CENTENARY OF THE OIV
45th WORLD CONGRESS OF VINE AND WINE
14-18 OCTOBER 2024 FRANCE-DIJON

Available on IVES Conference Series vine & wine

DOI : https://doi.org/10.58233/dxuxP7F1

Training vineyards resilience to environmental variations by managing vine water use

Cécile Laurent[1], Sébastien Payen[1] and Thibaut Scholasch[1]

[1] Fruition Sciences, 672 rue du Mas de Verchant 34000 Montpellier, France

Abstract. Climate change is undeniable. In response, many vineyards have installed, or intend to install, irrigation systems. However, vine irrigation is not trivial and it accentuates the question of vineyard resilience, understood as the ability to maintain interannually stable and high enough yields and qualities to meet production objectives, while ensuring efficient and minimal use of environmental resources such as water. To address this issue, Fruition Sciences has developed an irrigation method, called the Plant Aware Irrigation (PAI) method. The aim of this article is to illustrate how the PAI method is applied in practice, and to assess its benefits in terms of vineyard resilience in situ, i.e. in commercial vineyards, over the whole season, in various production contexts and for different climatic conditions. To do this, the performance of vines irrigated using the PAI method was compared with the performance of vines irrigated using the traditional vineyard irrigation management strategy for 10 pairs of blocks. Results showed that for the same or a lower amount of water applied, the PAI method achieved yields and sugar quantities per berry equal to those obtained with the traditional irrigation strategy, and reduced berry sensitivity to shriveling at the end of the season.

1. Introduction

Climate change is undeniable, and for many wine-growing regions, it does and will result in atypical vintages, with more frequent heat waves and droughts [9]. In response, many vineyards have installed, or intend to install, irrigation systems. However, vine irrigation is not trivial. Indeed, both a lack and an excess of water can, depending on the timing of their occurrence, have detrimental consequences on the harvest yield and quality but also on the vine ability to cope with further heatwaves and droughts [7,3]. In addition, without technical support, access to irrigation entails a high risk of over-consumption of water, due to winegrowers' understandable attempt to protect their income against extreme and variable climatic conditions. In other words, irrigation accentuates the question of vineyard resilience, understood as the ability to maintain interannually stable and high enough yields and qualities to meet production targets and ensure the vineyard profitability, while ensuring efficient and minimal use of environmental resources such as water.

In this context, numerous research works have focused on estimating vine water use to rationalize irrigation decisions [6]. However, regardless of the measurement method, the value of water use alone is not enough to justify irrigation if it is not backed up by references and knowledge. In this regard, some studies have focused on the effect of a water deficit applied at a given time of the season as part of a research experiment [7]. Still, it is difficult for winegrowers to integrate all these fragmented, sometimes nuanced, results and adapt the conclusions to their production context. To the authors' knowledge, very few studies have described irrigation methods and corresponding results in situ and on a seasonal scale.

To address this issue, Fruition Sciences has developed an irrigation method, called the Plant Aware Irrigation (PAI) method, that draws on experimental scientific results and local plant data. It's part of a broader method called the 5-period method, which encompasses other cultural practices but which will not be detailed in this article for greater clarity. It has been shown that soil or weather data alone are not sufficient to assess whether vine water needs are met, as the vine's ability to extract water from the soil and meet atmospheric demand is variable [4]. Therefore, the assumption underlying the PAI method is that only data measured directly on the plant can be used to estimate the vine water use. The PAI method relies on manually measured data such as shoot length and sugar quantity per berry, and optionally on sap flow data measured with sensors. Variations in these indicators, in particular whether or not they will quickly reach a certain threshold which is function of the production objectives, are used to trigger irrigations. The volume of irrigations is calculated so that the plant can remain above the trigger threshold for at least a week, ideally for as long as possible.

The aim of this article is to illustrate how the PAI method is applied in practice, and to assess its benefits in terms of vineyard resilience in situ, i.e. in commercial vineyards, over the whole growing season, in various production contexts and for different climatic conditions. To achieve this aim, 10 pairs of comparable blocks were set up. Each pair hosted 2 irrigation modalities: the first corresponds to the traditional irrigation method of the vineyard i.e. to the way irrigation has always been run and the second corresponds to a strategy resulting from the application of the PAI method. The studied blocks were situated in California (USA), Argentina and Spain and were monitored. As a first step, this article focuses on the results from the first year of the experiment (2022, 2023 or 2024) so as to evaluate the effect of irrigation on berry development only [5].

2. Material and method

2.1. Material

2.1.1. Experimental design

10 pairs of comparable blocks were monitored in different vineyards (Tab. 1). Within a pair, one block was irrigated using the traditional vineyard method (Control), while the other was irrigated using the PAI method (Treatment). The studied blocks were situated in California (USA), Argentina and Spain. They were monitored during the first year of the experiment, which falls between 2022 and 2024.

Table 1. Block main characteristics.

Block	Location	Year	Variety	Root-stock	Planta-tion	Vine spacing (m)	Row spacing (m)
1	Cal.	2023	Cab S	NA	2000	1,5	2,1
2	Cal.	2023	Cab S	NA	2018	1,5	2,4
3	Cal.	2023	Cab S	110R	1990	1,2	2,0
4	Cal.	2023	Cab S	5BB	1990	1,5	2,7
5	Cal.	2023	Cab S	5C, 110R	1990	1,5	2,7
6	Cal.	2023	Cab S	420A, 1616C	NA	1,2	2,1
7	Spain	2023	Temp.	NA	NA	1,2	3,0
8	Arg.	2022	Malb.	NA	NA	1,3	2,2
9	Arg.	2022	Malb.	101-14	2003	1,3	2,2
10	Arg.	2024	Malb.	NA	NA	1,0	2,2

Weather conditions were recorded using the closest physical weather station. Three indicators were used to summarize the growing conditions of the blocks: i) Growing degree days with a base temperature of 10°C from the 1st of January or the 1st of October, ii) vapor pressure deficit (VPD) and iii) cumulated precipitations.

2.1.2. Plant data to monitor vine water use

The vine water use was monitored by measuring sap flow with sensors fitted to 2 vines in an area of average vigor in each block (2*2*9 sensors in total). The water satisfaction index (WSI) corresponds to the plant transpiration standardized by its maximum transpiration. It is used to assess whether the vine water needs are satisfied taking into account that all vines are different and may therefore have different raw transpiration levels.

2.1.3. Vineyard resilience indicators

The yield, the total volume of water applied by irrigation and the number of irrigation applications were measured per block. Maturity controls, carried out every 4 to 7 days collecting 200 berries according to a stratified sampling scheme, were used to measure maximum sugar mass per berry, maximum berry mass and berry mass at harvest.

2.2. Method

Vineyard resilience was evaluated by comparing the vine performances within each pair of blocks in terms of yield, maximum sugar quantity per berry, berry maximum mass and the loss of berry mass i.e. the difference percentage between final and maximum berry mass. The total volume of irrigation water and the number of irrigation applications were also considered.

Differences in means between the control and the treatment groups were tested on R 4.4.1 using a student test for paired samples when normality of the samples difference was verified, a Wilcoxon test for paired samples otherwise.

3. Results

3.1. Weather conditions

2023 was an exceptionally wet and cold vintage in California: 700 to 900mm of precipitations were recorded in winter and early spring. Growing degree days hardly reached 1800 towards harvest. No VPDs above 4kPa were observed, and VPDs in September were particularly low compared with other vintages where heat waves are often observed. The example of weather conditions for block 6 is given in figure 1d.

2022 in Argentina received 120 mm of precipitations, half of it in early spring and the other half before harvest. Growing degree days reached 1700 at harvest. Frequent VPD peaks above 4.5 kPa were recorded throughout the season.

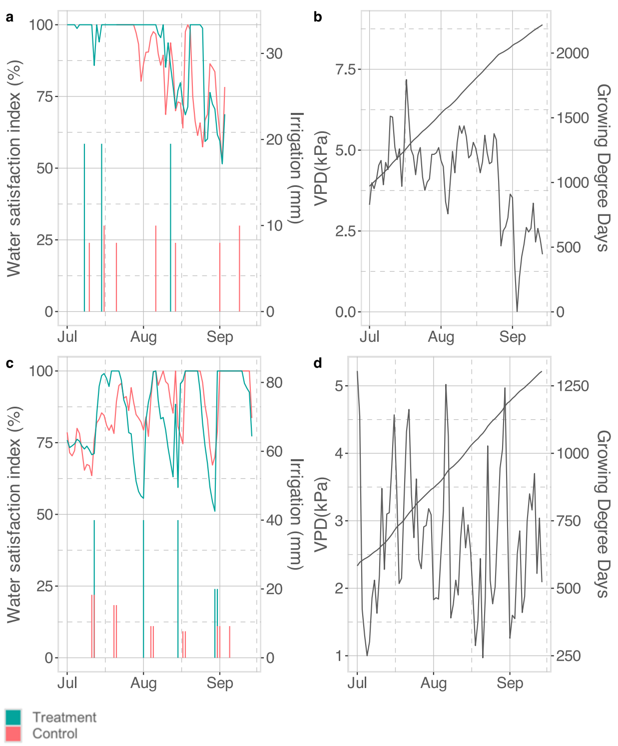
2024 in Argentina was particularly hot and dry in the first half of the season. The vines received 160mm of precipitations, distributed from the middle of the season to harvest. Growing Degree days reached 1750 at harvest. Very frequent peaks above 4.5 kPa were recorded throughout the first half of the season. VPDs were lower, between 2 and 3.5 from mid-January onwards.

2023 in Spain was very dry and hot. The only rain that was recorded from January to the end of the season were 80mm in May and 30mm in late August. Growing Degree Days reached 2300 by the time of harvest (Figure 1b). Daily maximum VPDs continuously remained above 4 kPa and frequently approximated 6kPa from early June to late August (Fig.1b).

3.2. Irrigation strategies

The vineyards traditional irrigation strategies varied but they generally relied on irrigations of more or less 10mm applied at regular intervals. In contrast, the Plant Aware Irrigation method (Treatment) resulted in irrigations of 20 to 40 mm applied in an irregular pattern with variable timings between vineyards. The examples of blocks 6 and 7 are shown in figure 1. It can be noted in figures 1a and 1b that irrigation applications were triggered when the WSI was about to reach 60% in the case of the treatment.

Figure 1. Summary of the season in terms of water satisfaction index and irrigation applications as well as growing degree days and vapor pressure deficit for blocks 7 (a and b) and 6 (c and d).



3.3. Water use profiles

As exemplified in figures 1a and 1b, the vineyard traditional irrigations generally failed to restore WSI to 100%, and WSI fell back the day after irrigation, highlighting the limited durability of the irrigation benefits. No WSI threshold were observed in between irrigations are those were scheduled according to the civil calendar. In contrast, the treatment irrigations usually achieved a WSI of 100% for 1 to 4 days, dropping back to 60% in 1 to 3 weeks as a function of evaporative demand.

3.4. Vineyard resilience evaluation

3.4.1. Use of water resources

The total volume of water applied by irrigation is shown for both modalities and for the 10 pairs of blocks in figure 2a. The mean of the 2 groups were proved different by a Wilcoxon test. For 6 pairs of blocks, irrigation volumes were around 100 mm and the treatment modality saved from -5 mm to 66 mm. Differences between modalities increased when vineyards traditionally irrigated more than 400mm. In this case, the treatment modality resulted in savings of 69 to 405mm (Tab. 2).

The number of irrigation applications is shown for both modalities and for the 10 pairs of blocks in figure 2b. The 2 groups were also proved different by a Wilcoxon test. The treatment modality decreased the number of irrigations for the 10 pairs of blocks and saved from 2 to 23 irrigations (Tab. 2).

3.4.2. Yield performances

The block yield is shown for both modalities and for the 10 pairs of blocks in figure 2c. The 2 groups were found similar by a Student test (p-value of 0.2952). The treatment modality allowed a yield increase from 1 to 1.8 T/ha for blocks 1, 6 and 8. For the other blocks, yields were close to each other i.e. plus or minus 0.5 T/ha (Table 2).

The maximum mass of a berry is shown for both modalities and for the 10 pairs of blocks in figure 2e. The 2 groups were found similar by a Student test (p-value of 0.6651). Indeed, variable situations were found where the treatment modality increased, decreased or did not affect maximum berry mass (Tab. 2).

The loss of berry mass is shown for both modalities and for the 10 pairs of blocks in figure 2f. The 2 groups were proved different by a Student test (p-value of 0.0279, mean difference of 2.5%). The treatment modality decreased or did not impact the berry loss for 8 out of the 10 blocks (Tab. 2).

3.4.3 Sugar accumulation

The maximum mass of sugar per berry is shown for both modalities and for the 10 pairs of blocks in figure 2d. The 2 groups were found similar by a Student test (p-value of 0.7621). Variable situations were found where the treatment modality increased, decreased or did not affect maximum berry mass. Variable situations were found where the treatment modality increased, decreased or did not affect the maximum mass of sugar per berry but always within a 9% margin.

Figure 2. Vineyard resilience indicators for each pair of blocks.

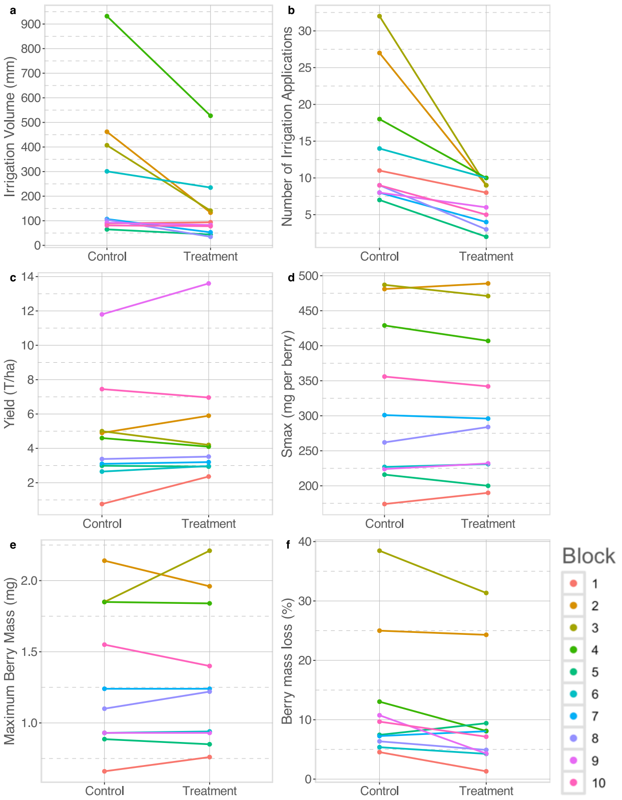


Table 2. Difference between Treatment and Control values for vineyard resilience indicators for each pair of blocks.

Block	Yield (T/h)	Smax (mg)	Irrigation volume (mm)	Irrigation number	Berry maximum mass	Berry mass loss (%)
1	1,6	16,0	5,0	-3,0	0,1	-3,2
2	-0,1	-16,0	-21,0	-5,0	0,0	2,0
3	0,3	4,0	-66,0	-4,0	0,0	-1,1
4	0,1	-5,0	-54,0	-4,0	0,0	0,8
5	0,1	22,0	-69,0	-6,0	0,1	-1,4
6	1,8	8,0	-9,0	-2,0	0,0	-6,5
7	-0,5	-14,0	-3,0	-4,0	-0,2	-2,5
8	1,0	8,0	-329,0	-18,0	-0,2	-0,7
9	-0,8	-16,0	-266,0	-23,0	0,4	-7,1
10	-0,5	-22,0	-405,0	-8,0	0,0	-4,9

4. Discussion

The aim of this study was to demonstrate the ability of the Plant Aware Irrigation Method, called treatment modality in the article, to increase vineyard resilience, whatever the production context and climatic conditions. To this end, the results of this irrigation strategy were compared with those of the irrigation strategy classically used in each vineyard.

The results showed that yields were equivalent between the 2 modalities. Since the modalities were only introduced in year n, i.e. the year of harvest, the effect of the irrigation strategy should not have affected the number of bunches or inflorescence size but rather berry development i.e. the number of berries and berry weight [5]. In this sense, there is no clear difference between the final berry mass of the modalities (Fig. 2e), but rather a smaller loss of berry mass at the end of the season in the case of the treatment (Fig. 2f). Thus, the Plant Aware Irrigation strategy achieved the same level of yield and reduced the sensitivity of this yield to extreme climatic conditions at the end of the season, when yield loss through berry can be observed due to dehydration [1,2]

In terms of harvest quality, the Plant Aware Irrigation strategy had no significant impact on the total sugar content of the berries (Fig. 2d). On the other hand, it has been shown that a moderate deficit before veraison can increase of qualitative compounds in the fruit [7], particularly in the case of red wines. Although this was not tested in the study, it can be assumed that other quality parameters, such as color and aroma, were improved. This was confirmed through wine tasting and cuvee allocation in the winter following the experiment (data not shown).

In terms of water resources, the Plant Aware Irrigation strategy significantly reduced both the total amount of applied water and the number of irrigations. The use of water resources is therefore reduced, as is the amount of field work required to trigger irrigation.

In short, for the same or a lower amount of water applied, the Plant Aware Irrigation method achieved yields and sugar quantities per berry equal to those obtained with the traditional irrigation strategy, and reduced berry sensitivity to shriveling at the end of the season. It can therefore be concluded that the Plant aware Irrigation strategy has increased vineyard resilience within the season of the experiment. Furthermore, the more challenging the climatic conditions (Blocks 6 to 10), the greater the amelioration allowed by the Plant Aware Irrigation strategy. Indeed, 2023 having been a particularly water stress-free year in California, we can only expect more impactful results for the next years of the experiment.

Based on a dataset including blocks of various production contexts and climatic conditions, this extends the results previously found for 3 Californian vineyards monitored during 2 seasons [8]. The training effect of the vine's resilience shown by the present results is also in line with more fundamental findings, showing that stomatal conductivity become increasingly more tolerant to low water potentials throughout the growing season [4]. This is good news, as it shows that in addition to more substantial strategic changes such as changes in planting practices and vegetative material, tactical adaptations that can be implemented right away are possible and offer a great potential for improving the resilience of vineyards. While few studies have directly compared the effect of volume, and therefore frequency and timing of irrigations, these 2 studies are intended to show the benefits of an irrigation strategy with less frequent large irrigations. Obviously, this study only concerns year n i.e. the harvest year. Other results are yet to come, notably concerning the carry-over effect from one year to the next on vine performance for experimentation over several consecutive years. However, Herrera et al. (2024) already showed that water use efficiency increases from the third year of experimentation for a legacy of long water deficit episodes. We therefore expect to find that vine resilience is dependent on the long-term consistency of the irrigation strategy. It is also expected to find that vineyard resilience is further enhanced when the Plant Aware method is extended over several years.

Finally, the question of the practical feasibility of the Plant Aware Irrigation method on a large scale can be raised. The study by Scholasch and Laurent (2021) gave a first demonstration that it was possible to apply the strategy on a 150-hectare scale. It is also important to acknowledge that it is not always possible to apply 20mm at once due to irrigation system dimensions and water limitations in each vineyard. However, it still seems possible to do better than a regular and immutable water rotation where all the blocks are irrigated each rotation. The underlying hypothesis is that it is better to group blocks with similar water needs (even if it means not irrigating certain groups sometimes) to respond quickly in the event of extreme weather conditions, rather than trying to customize irrigation by irrigating each block individually and potentially not being able to irrigate all blocks in need due to an excessively long water rotation.

5. References

1. Carlomagno, V. Novello, A. Ferrandino, A. Genre, C. Lovisolo, and J. J. Hunter, Scientia Horticulturae, 233, 394–406 (2018)
2. D. H. Greer and S. Y. Rogiers, Am J Enol Vitic., 60, 2, 155–163(2009)
3. J. C. Herrera, S. Savoi, J. Dostal, K. Elezovic, M. Chatzisavva, A. Forneck, T. Savi., Plant Biology (2024)
4. J.C. Herrera et al., The Plant Journal, 109, 804–815 (2022)
5. C. Laurent, B. Oger, J. A. Taylor, T. Scholasch, A. Metay, and B. Tisseyre, European Journal of Agronomy, 130, p. 126339 (2021
6. M. Rienth and T. Scholasch, OENO One, 53. (2019)
7. T. Scholasch and M. Rienth, OENO One, 53 (2019)
8. T. Scholasch and C. Laurent, Revue des Oenologues, 181, pp. 50–51 (2021).
9. C. van Leeuwen et al., Nat Rev Earth Environ, 5, 4, 258–275, (2024)