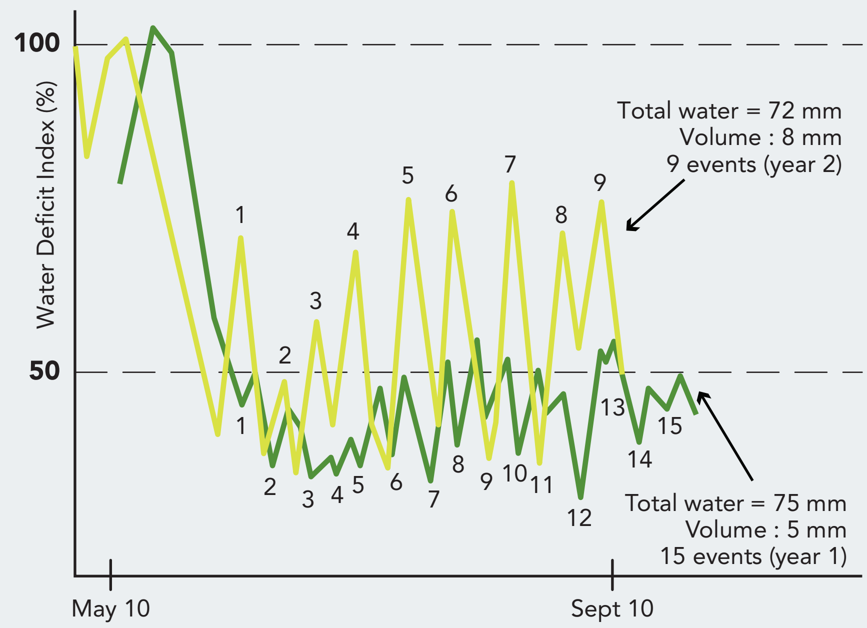

FIGURE 3: Water deficit index variations in response to decreasing irrigation frequency between year 1 (5 mm per irrigation) and year 2 (8 mm per irrigation). Each number on the graph corresponds to one irrigation event.

FIGURE 4

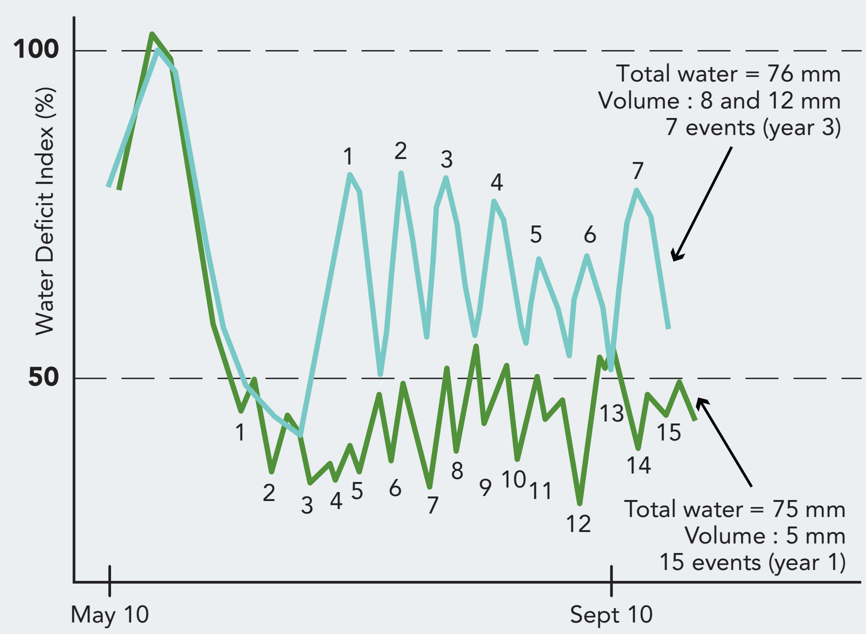

FIGURE 4. Water deficit index variations in response to decreasing irrigation frequency between year 1 (5 mm per irrigation) and year 3 (8 to 12 mm per irrigation). Each number on the graph corresponds to one irrigation event.

3. Short Irrigation Intervals Can Increase the Risk Ripening Disorders

Berry volume reduction is mainly caused by berry pulp water loss (Keller, 2010). Thus, when berry transpiration and xylem outflow exceed xylem inflow, water deficit post-veraison can lead to a loss of berry volume (Delrot et al, 2014). Furthermore, when water deficit gets too severe during ripening, berry sugar accumulation can be reduced due to lower photosynthetic activity. Thus, after veraison, water deficit should remain moderate; otherwise, it can negatively affect berry ripening processes. As such, beyond their impact on seasonal vine water deficit, consequences of increased irrigation intervals have been analyzed on berry ripening profiles for the same experiment described in FIGURES 3 and 4. Over a same area of 50 vines, centered on sap flow-equipped vines, four berries per cluster were collected weekly. We discuss berry volume and sugar accumulation profile in response to different irrigation strategies.

OBSERVATIONS AT A SINGLE VINEYARD SCALE

In the same three-year experiment, berry mass and berry sugar amount were collected. Berry mass and berry volume are linearly correlated (Gray and Coombe, 2009), and we use berry weight as a proxy for berry volume.

FIGURE 5A shows that under short irrigation intervals (year 1), berry volume accumulation is disrupted and delayed. Shortly before harvest, shriveling symptoms caused a berry volume loss. In contrast, when longer irrigation intervals are applied and a more moderate water deficit is observed, the berry volume accumulation profile is smooth, reaches a peak and maintains its value until harvest (Year 2 and 3).

FIGURE 5B shows that under short irrigation intervals, berry sugar accumulation stops momentarily around 1,200 degree-days, probably because water deficit was too severe. Under longer irrigation intervals, sugar accumulation is smooth until it reaches its maximum value (Year 2 and 3).

Conclusions

Under short irrigation intervals, seasonal water deficit can be more severe. As a consequence, berry volume decreases, and sugar accumulation is discontinuous. Severe water deficit reduces photosynthetic activity and the transportation of sugars, which, in turn, induces berry ripening disorders. Under large irrigation intervals, seasonal water deficit is more moderate, berry volume and sugar amount per berry are higher, and the ripening profile is smoother.

Short intervals between irrigations can increase the risk of berry shrivelling between two irrigations and before harvest. Significant variations in vine water deficit can disrupt the accumulation of berry volume and sugar per berry and can also induce sudden berry volume loss as observed year 1.

FIGURE 5A

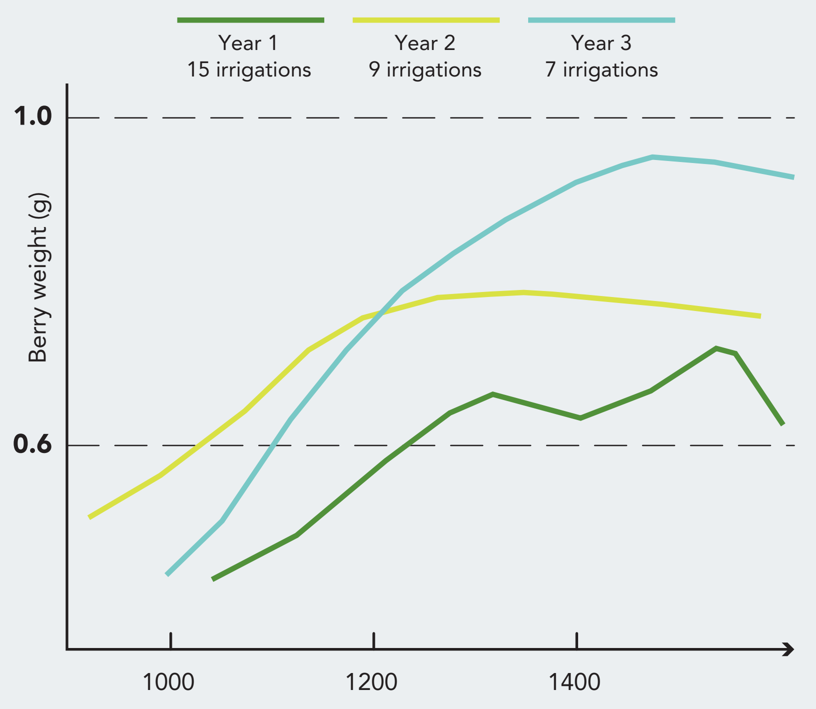

FIGURE 5A: Effect of irrigation intervals on berry weight profile (source: Fruition Sciences)

FIGURE 5B

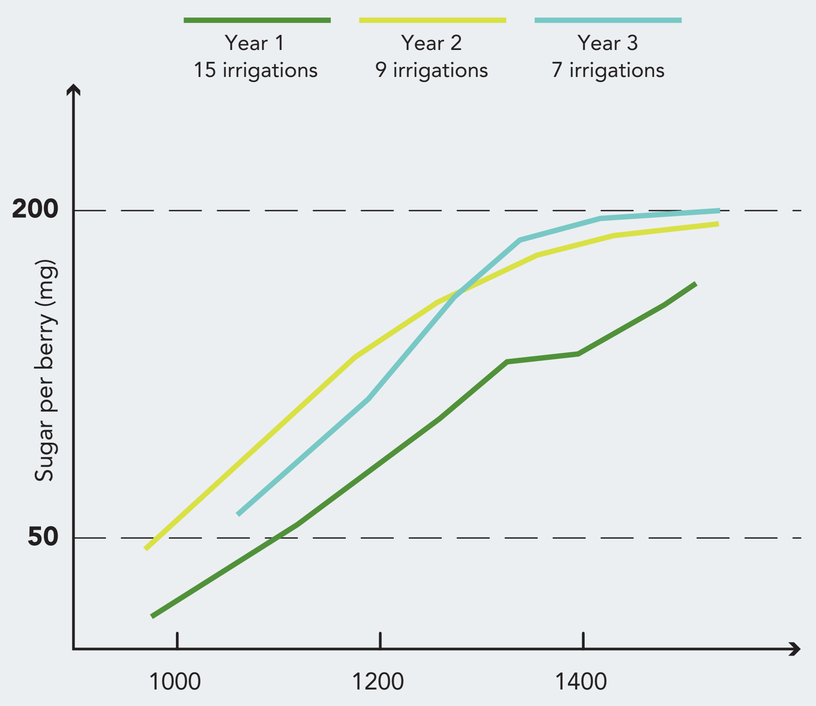

FIGURE 5B: Effect of irrigation intervals on berry sugar accumulation profile (source: Fruition Sciences)

OBSERVATIONS AT A REGIONAL SCALE

We have observed that longer intervals between irrigations can decrease the severity of seasonal water deficit with positive impact on yield and fruit maturation. We tested the hypothesis over a large scale experiment. The goal of the experiment is to investigate the amount of water savings and the consequences on fruit composition when longer intervals between irrigations are imposed. We focused on three California regions: Sonoma, Napa and Paso Robles. In each vineyard, short interval irrigations were compared to long interval irrigations side by side. At one vineyard the treatment was applied for three consecutive years (sites H-JT). Sap flow sensors were used to trigger irrigation alerts under the long interval irrigations. The short interval irrigations were applied according to traditional irrigation methods. The study was funded by the **Metropolitan Water District of Southern California**, the **Bureau of Reclamation**, the **Southern Nevada Water Authority** and the **Central Arizona Project**.

FIGURE 6 reports the amount of irrigation events for each treatment, depending on site-specific conditions. Over the season, we observed 5 to 25 irrigation events when short irrigation intervals are applied: 0 to 4 irrigation events when larger volumes and intervals are applied. Seasonal irrigation volume varies between 27 and 157 mm under short intervals and between 0 and 76 mm under large intervals as reported in Figure 6. Across all sites, the total amount of seasonal irrigation is lower when larger volumes and longer intervals are applied. This result is in agreement with longer drought intervals contributing to a more gradual vine water deficit regulation.

Considering the effect of irrigation frequency on seasonal water deficit and berry volume variations, we also investigated how irrigation frequency impacted yield. **FIGURE 7** shows the effect of irrigation strategy on yield collected at harvest. Average yield is higher when longer drought intervals are applied between irrigation, probably because berry volume is better maintained after reaching its maximum value. In contrast, when short irrigation intervals are applied, berry volume loss pre harvest is greater, causing a lower yield. No differences were observed in the total amount of sugar per berry between the two strategies (data not shown). This result is consistent with the sugar accumulation rate being less sensitive to water deficit as reported in the literature (Sadras and Petrie, 2011; Delrot et al., 2014).

Conclusions

Despite site-specific differences in the seasonal amount of irrigation water needed, strategies that favor longer intervals between irrigations reduce the total amount of water applied. On average, in this experiment, 50 percent of water saving is observed when long intervals are imposed compared to short intervals.

Longer periods of drought between irrigations improve vine water use regulation mechanisms, which, in turn, decrease berry water loss pre-harvest and help maintain a higher yield.

FIGURES 6A & 6B

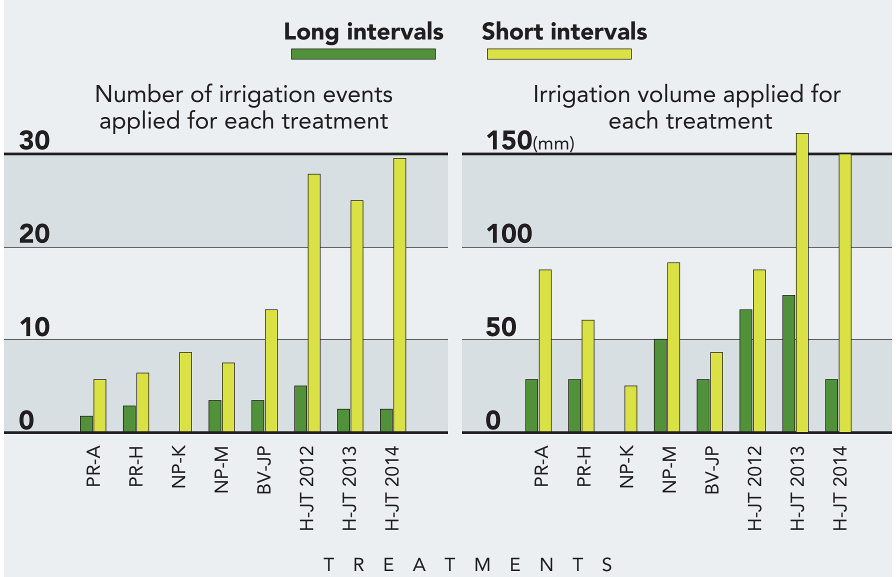

FIGURE 6A: (Left): number of irrigation events applied over the season for each treatment. **FIGURE 6B:** (Right): seasonal irrigation volume applied for each treatment (adapted from Scholasch, 2015)

FIGURE 7

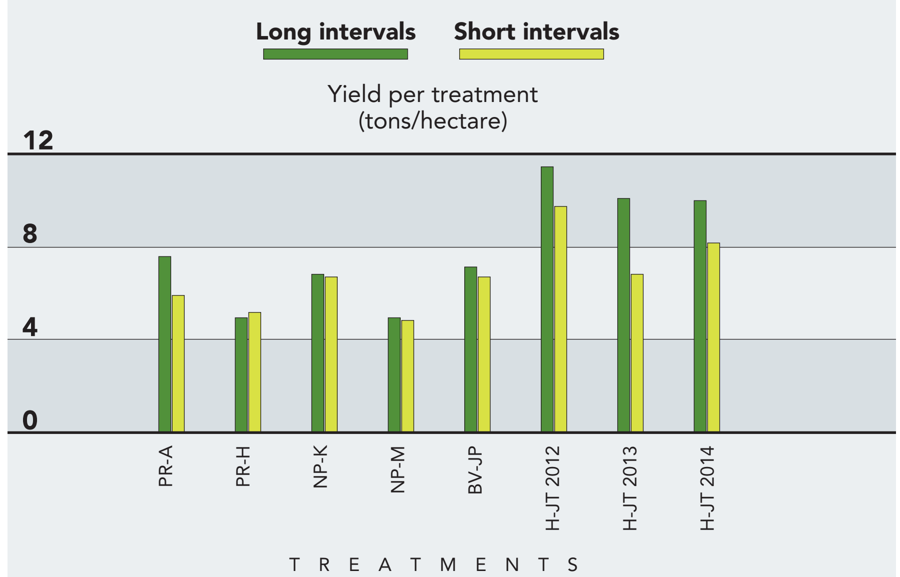

FIGURE 7: Yield per treatment (adapted from Scholasch, 2015)

4. How Can Drought Periods Between Irrigations Promote Better Water Use and Ripening Conditions?

Vine water use response to irrigation is mediated by hydraulic but also chemical signals sent from drying roots to the shoot (Comstock, 2002). An important chemical signal is the root-sourced hormone abscisic acid (ABA) involved in stomata regulation and subsequent vine water use regulation and transported via the xylem (Davies et al., 2005). When root tips are subjected to soil drought, higher ABA levels are observed in the sap of field-grown vines as reported in Figure 8, adapted from Rodrigues et al. (2008).

FIGURE 8

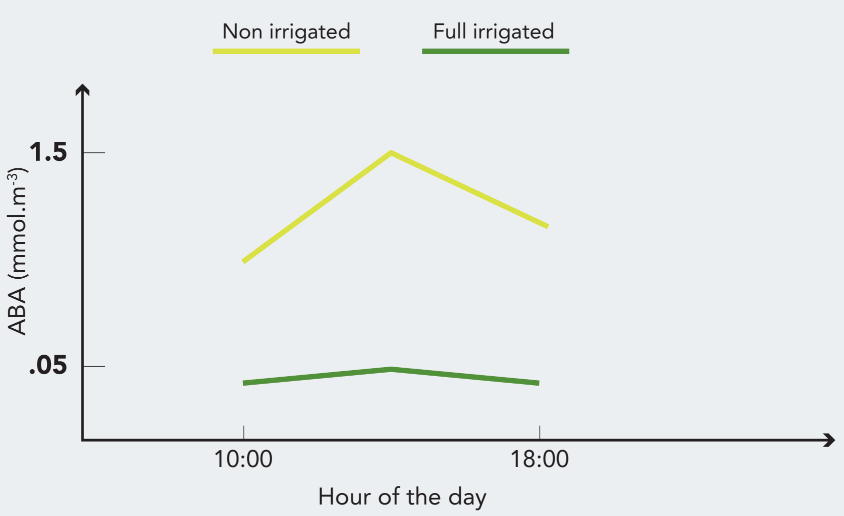

FIGURE 8: Diurnal changes in concentration of abscisic acid (ABA) in the xylem sap field-grown at mid-ripening (August 22) - Adapted from Rodrigues et al. (2008)

Those results suggest that over the season longer drought periods between irrigations may increase sap ABA concentration, which in turn promotes a more gradual down regulation of vine water use. In contrast, imposing shorter drought period between irrigations may lower sap ABA concentration. In turn, vine water use is not down-regulated as gradually as soil dries down. After reaching a high level after irrigation, vine transpiration rate brutally declines as soon as root available water gets limiting. Consequently, when irrigation volumes and intervals are shorter, vine water deficit level may vary more brutally in between.

Bonada et al (2018) have measured vine transpiration with sap flow in an experiment combining two thermal and two water regimes. Similar to our results, the authors reported that after irrigation, lower sap flow is observed under the wet treatment. Furthermore, while warming increased sap flow, seasonal sap flow in wet and heated vines was reduced along the season to a similar level to that in dry treatments. Their results confirm that under warmer conditions, increased sap flow in wet vines is observed only during the irrigation period. In fact, after two years, the wetter treatment shows a reduced water use over the whole season, which is similar to our results. The authors hypothesized that higher transpiration rates lead to faster depletion of soil water, which, in turn, can lead to lower water use after irrigation. The practical implication is that under warmer conditions, sap flow is reduced post-irrigation.

Charrier et al. (2018) used long-term observations in Napa and Bordeaux to reveal that vines never reach their lethal water-potential thresholds under seasonal droughts. Their results confirm a vine's ability to cope with reduced water use without risking its hydraulic integrity. However, even if a vine can resist severe drought, it is not desirable for berry ripening. Thus, defining exactly how long intervals should be between irrigations should consider not only the effects on seasonal water deficit but also the effects on berry chemical composition and mechanical properties.

New results suggest that other benefits to prolonged drought between irrigation may exist. Cooley et al. (2017) reported a higher level of berry skin resistance to mechanical deformation when drought is imposed between two irrigations. The authors hypothesized that a period of drought imposed prior to veraison induces changes in berry cell wall composition, leading to greater mechanical resistance. Authors further observed that berry skin compositional changes induced by prolonged drought also led to an easier color extraction in red wine, which is desirable for winemakers.

5. Conclusions

In practical terms, our results point to a similar trend: imposing longer intervals between two irrigations enhances the mechanisms of vine water deficit regulation and probably promotes a more uniform root mass distribution along the soil profile. In turn, a higher berry volume can be maintained until harvest and more uniform fruit ripening conditions are observed. Within the same season and over multiple seasons, field results show that water deficit level is more easily managed and remain more moderate as larger volumes and longer drought intervals are imposed.

In contrast small volumes and small intervals between irrigations can result in more extreme water deficit variations, which are harder to manage in a context of warmer temperatures. Short periods of severe water deficit between two irrigations are more likely to occur. Over the season water deficit can be more severe which can impact negatively fruit ripening conditions and reduce yield. In a context of warmer temperatures and water scarcity, short periods of severe water deficit should be avoided to reduce risk of yield loss pre harvest. Moreover, under high temperatures, the negative impact of severe water deficit periods is worsened due to a synergistic effect between heat stress and water stress (Carvalho, et al., 2016).

Ultimately, understanding yield and fruit composition responses to longer intervals between irrigations can be achieved by monitoring vine water deficit variations along berry volume variations and fruit ripening profile. By tracking vineyard responses at key locations, irrigation strategies can be improved while considering site-specific conditions and production objectives. WBM

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