INNOVATIVE CONSERVATION PROGRAM
Metropolitan Water District of Southern California

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Southern Nevada Water Authority

A comparative study of traditional vs. plant-sensor based irrigation across multiple sites: consequences on water savings and vineyard economics. Application during a drought in California.

Thibaut Scholasch *

** Corresponding author: thibaut@fruitionsciences.com*

ABSTRACT

California's population growth and greater awareness of environmental water requirements has increased the pressure on agriculture to use water more efficiently. By monitoring plant water use continuously, new irrigation techniques can be implemented to promote more efficient irrigation strategies. However those irrigation methods are new and more expensive compared to the traditional methods and the industry has been slow to embrace new techniques. In order to demonstrate the benefits in terms of energy and water savings as well as vineyard performances, we designed an experiment across multiple vineyard sites. First we wanted to validate that traditional irrigation techniques overuse water. Second we wanted to show that a plant sensor-based approach to irrigation could be effectively implemented throughout the state of California. Third, we wanted to demonstrate that more conservative irrigation practices could be adopted compared to tradition, even in a context of drought while evaluating the consequences of irrigation reduction on vineyard performances.

To validate our hypothesis, 6 vineyard sites were selected and split to compare the effect of 2 irrigation strategies in 3 distinct areas of California (Sonoma, Napa and Paso robles). With the traditional strategy, irrigations are based on empirical knowledge, visual observations and a climatic model. With the experimental strategy, irrigations are triggered based on the continuous monitoring of plant water use combining sap flow sensors with climatic data. We analyzed the effect of the 2 irrigation strategies on water saving, energy saving, yield and fruit composition. Results show that water and energy input related to irrigation could be reduced by 40 to 100% in the experimental treatments. Yield was not affected and fruit composition was positively affected in the experimental treatment. Furthermore, by designing a framework that incorporates plant sensing data from a few reference sites it is possible to extrapolate irrigation decisions over large areas and remotely. The approach can be deployed under contrasted soils and climates throughout California and it leverages pre-existing vineyard information such as historical weather data and other plant or fruit measurements. Our study concludes that plant-sensing irrigation promotes more conservative vineyard water use and improves vineyard economics.

Keywords: irrigation, drought, Ks, sap flow, vineyard economics

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1. INTRODUCTION:

California's population growth and greater awareness of environmental water requirements has increased the pressure on California agriculture to use water more efficiently and to make more water available for urban and environmental uses. In September 2013, reports from San Luis Obispo County claimed that a rapid decline in well levels coincided with a surge in large vineyard plantings. In context, the goal of this project is to push forward plant sensor-based approach to optimize water use in viticulture. Prior to this project, various testimonials had reported that a plant sensor-based approach to irrigation has a positive impact on water savings in viticulture. Additionally, because vineyard water deficit benefits fruit composition, wine quality has been reported to improve.

These preliminary results, confirmed by winemakers' testimonials, are an incentive to promote a more conservative approach to irrigation in viticulture. However, because of its seasonal nature and its resistance to change traditional practices, viticulture is slow to adopt new ideas. Consequently, to push forward new irrigation strategies over larger scales, we wanted to demonstrate the benefits of a plant sensor-based approach to irrigation while comparing its effect with traditional irrigation methods on a small number of vineyard selected in contrasted locations.

The objective of the study is to compare traditional methods of irrigation (control treatment) with plant sensor-based method (Fruition treatment) over 6 vineyards in 2014 located in the Paso robles, Napa and Healdsburg areas.

Differences in irrigation water volume and energy related to the cost of pumping water will be analyzed. We will also assess the impact of each treatment on vine yield and fruit composition.

Our main objective is to demonstrate that water savings can be done through better irrigation practices based on plant measurements. The main hypothesis is that a treatment triggering irrigation according to plant-based measurements saves water and improves fruit composition. Using sap flow sensors, we wanted to quantify how much more conservative irrigation could be. To reach that objective we will:

- Compare 2 irrigation treatments: plant-based irrigation vs. traditional irrigation and analyze their impact on water saving.
- Show the impact of reducing water input on plant water use and fruit composition. If successful, this demonstration should incentivize wine grape growers to switch more quickly to plant-based irrigation and save water without compromising their quality or revenue.

2. MATERIAL AND METHOD

a. SITE LOCATION

Table 1 shows the GPS location of each vineyard site where the split treatment experiment took place. Figure 2.1 shows approximate site location on the California map. The 6 vineyard sites belonged to 6 different wineries located between (38.38 -122.64) and (35.59-120.74) in Paso Robles (PR), Napa (NP), Healdsburg (HB).

TABLE 1: GPS COORDINATES CORRESPONDING TO THE DIFFERENT VINEYARD SITES

Region	Site Name	Site #	GPS
Paso Robles	PR-A	1	(35.592733, -120.7377326)
Paso Robles	PR-D	2	(35.637947, -120.776023)
Paso Robles	PR-H	3	(35.649643, -120.798060)
Napa	NP-K	4	(38.415266, -122.398853)
Napa	NP-M	5	(38.507500, - 122.415300)
Sonoma	HB-JP	6	(38.386332, -122.640000)

FIGURE 1: MAP OF CALIFORNIA SHOWING BLOCK LOCATION WITH THEIR CODE NAME

b. Vineyard properties

Table 2 shows the main characteristics of block properties decided pre-planting ; Table 3 shows information about plant material.

Table 2: block planting information

Site name	Block area (Acres)	Plant per acre	Planting date
PR-A	2.3	2212	1999
PR-D	3.23	2234	2008
PR-H	13.01	908	2001
NP-K	7.78	725	2000
NP-M	3.31	2212	1997
HB-JP	6.1	1561	1999

Table 3: Plant material

Site name	Varietal	Clone	Rootstock
PR-A	Syrah	Estrella	420A
PR-D	Cabernet sauv.	4	1103P
PR-H	Cabernet sauv.	337	110R
NP-K	Cabernet sauv.	4	St. George
NP-M	Cabernet sauv.	337	1103P
HB-JP	Merlot	181	101-14

Other vineyard information related to block layout can be seen in Annex.

c. Experimental layout

We used weekly aerial pictures (NDVI) to identify areas of uniform vegetative expression within each vineyard and to select the split treatment location. Experimental areas are divided into 2 sections for treatment application, referred to as “Fruition” (Experimental treatment) and “Traditional” (Traditional treatment). The goal of the experiment is to compare the effect of each irrigation treatment on block performance (yield and fruit quality) across 6 distinct vineyards.

- Traditional treatment: this is the control treatment where irrigation is applied according to vineyard historical management practices and/or irrigation logs.
- Fruition treatment: this is the experimental treatment where irrigation is triggered according to plant-sensor data. The fruition irrigation treatment will be triggered according to a threshold derived from a plant water deficit index calculated daily.

FIGURE 2: EXPERIMENTAL DESIGN

Blocks under treatment are divided into 2 areas where the 2 irrigation treatments are applied side to side. The boundary line splits the two treatments. The white crosses point the sap flow devices locations that are referred to as "Smart point".

Based on preliminary works related to "wet bulb" dimension under drip irrigation across various soil types[1], we did not expect the water from one vine row to contaminate the other vine row. Under production conditions, vineyard managers apply irrigation treatment on a per block basis and irrigation block boundaries follow row position. However, in the context of our experiment, we systematically imposed a minimum of 7 rows between the treatment boundary line and the location

[1] Neshat A., Nasiri S.: The estimation of wet bulb dimensions in the drip irrigation by dimensional analysis model, Int. J. Forest, Soil and Erosion, 2014 4 (3): 82-88

of the sap flow devices (ie. smart point location). This extra "buffer" zone between irrigation treatments guarantees no water contamination from one side to the other.

It is also important to note that experimental sites were selected in situations where row orientation was parallel to the slope and never perpendicular. Consequently, even if irrigation water could have overflown on surface after irrigation (a potential concern on steep slope vineyard site like PR-H), it should not have impacted treatment integrity. In practice, no surface water overflow was reported after irrigation and water penetrated vertically under the dripper. (maximum horizontal wetted diameter of the soil never exceeded 70 cm)

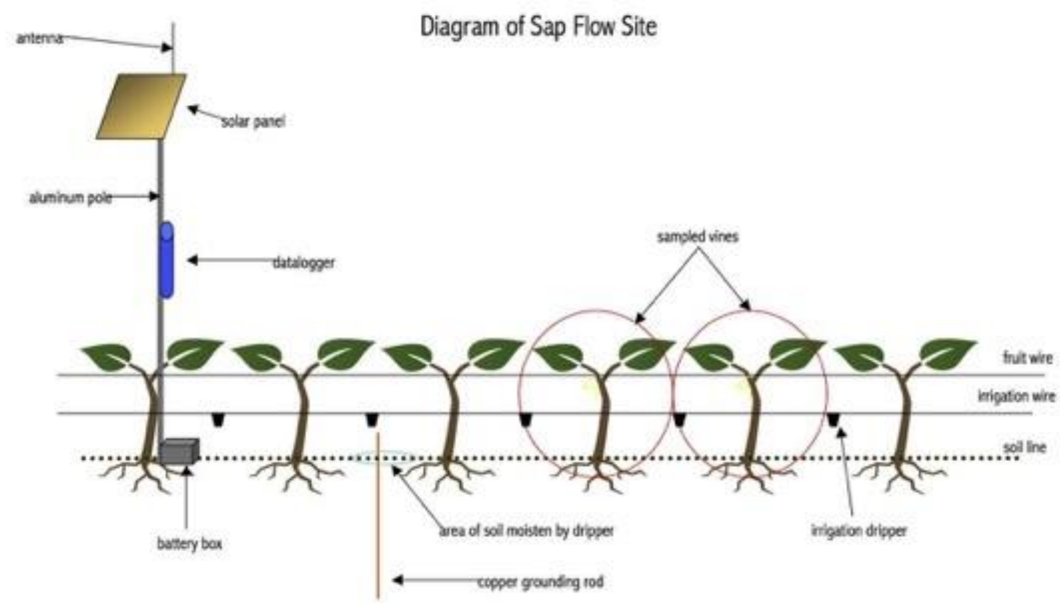

Figure 3: Sap flow diagram depicts the hardware installed at every smart point

To monitor vine performances and extrapolate results within the area under treatment, we selected a few plants in a geometric pattern as described in Figure 4. This location from where fruit and plant data is collected is referred to as a "smart point" area. It provides site-specific information for extrapolation to the rest of the area under treatment. (As described in section G: Leaf area dynamics and spatial extrapolation).

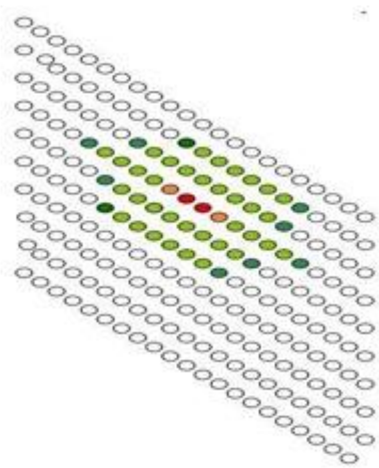

FIGURE 4: SMART POINT LAYOUT

In Figure 4, each circle corresponds to a vine:

- Red dots correspond to vines monitored by sap flow
- Orange dots correspond to vines monitored for shoot elongation early in the growing season and then for predawn leaf water potential
- Pale green dots correspond to vines monitored for berry sampling
- Dark green dots mark the end of the sampling area.
- Blank dots: shows vineyard rows and vine outside of the smart point layout..
- The smart point area encompasses 50 vines - all of which are included in berry sampling.

d. ENVIRONMENTAL MONITORING:

Weather station:

Climatic measurements include 4 parameters to compute ET_{ref} according to the Pennman-Monteith equation; temperature, relative humidity, global radiation, and windspeed. Table 4 lists the different weather stations used to compute site-specific climatic demand.

TABLE 4: ORIGIN OF WEATHER DATA

Site name	Weather station
PR-A	PRWCA membership - Paso Robles #6730
PR-D	Privately owned/ on site
PR-H	Privately owned/ on site
NP-K	CIMIS - Oakville #77
NP-M	Privately owned/ on site
HB-JP	CIMIS - Bennett valley # 158

Water input

FIGURE 5: IRRIGATION GAUGE INSTALLED AT EACH SMART POINT

Irrigation gauges were installed at each smart point to monitor the amount of water applied through the irrigation line. For each treatment, a rain gauge (Decagon Devices, Inc. ECRN) recorded the amount of water from the dripper. The EM50 data logger stored data with a 10-minute interval. Data was manually collected bi-weekly to confirm irrigation duration and volume. One gauge was installed for each treatment (there was a total of 12 gauges). To ensure reliability of irrigation gauge data, gauge calibration was tested. For that, we collected the volume of water emitted by the dripper into a graduated container and compared the volume collected with the volume of water reported by the gauge under the same dripper. Our results confirmed that manufacturer calibration was reliable.

FIGURE 6: IRRIGATION GAUGE CALIBRATION

Figure 6 shows the graduated containers used for calibration of irrigation gauge.

e. PLANT WATER USE MONITORING

Continuous measurement

In each treatment one row was selected. In each selected row, 2 vines were equipped with one sensor each. Each sensor measured vine sap flow rate every 15 minutes. The 2 selected vines were within 25 meters of each other within the same row. Sap Flow sensors were wrapped around the stem section (Figure 7). To ensure good control over the amount of heat applied on the stem, vine used for the measurement were insulated with aluminum foil (Figure 8).

The energy balance method was used to measure sap flow with Sap IP system (Dynamax, Houston, TX, USA). Sap flow rates measured on each vine were averaged on an hourly basis within each row. Various expert methods were applied to filter out nighttime, weak and erroneous signals. Sap flow measurements were scaled at the plant level according to plant leaf area estimates corresponding to each sensor. The daily sap flow assumed to measure daily vine transpiration was computed by adding all hourly sap flow rates measured during the day.

Water deficit index computation: water deficit index (WDI) is the ratio between actual and maximum vine transpiration, defined as:

$WDI(t) = T(t)/ T_{max}(t)$.

WDI represents the level of daily vine water use by reference to its maximal level. WDI=1 reflects a situation when maximal level of vine water use is fully satisfied. When *WDI* <1, daily vine water use is limited. *T* is daily measured transpiration from sap flow and T_{max} is daily maximal vine transpiration obtained under dry soil condition when soil moisture is non-limiting, as in Allen et al. (2009[2]).

$T_{max}(t)=Kc_B(t)\ ET_{ref}(t)$. ET_{ref} is the reference evapotranspiration and Kc_B a coefficient linearly related to the leaf area index (Picón-Toro et al., 2012[3]).

FIGURE 7: SAP FLOW SENSOR AND STEM SECTION. THE SENSOR IS WRAPPED AROUND THE STEM TO MONITOR VINE SAP FLOW.

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[2] (4) Allen, R. G., & Pereira, L. S. (2009). Estimating crop coefficients from fraction of ground cover and height. *Irrigation Science*, *28*(1), 17–34.

[3] Picón-Toro, J., González-Dugo, V., Uriarte, D., Mancha, L. a., & Testi, L. (2012). Effects of canopy size and water stress over the crop coefficient of a "Tempranillo" vineyard in south-western Spain. *Irrigation Science*, *30*(5), 419–432.

FIGURE 8: TWO VINES EQUIPPED WITH SAP FLOW SENSORS AND INSULATED.

Discontinuous measurements

Porometer measurements and pressure bomb measurements are both manual and cannot be automatic. Porometer measures leaf stomata conductance; pressure bomb measures leaf water potential. Both measurements are related to vine water use.

- Pre-dawn leaf water potential was collected at each smart point regularly (7 to 10 days intervals) throughout the season. Predawn Leaf water potential measurement is destructive. To perform a reading, the leaf must be cut from its attachment to the stem before it is introduced into a pressure chamber. 4 leaves were sampled on 4 different plants (figure 4) between 4:00 AM and before sunrise.

- In site HB-JP, stomata conductance measurements were performed weekly instead of predawn leaf water potential. Stomata conductance measurements using a porometer are not destructive. Thus, measurement reading can be performed while the leaf remains attached to the shoot. Leaf stomata conductance measurements were conducted on a weekly basis. However, due to an important leaf-to-leaf variations in terms of conductance values a high number of reading is necessary to get a reliable average. Consequently, stomata conductance measurements require a high number of leaves to be sampled (for practical reasons and due to time constrain we could only measure 8 leaves per site). For consistency the measurement period was restricted to 11:30 AM -1 PM.

f. FRUIT DATA

During the maturation phase we sampled berries at each smart point for berry weight and juice analysis at key stages of fruit production cycle . In a few sites, vineyard owners expanded the fruit analysis and decided to track skin composition alongside berry weight and juice composition. When available, we presented and discussed those results in annex (see the site specific analysis report section).

g. LEAF AREA DYNAMICS AND SPATIAL EXTRAPOLATION

At each smart point, shoot length was measured over 4 vines (Figure.4) on 5 shoots per vine and during the rapid phase of shoot elongation (from early May to the end of June).

At the same time we conducted plant-based measurement at each smart point, we also conducted block scale measurements. To that end weekly aerial pictures were provided by Terravion Inc. After image processing, aerial pictures reflected the amount of chlorophyll (ie. biomass) covering the ground based on the analysis of a vegetative index called NDVI. NDVI spatial distribution was used as an ancillary data to extrapolate information collected within the smart point area to the rest of the block under treatment.

Thus, by combining aerial pictures with plant-based measurement on the ground, we could control the uniformity of plant development rate as well as plant response during the season for the whole area under treatment.

3. Results

a. Climate

A) Temperature analysis

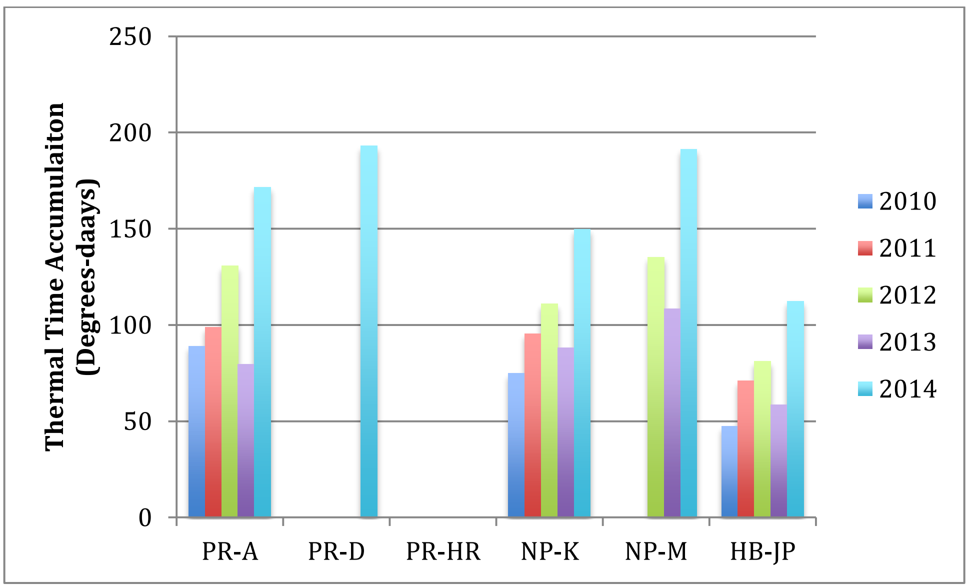


Figure 9: Thermal time accumulation pre-budbreak (DOY 1-60)

Period Pre-budbreak (DOY1 - DOY 60 – March 1st): Figure 9

We observe that 2014 is the warmest winter with the highest thermal time accumulation. Given the climatic context, it is expected that plant cycle will start earlier. By contrast, colder winter (like 2010) induces a delayed phenology and the onset of plant growing cycle is observed later in the season. Note that no temperature data were available in site PR-HR (Temperature sensors were not functioning before February 2014)

Period Pre veraison (DOY 60- DOY 195 – July 15th): Figure 10

Leaf area fast growing phase and vegetative period ends when fruit undergoes veraison. Across all sites, the earliest veraison date was July 15th (DOY 195). Thus, we analyzed thermal time accumulation during the preveraison phase over the period March 1st- July 15th across all sites.

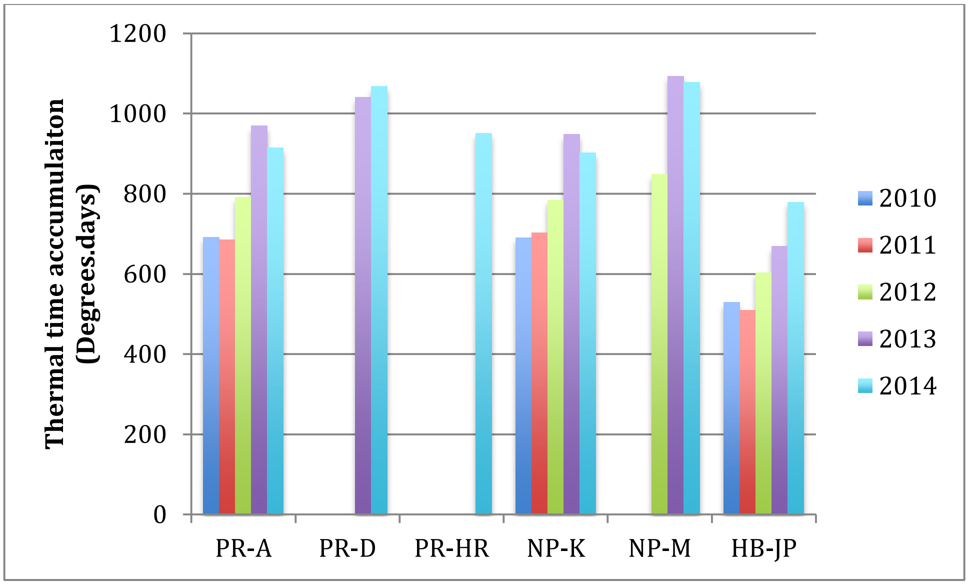


FIGURE 10: THERMAL TIME ACCUMULATION DURING THE VEGETATIVE PHASE (DOY 60-195).

At all locations, 2013 and 2014 show the highest temperature accumulation. This means that changes in plant development stages will occur earlier during the year. The Fruition irrigation strategy aims at increasing water deficit before veraison and reducing the severity of water deficit post veraison. Consequently, when plant phenological development happens at a faster rate, the timeframe during which water deficit is expected to have a positive impact on fruit quality is shorter. This climatic context induces a faster plant-growing rate, which makes it more difficult to implement irrigation strategies that conserve water. As such, it is more challenging to reduce water in 2014.

Period Veraison to Harvest (DOY 195- DOY 288- October 15th): Figure 11

Across all sites the latest harvest date was October 15th (DOY 288 for site PR-HR). Over the period veraison harvest, and across all sites, 2014 has been the warmest year.

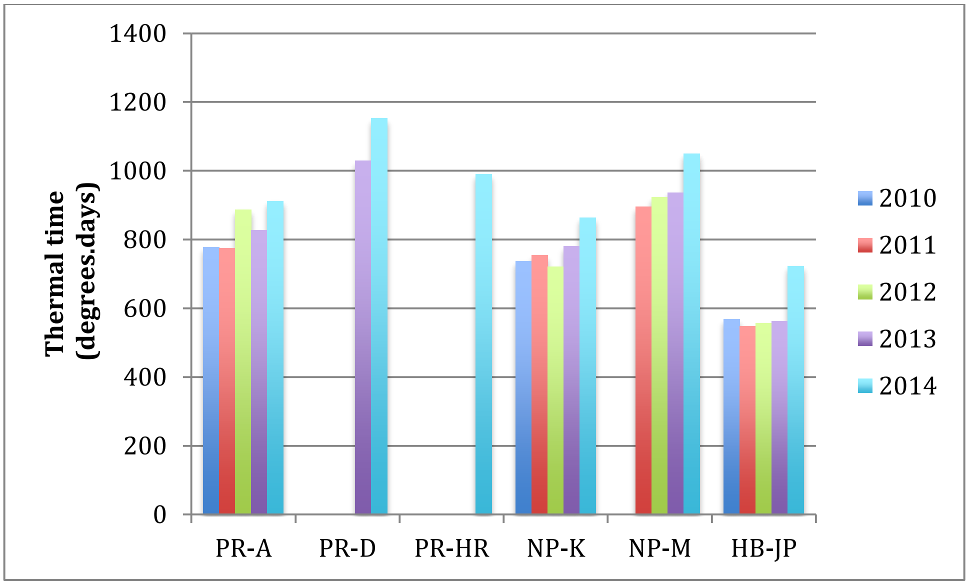


Figure 11: Thermal time accumulation during post veraison phase (DOY 195-228)

Conclusions:

Analysis of the temperature reveals that 2014 is the warmest year across all sites, particularly before budbreak and after veraison. This suggests that 2014 is a more propitious year to increase vine water needs and irrigation volume compared to previous years. In particular the speed of leaf area development is expected to be faster because it is linearly related to thermal time accumulation. This implies that vine leaf area was fully transpiring earlier during the year, which is expected to increase vine water needs over the season and consequently irrigation needs compared to cooler years.

B) Rain Analysis

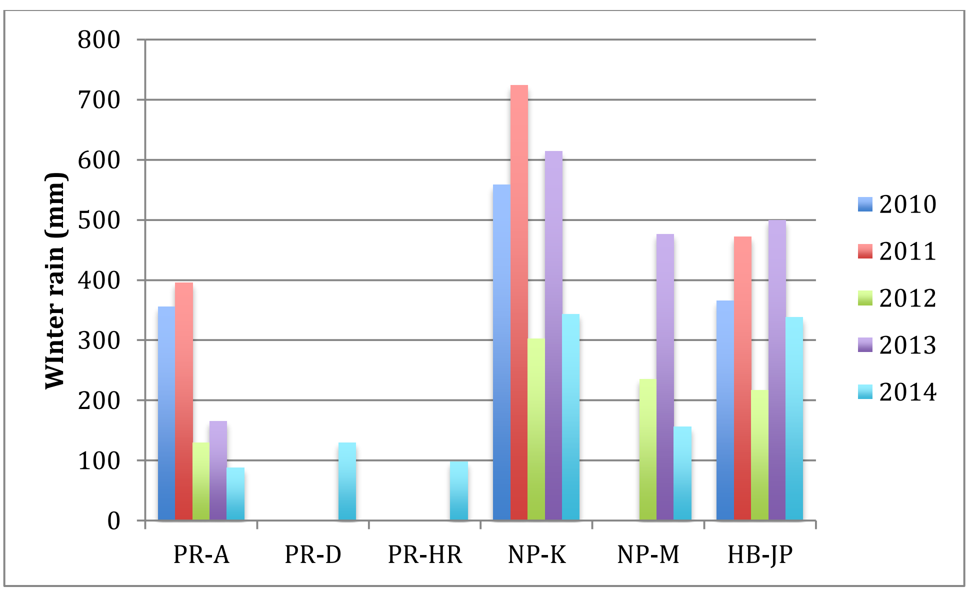


Figure 12: Cumulated rain amount during winter

(from November 1 to February 28)

Period Pre-bud break : November 1st (last year) - March 1st (current) : Figure 12

We analyzed the cumulated rain during the winter (from November 1st of the previous year, until March 1st of 2014).

From November 1st (after leaf loss from the previous season) until the beginning of the season (ie. before budbreak - DOY 60), we observe that Paso robles is the drier area with level of winter rain refills around 100 mm. Napa and Healdsburg show levels of water refill similar to 2012. (Between 150 and 320mm)

Period of vine production cycle (DOY 60-288): Figure 13

October 15th being the latest harvest date we analyzed cumulated water input across all sites. Figure 3.5 shows cumulated rain received during that period.

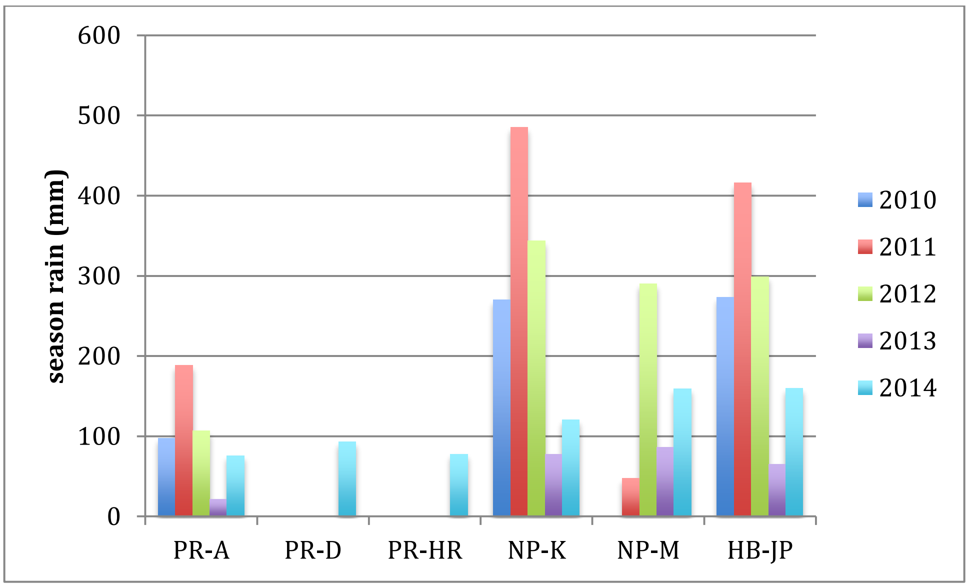


FIGURE 13: CUMULATED RAIN AMOUNT DURING SEASON

(from March 1 to October 15 - DOY 60-288)

In Paso robles sites, cumulated rain amounts between 75 to 93 mm. In Napa and HB sites, cumulated rain varies from 120 to 160 mm. Compared to 2012, we observe a much lower rain supply (around 300 mm in 2012).

Conclusions

From November 1st to October 15th, we observe that 2014 is the driest year with the lowest amount of rain. Table 5 summarizes the total amount of water supplied for the season in 2014. Table 5 shows that PR is the driest area, HB the wettest area.

Table 5: Total amount of rain received between November 1, 2013 and October 31, 2014.

Site	Total rain (mm)
PR-A	175
PR-D	222
PR-H	176
NP-K	464
NP-M	315
HB-JP	497

C) Evaporative demand analysis (ETref)

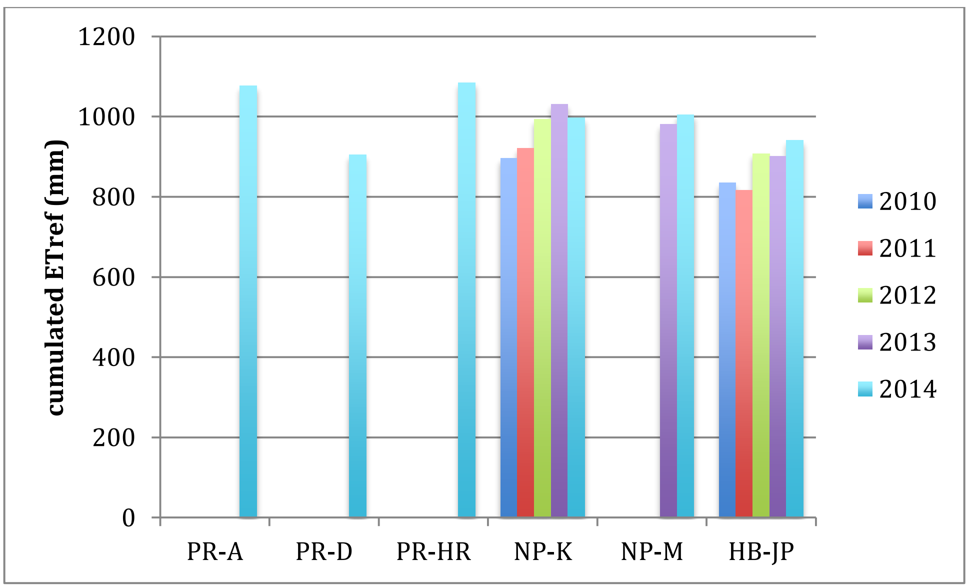


Figure 14: Cumulated ETref

-between March 1 and October 15 (DOY 60-288)-

Period of vine production cycle (DOY 60-288) : Figure 14

Evaporative demand in 2014 is comparable to previous seasons when historical data is available. Table 6 shows that evaporative demand is the highest in site PR-H and PR-A; it is the lowest in site HB-JP.

TABLE 6: CUMULATED ETREF BETWEEN MARCH 1 AND OCTOBER 15, 2014.

Site	Total ETref (mm)
PR-A	1077
PR-D	904
PR-H	1085
NP-K	997
NP-M	1005
HB-JP	941

D) VAPOR PRESSURE DEFICIT ANALYSIS

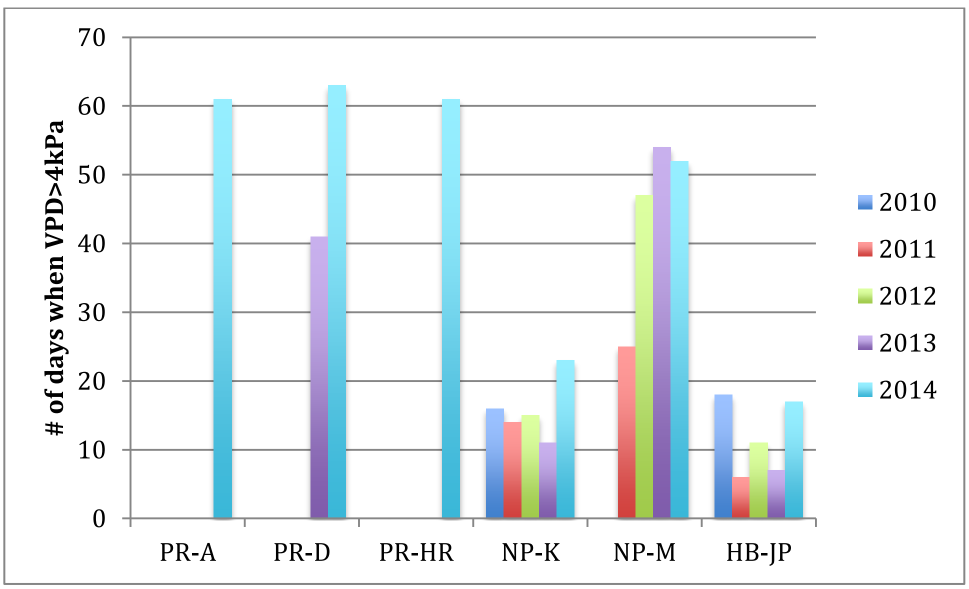


FIGURE 15: NUMBER OF DAYS WHEN VPD>4 KPA

-between March 1 and October 15 (DOY 66-288)-

The frequency of heat waves was the highest in 2014 except in site NP-M where the frequency in 2014 is similar to 2014. In PR sites, the frequency is higher than at other locations (more than 60 days of heat waves during the season). Years before 2014 when data is missing are due to missing relative humidity sensors.

b. Traditional Irrigation

A) volume

Table 7 reports the volume of irrigation traditionally applied at each location.

Table 7: Irrigation water applied from June 1 to Harvest in the traditional treatment

Site	2014 *(mm)	2013 **(mm)
PR-A	88	83
PR-D	51	61
PR-H	57	n/a
NP-K	27	52
NP-M	91	88
HB-JP	44	>55

(* from irrigation gauge, ** from verbal reports)

As expected from the climatic analysis, the higher amount of temperature accumulation in 2014 increased the volume of water applied in 2014, as observed in sites PR-A and NP-M. However, despite the warmer climatic context, a lower amount of irrigation was applied in 2014 compared to 2013 in sites PR-D, NP-K and HB-JP **which is counter intuitive**.
Logically, **under traditional practices**, Table 7 should have reported that a larger amount of water was applied in 2014 compared to 2013 and for each location to compensate for the warmer season. In fact, water amounts lower than expected under the "traditional irrigation" treatment in 2014 reveal that even the traditional irrigation strategy was "influenced" by the fruition strategy.
Vineyard managers and winemakers have admitted and confirmed that they reduced their traditional irrigation volumes because they were observing how vines were responding to reduced irrigation in the Fruition Treatment.

TAKE HOME

Traditional farming behavior can be "psychologically impacted" by small experimental area.

The observation that more conservative irrigation practices can be adopted without negative impact on vineyard performance has immediate effect over larger production area.

This is encouraging and suggests that the Fruition strategy could quickly become a new norm to apply irrigation more conservatively over large area.

Consequently, 2014 water savings volumes between treatments will be underestimated in sites PR-D, NP-K and HB-JP. However, we could not account for these extra water savings.

B) Energy cost estimate.

Based on our survey and participants testimonial, we found an average of $0.0002/liter (i.e. 0.0008/Gallons). However, data published by PG and E and the Center for Irrigation Technology reports a cost of $70 per acre-feet of water or $0.00006/liter. Table 8 reports the estimated pump cost to apply 1 mm of water based on those 2 different estimates.

Table 8: cost to apply 1mm of water in different vineyard location.

Site	Volume per vine to supply 1 mm of water (liters)	From Customer report ($)	From Center for irrigation technology ($)
PR-A	1.8	0.00036	0.000108
PR-D	1.8	0.00036	0.000108
PR-H	4.4	0.00088	0.000264
NP-K	5.6	0.00112	0.000336
NP-M	1.8	0.00036	0.000108
HB-JP	2.6	0.00052	0.000156

c. Treatment Effect on plant water status

A) Why comparing different methods of Plant water status Monitoring?

One of the study objectives was to compare the efficiency of different water status monitoring techniques at implementing more conservative irrigation strategies. Under the Fruition treatment, an average of 60% less water is applied (Table 13) and the first irrigation is systematically delayed.

For its application, the Fruition treatment requires the monitoring of plant water status continuously, as irrigation is triggered thanks to the analysis of a daily water deficit index. The trigger for Fruition treatment consists of detecting the following thresholds:

- Before Veraison : triggering irrigation before WDI reaches 40%
- After Veraison: triggering irrigation before WDI reaches 60%

To analyze whether the Fruition treatment could be reproduced using discontinuous measurements instead, we reported and discussed how water savings affect the variations of other plant water status indexes. Consequently, each site was monitored according to a discontinuous measurement technique (water potential or stomata conductance) as well. Because we wanted to test whether the Fruition method, could be reproduced with more classic measurement methods we compared treatment effect in one hand over 2 classic plant index (predawn LWP and stomata conductance) and in the other hand over water deficit index computed from sap flow measurements.

B) PREDAWN LWP POTENTIAL

Figure 16 reports average predawn leaf water potential for each treatment during the early phase of plant cycle. Over that phase, no irrigations is applied in the Fruition treatment while irrigation is applied in the traditional treatment.

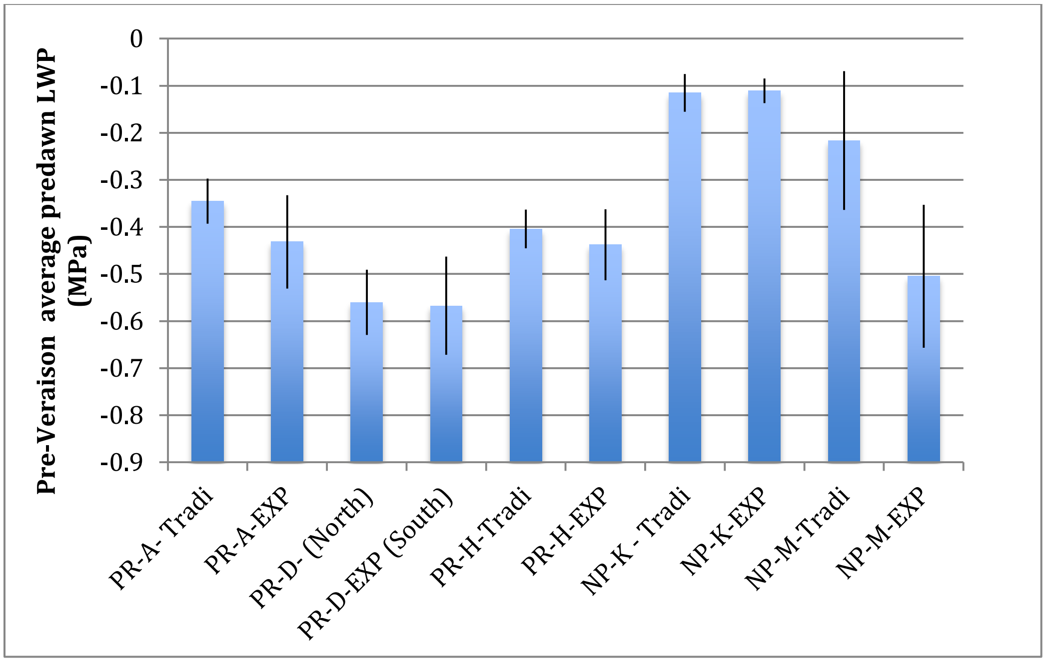


FIGURE 16: AVERAGE PREDAWN LWP MEASURED OVER THE PRE-VERAISON PERIOD

June 1 - July 15 (error bars = 2 standard deviations).

Figure 16 shows that early season, no differences are seen between treatments except in site NP-M. Over the whole season, Figure 3.9 shows that no significant differences were found between treatments except in site NP-M.

Pre dawn LWP is not discriminating the effect of treatment in 4 out 5 situations.

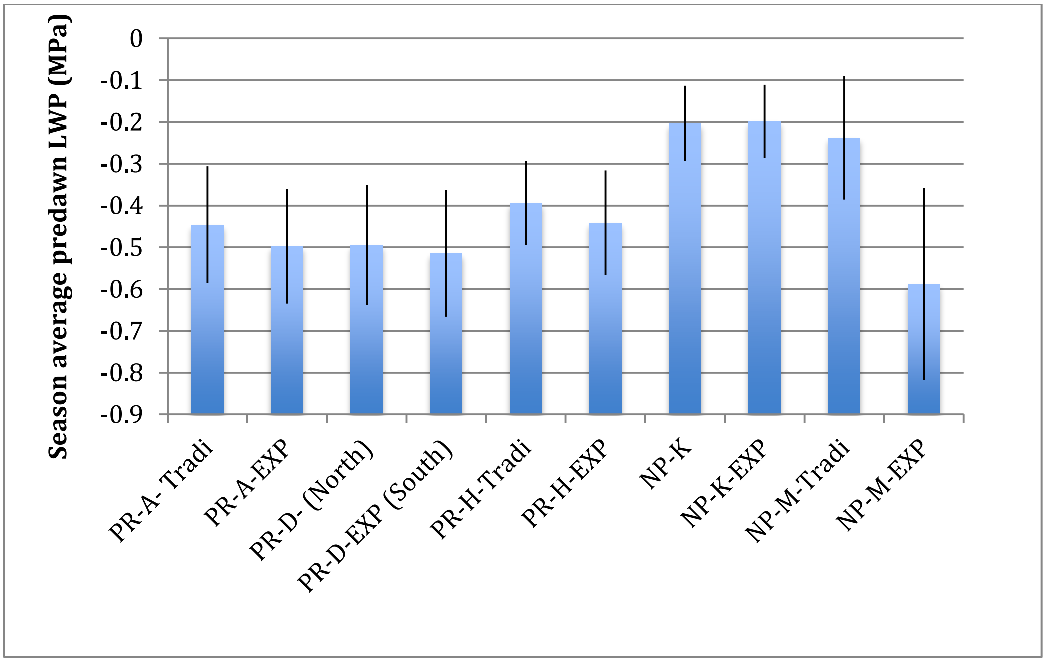


FIGURE 17: AVERAGE PREDAWN LWP MEASURED OVER THE SEASON

(error bars = 2 standard deviations).

Conclusion: even if we focus on the early stages of plant development, when vine water status variations are expected to be the most discriminating, **average predawn LWP does not discriminate treatment effect in 4/5 situations and no triggering threshold can be identified.**

TAKE HOME

In practice, predawn Leaf water potential cannot replace sap flow measurements to impose Fruition irrigation strategy

C) STOMATA CONDUCTANCE.

In site HB-JP, stomata conductance measurement was performed instead of leaf water potential. Results show average stomata conductance values over distinct periods of plant cycle.

Figure 18 shows that average stomata conductance values are lower in the Fruition treatment during the early phase of plant cycle (pre-veraison).

Compared to the traditional treatment (first irrigation reported on June 10th), Fruition treatment delayed the timing of the first irrigation until July 22nd. Consequently, vine water status differences between treatments are the largest during pre-veraison phase. Over that period the traditional treatment is frequently irrigated while the experimental Fruition treatment is not.

However, because error bars are overlapping, treatment differences are difficult to reveal in practice. Consequently, it is not possible to define a stomata conductance threshold value to trigger irrigation and reproduce the fruition treatment.

Due to time and operational constraint, it is not realistic to expect the vineyard technician to perform more than 8-10 measurements per smart point during the 90 minutes window (vineyard manager at site JP- pers. communication).

Large standard deviations with stomata conductance measurements are expected since important variations exist between leaves on a same vine. In fact, stomata conductance does not only depend upon vine water status but also upon leaf exposure to sunlight and temperature (ie. leaf angling, leaf height above the ground, etc…)

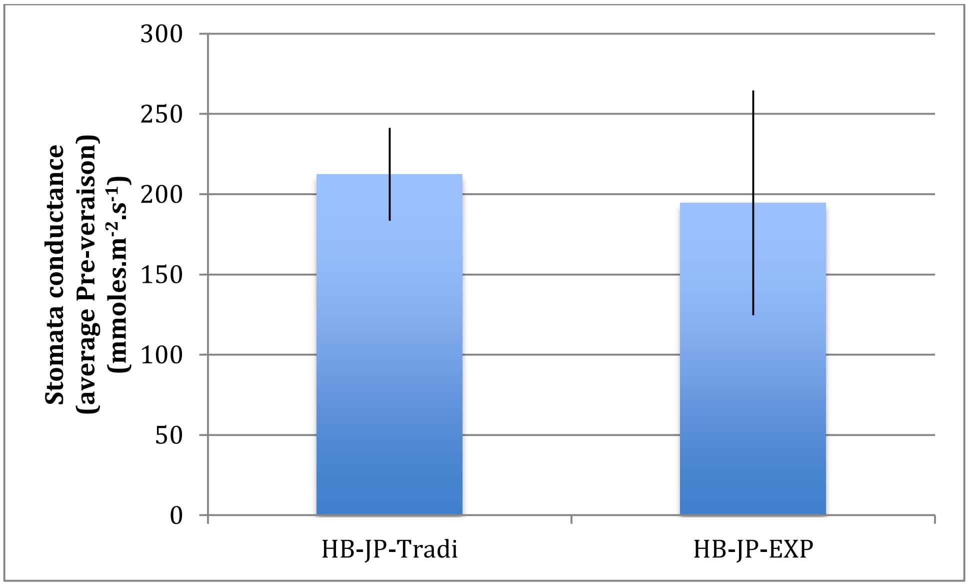


FIGURE 18: AVERAGE STOMATA CONDUCTANCE VALUES MEASURED DURING THE PRE-VERAISON PHASE

(June 1 - July 27; error bars = 2 standard deviations).

Over the whole season, a higher average stomata conductance is measured under the Fruition treatment (Figure **19**). **This means that under fruition treatment, the vineyard experiences a similar or lower level of water deficit (resulting into a higher average stomata conductance). Note: those trends pre and post veraison are also observed with the sap flow measurement method (Table 6 and 7).**

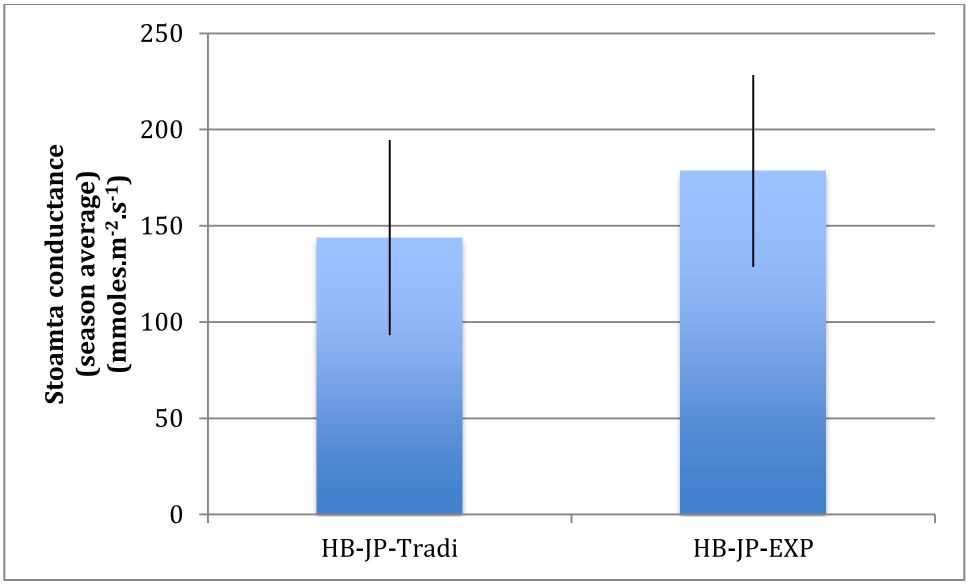


FIGURE 19: SEASON AVERAGE STOMATA CONDUCTANCE.

Conclusion:

Since the Fruition treatment delays the first irrigation, the pre-veraison phase corresponds to the period during which vine water status variations between treatments are most contrasted. During the early phase of the season and before irrigation is applied, average stomata conductance value is lower in the Fruition treatment.

However, over the whole season, stomata conductance is higher in the Fruition treatment which means that the Fruition treatments impose less water deficit. This suggests that by applying less water early season, the Fruition treatment has 2 effects on stomata conductance:

- it reduces stomata conductance at the beginning of the season (figure 18)
- it increases stomata conductance at the end of the season even if total amount of water applied over the season is lower. (figure 19)

We interpret such vineyard response as a carryover effect from early water deficit and longer intervals between irrigations under the Fruition treatment. Because larger amounts of water are applied when irrigation is decided, stomata conductance declines less brutally between 2 irrigations, consequently water deficit unfolds more gradually over the season and stomata conductance stays higher over longer periods of time.

Under the traditional treatment, irrigation amounts are lower and more frequent, and we observe more stomata conductance variations. As the season unfolds, there is less and less water in the soil and stomata conductance declines more brutally between 2 irrigations. We observe that stomata conductance drops less gradually over the season, particularly during the post veraison period (after July 27th). Thus, **water deficit is more severe under the traditional treatment even if more water is applied.**

Take home:

A relationship exist between sap flow and stomata conductance

However, in practice stomata conductance measurements cannot replace sap flow measurements to impose Fruition irrigation strategy.

D) WATER DEFICIT INDEX

The concept of Water deficit index, the positioning and number of sensor per area as well as the method for spatial extrapolation are explained in Material and Method.

When the value of WDI is high (100%) it means that 100% of the vine water needs are satisfied. The vine experiences no water deficit and does not need water. When the value of WDI is low (0%), the vine is "dead". We computed a daily WDI for each treatment. We cumulated the percentage of daily WDI over different periods across all sites to compare treatment effect over different vineyards.

Table 9 shows that over the pre-veraison period, site NP-M (EXP) experiences the most severe water deficit (ie. low satisfaction of vine water needs). Site PR-H Traditional experiences the lowest amount of water deficit (ie very high satisfaction of vine water needs).

TABLE 9: CUMULATED WDI PRE-VERAISON.

Site	Traditional (%)	Fruition treatment (%)
PR-A	2381	2202
PR-D	n/a	1767 (North) /2025 (South)
PR-H	2665	2630
NP-K	2412	2320
NP-M	1990	1741
HB-JP	2192	1867
Average(*)	2328	2152

(cumulated from June 18th to July 15th)

*: Site PR-D is not included in treatment average.

<u>Preveraison phase (June18-July 15th)</u>

Table 9 shows that cumulated WDI is lower in the Fruition treatment, as expected since the first irrigation is delayed. Note that sites PR-D North and PR-D-EXP south are both under the same irrigation regime (ie. Fruition treatment) but reflects different values due to soil heterogeneity. Higher WDI measured in PR-D- Exp south is due to soil textural properties allowing a higher retention of moisture compared to site PR-D- North and WDI differences are not related to different irrigation volumes.

TABLE 10: CUMULATED WDI OVER THE SEASON.

Site	Traditional (%)	Fruition treatment (%)
PR-A	5757	6962
PR-D	n/a	5696 (north) /6359 (south)
PR-H	6702	7328
NP-K	7524	7595
NP-M	6950	6254
HB-JP	5373	5859
Average(*)	6461	6800

(cumulated from June 18th to September 14th)

*: site PR-D is not included in treatment average.

Whole season (June 18th - Sept 18th)

Over the season Table 10 shows that cumulated WDI is higher in the fruition treatment except in site NP-M -EXP. **This means that over the season the level of water deficit is less severe under the Fruition treatment, even if less water is applied.**

Conclusion: Even if less water is applied, water deficit is on average less severe over the season under the fruition irrigation strategy. However, when water deficit is severely limiting early season (site NP-M Exp), cumulated WDI over the season can remain lower under the Fruition treatment. Site NP-M, is the only site where season water deficit has been more severe under the Fruition treatment.

Take home

By computing WDI daily, a threshold to trigger irrigation can be used to apply lower amount of water. This strategy leads to an average of 60% water savings compared to traditional technique.

Reducing water use in the vineyard does not necessarily translate into imposing more water deficit to the vine. Paradoxically, applying more water with more frequent irrigations contributes to increasing the severity of water deficit experienced by the plant, particularly during the second part of the season (post veraison period)

d. Yield

Table 11: Yield comparison.

Site	Traditional (tons/acre)	Fruition treatment (tons/acre)
PR-A	2.58	3.13
PR-D	4.67	4.55
PR-H	2.12	2.08
NP-K	2.86	2.91
NP-M	1.98	2.03
HB-JP	2.80	2.95
AVERAGE	2.83	2.94

Table 11 shows that yield levels are similar for the 2 treatments. On average, production levels are higher under the Fruition treatment even if less water is applied. In the most dramatic yield increase situation (site PR-A), yield levels are 20% higher in the Fruition treatment despites a reduction of 75% of water. Yield decline under Traditional treatment can be interpreted as a carryover effect of more frequent irrigation. When more water is applied early season, berry size is expected to be larger at the end of the season (the number of berry cell increases). However, this strategy also increases berry susceptibility to dehydration. This is particularly noticed when heat waves are experienced by the vineyard (which was the case end of August in site PR-A; see annex)

e. Fruit composition and quality

Results from the site-specific study are reported in annex. Similar maturation profiles (sugar accumulation and berry weight) were obtained for both treatments.

Table 12 reports the total amount of sugar per berry and the sugar concentration at harvest (except in site D). Maturity levels were considered appropriate for winemaking purposes, regardless of the treatment.

TABLE 12: SUGAR ACCUMULATION

Site	Treatment	Sugar amount (mg/berry)	Sugar concentration (Brix)
PR-A	Traditional	261.4	25.1
	Experimental	261.2	25.9
PR-H	Traditional	171.4	24.7
	Experimental	177.1	24.6
NP-K	Traditional	270.6	25.9
	Experimental	273.3	26.9
NP-M	Traditional	200.5	24.9
	Experimental	187.8	25.3
HB-JP	Traditional	188.6	22.9
	Experimental	184.2	22.8
Average	Traditional	216.7	25.1
	Experimental	218.5	24.7

(Average over the last 3 sampling dates before harvest)

When more complex chemical analyses were available (particularly skin composition- color or polyphenols), data shows that fruit composition is systematically higher under the fruition treatment. Higher color or polyphenols concentration is generally considered a good thing by winemakers. This overall improvement of fruit quality under the Fruition treatment was reflected through the following winemaker comments:

Owner Site PR- A:

“Despite applying less water we observe no decline in yield.” “Average brix coming from **combined** sample of juice extracted while the fruit was harvested: Traditional 27 Brix vs 26.5 Brix in Fruition it means that contrarily to what one would have expected there is more dehydration in the traditional treatment (coherent with lower yield). “

Traditional treatment yield a juice concentration at harvest of 5.67g/L of tartric vs. 6.9 g/L in Fruition. “We observe a better equilibrium in terms of “ physiological maturity” in the fruition treatment”

In conclusion: “no yield difference even if we would have thought that more dehydration should have occurred onto the Fruition treatment. The physiological maturity level is better in Fruition treatment, which suggests that vine suffered less! An asset for wine quality under the fruition treatment

Owner Site PR-D:

Sections within block 11 where WDI was lower pre veraison shows more polyphenols” …“In the fruition block 11 we have observed a rise of 30% to 40% in phenolics in 2014 compared to 2013”

In 2013, the maximum amount of anthocyanin block 11 achieved was 780 while in 2014 the highest we achieved was 1,192 resulting in a 52% increase! The ROI increases because this wine makes it into our $100 dollar bottle while before it made it into our $56 bottle. Compared to the wines in 2013, the wine in block 11 is clearly superior. It is more beefy, darker, more intense.

Winemaker Site PR-H:

“Due to the age of the vines and the positive virus testing the small difference in yield is negligible from a production standpoint. “

In house phenolic analysis were ran during fermentation and at pressing time. We found that both Fruition blocks were higher in color than the standard blocks (40 parts per million higher in color in the Upper section and 80 parts per million higher in color in the Lower section, a 4% and 8% increase respectively). Color is the most important aspect of phenolic analysis as the color is where flavor and concentration come from in winemaking. When tasting the blocks individually we gave a slight edge to the Fruition blocks

Owner Site NP-K:

“I feel like the tannins came around faster in the Fruition treatment and perceived less greenness”

This testimonial is featured on NPR interview - December 15th, “market place”

file://localhost/“http/::www.marketplace.org:topics:life:mid-day-update:podcast-fighting-drought-technology”

Winemaker Site NP-M:

“I observed an earlier maturation in the Fruition treatment. Fruit quality is surprisingly good in the fruition treatment despite having applied less water.

I saw similar phenolics profiles, and extractions between the 2 wines even if we tackled extraction in different ways on the winemaking size due to volumes (constraints). We also saw similar maxima of free anthocyanins around 1100+ppm. (As of today) the wines are similar in terms of quality and intensity

Winemaker Site HB-JP:

"Wine quality has been assessed post-drain and Fruition treatment was preferred for its broader and more concentrated mouth feel. Aromatics were more similar."

TAKE HOME

Yield and Fruit Quality is preferred with Fruition treatment.

Improvement in fruit quality was reported to increase the wine price in some situations.

Some winemakers are very vocal and accepted to testify publicly on Media (NPR news)

f. Water and Cost savings

Table 13: Comparison of water volumes applied according to treatment

Site	Traditional (mm)	Fruition treatment (mm)	Water and cost saving
PR-A	88	25	71%
PR-D	51	28	45%
PR-H	57	27	53%
NP-K	27	0	100%
NP-M	91	50	53%
HB-JP	44	26	40%
Average	60	26	60%

(Irrigations are cumulated from June 1st until harvest).

We reported the amount of water applied in each site and for each treatment in table 13.

Table **13** shows that under Fruition Treatment irrigation reduction are systematic. Water savings are important, and sometimes dramatic. In site HB-JP, the lowest amount of water savings was reported: only 40%. In site NP-K, the highest amount of water savings was reported as no water was applied (100% of water saving).

Under the Fruition treatment, the vineyard behaves normally despite the reduction in water volume.

- Aerial pictures reflected no differences between treatments in terms of leaf area development.
- Winemakers have confirmed that no leaf losses were observed under the fruition treatment.
- Plant physiological "behavior" is "normal": this is reflected through the maintaining of similar leaf area sizes in both treatments, and through a leaf photosynthetic activity allowing a proper fruit maturation level.
- By adapting the vine early season to get less water, crop production seems less sensitive to drought. This resulted in higher yield under the Fruition Treatment (See Table 11) as fruit shriveling can be more severe under traditional treatment (as discussed for site PR-A).
- Winemakers testimonials confirm that fruit quality is preferred under the fruition treatment which translates into a potential revenue increase (as confirmed by the owner of Site PR-D)

TAKE HOME:

Dramatic reduction of irrigation, even during a drought, does not necessarily affect vineyard performance or vineyard production.

Site specific analysis of shoot elongation rate, vine water use and maturation profile (sugar accumulation rate and berry weight increase over the season) are reported in annex.

4. CONCLUSIONS

We used an analytical framework to implement more conservative irrigation practices in vineyards and to monitor their impact on vineyard performances. Vineyard data were analyzed, discussed and confirmed with each winery participant separately. Site-specific reports for each situation were written to describe the results for each situation.

Overall, results show that an average of 60% of water savings could be achieved compared to the traditional irrigation strategy. Moreover, financial benefits in terms of production and vineyard performances have been associated with the implementation of more conservative irrigation strategies: yield is maintained or slightly increased, fruit quality is better and in some cases an increase in wine bottle price is reported. Each participant accepted to testify and confirm the benefits related to the implementation of the fruition treatment.

The method was implemented under contrasted climates and over vineyards of various sizes. The method consists of extrapolating plant – sensing data over larger areas from a few references sites located at strategic vineyard location (so called "smart points "). Irrigation is triggered according to a threshold of vine water deficit computed daily.

The framework leverages historical climatic data, as well as other sources of vineyard information (shoot elongation, water potential, stomata conductance, aerial imagery). It combines various plant sensing approaches to optimize the timing and the volume of irrigation as well as the monitoring of key production indexes (berry weight, sugar accumulation, etc…).

Our study demonstrates that vineyard economic performances are positively affected by the adoption of a more conservative approach to irrigation. The experimental treatment for irrigation optimizes vineyard water use and improves vineyard financial performances. Our study shows that the approach is scalable and can be simultaneously implemented in contrasted situations.

By providing real time analytics to the decision process, the framework successfully enables the adoption of more conservative irrigation strategies and improves vineyard performances.

Thanks

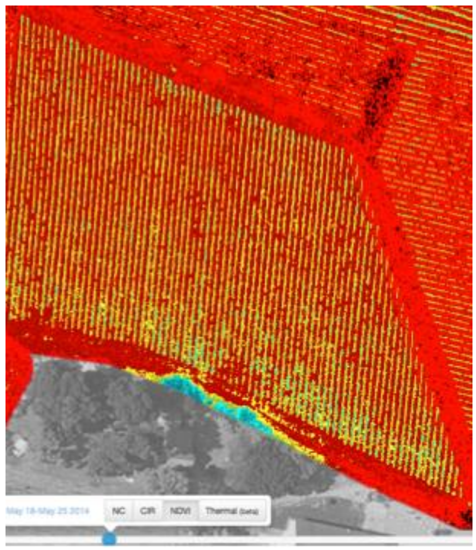
We would like to thank the Innovative Conservation Program, funded by the Bureau of Reclamation, Central Arizona Project, Metropolitan Water District of Southern California, and Southern Nevada Water Authority for the financial support in this study. Also, we would like to thank the Fruition team and interns for participating to the fieldwork and technical support. Last, we thank the wineries, which accepted to partner with this project for their help, trust and financial contribution.

ANNEX

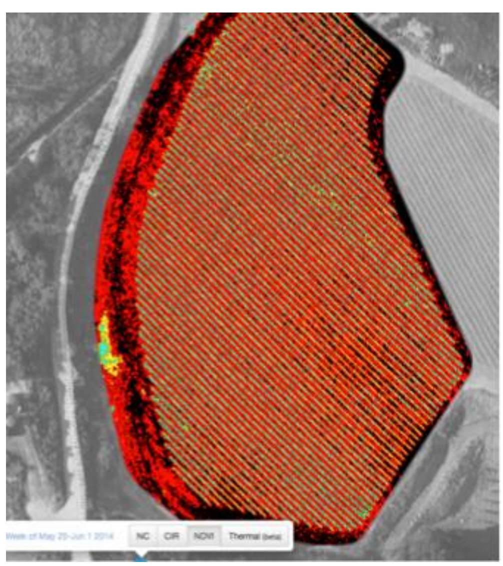
NDVI

Every week each vineyard was flown. After image processing we used the pictures for spatial monitoring. We reported one picture from each site. Pictures were selected at random date from snapshot taken from the Fruition website showing the NDVI aerial picture

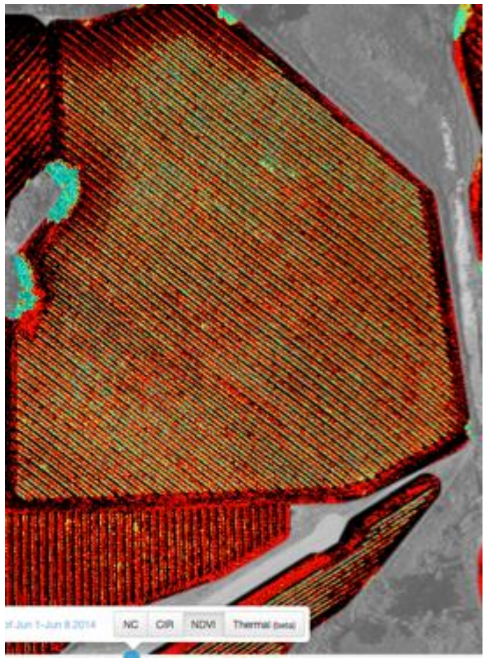
Site PR- A- May 22, 2014



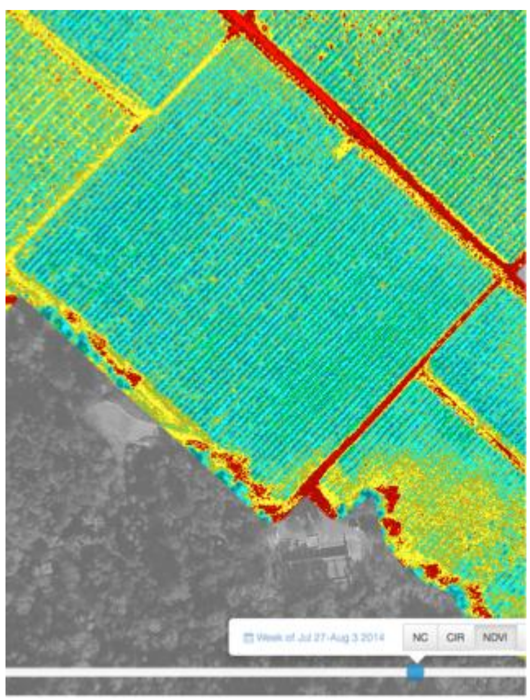
Site PR-D- May 27 2014



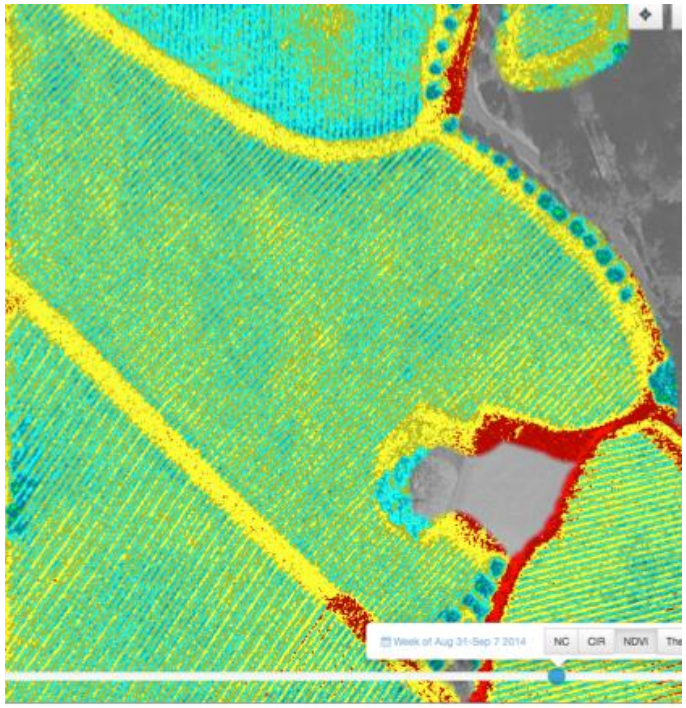
Site PR-HR – June 6th, 2014



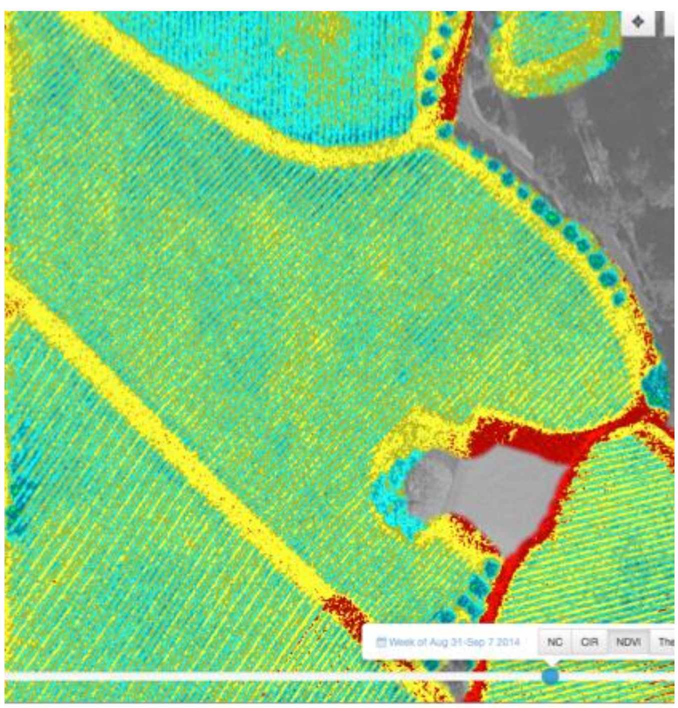
Site NP-K – July 31



Site NP-M September 2nd



Site HB-JP August 26th 2014



Scientific communications:

2 communications for scientific conferences were submitted following the experimental project. At the present time one has already been accepted for oral presentation at the Giesco meeting on June 2nd 2015 in France.

Note: the winery KJ had launched the same experimental protocol with a different block and for 3 consecutive years (starting in 2012). Because the traditional treatment was not applied in site PR-D in 2014, we replace site PR-D by site KJ-JT for the scientific communications. The site KJ-JT was not studied in this report. However, the data obtained from site KJ-JT confirm the results observed elsewhere with 75% water savings in the Fruition treatment without any yield decline.

Abstract Title and conference information

- 19th international meeting GIesco (accepted for oral presentation)

  "A comparative study of traditional vs. plant-sensor based irrigation across multiple sites: consequences on water savings and vineyard economics. Application during a drought in California".

  https://colloque.inra.fr/giesco-2015_eng/Program

- 66th ASEV National conference (submitted)

  "Comparison of traditional vs. sap flow based irrigation across multiple sites and multiple years: impact on water saving."

  http://www.asev.org/2015-national-conference

A comparative study of traditional vs. plant-sensor based irrigation across multiple sites: consequences on water savings and vineyard economics. Application during a drought in California.

Thibaut Scholasch [(1)] *

(1) *Fruition Sciences, SAS. MIBI, 672 rue du Mas de Verchant 34000 Montpellier,France, * Corresponding author: thibaut@fruitionsciences.com*

ABSTRACT

By monitoring plant water use continuously, new irrigation techniques can be implemented to promote more efficient vineyard water use. In order to demonstrate the impact of a new plant-based irrigation method in terms of water savings and vineyard performances, we designed an experiment across multiple vineyards in contrasted climatic condition during a very dry season. We selected and split 6 uniform vineyard areas to compare the effect of 2 irrigation strategies over 3 distinct wine growing regions. First we implemented a sap flow sensor-monitoring method to track continuous vine water deficit variations. Second we triggered irrigation according to real time assessment of vine water deficit based on sap flow and climatic data. Third, we evaluated the effect of sap flow-based irrigation based on real time monitoring of plant water deficit on vineyard performances and water savings by comparing two irrigation strategies. Under traditional strategy, water is applied based on empirical knowledge, visual observations and some measurements but without any specific rules. Under experimental strategy, irrigations are triggered each time vine water deficit reaches a threshold value. Our study demonstrates that more conservative irrigation practices can be adopted with the experimental strategy. Despite reducing irrigation volume in a context of drought (40% to 100% less water volume is used in the experimental treatment), no yield losses were reported and sugar accumulation was observed at a similar rate. By focusing on a few reference sites and by integrating various sources of vineyard data into a framework, it is possible to track vine water deficit in real time and to extrapolate irrigation decisions over large areas. Implications to implement more conservative and varietal-specific irrigation strategies are discussed.

Keywords: irrigation, drought, Ks, sap flow, yield.

1) Introduction:

California's population growth and greater awareness of environmental water requirements has increased the pressure on California agriculture to use water more efficiently and to make more water available for urban and environmental uses. In this context of water scarcity, the goal of this project is to evaluate the benefits of adopting a plant sensor-based approach to irrigation in viticulture. The hypothesis is that a treatment triggering irrigation according to plant-based measurements (using sap flow sensors) reduces irrigation volumes compared to traditional method. The objectives of the study are: A) Implementing a new technology to monitor continuously and in real time vine water needs variations using sap flow sensors; B) Using real time information to trigger irrigation according to a plant-based signal in a production context and across contrasted climatic conditions; C) Evaluating the effect of real time plant based irrigation on water savings, fruit maturation and yield by comparing with traditional irrigation.

2) Material and Method

Site Location: 6 vineyard sites from 6 different wineries located between (38.38 -122.64) and (35.59-120.74) in Paso Robles (PR), Napa (NP), Healdsburg (HB). **Vineyard age:** all vineyards were planted between 1997 and 2001; **Plant material:** Syrah on 420A (PR-A); Merlot on 101-14 (HB-JP); Cabernet sauvignon (on 110R-site PR-H, on St Georges-site NP-K, on 1103 Pa-site NP-M, on 101-14-site HB-JT). **Experimental layout:** we used weekly aerial pictures (NDVI) to identify areas of uniform vegetative expression within each vineyard and to select the split treatment location. Experimental areas varied from 1.3 Ha to 5.2 Ha and are divided into 2 sections for treatment application. **Weather station:** ET_{ref} was computed according to the Pennman-Monteith equation from weather station located in the vineyard or nearby. **Water input**: Irrigation gauges were installed within each treatment to monitor the amount of water applied through the irrigation line. A rain gauge (Decagon Devices, Inc. ECRN) recorded the amount of water directly underneath the dripper. **Sap flow***:* the energy balance method was used to measure sap flow with Sap IP system (Dynamax, Houston, TX, USA). In each selected row, 2 vines were equipped with one sensor each. Each sensor measured vine sap flow rate every 15 minutes. The 2 selected vines were within 25 meters of each other within the same row. Sap flow rates measured on each vine were averaged on an hourly basis within each row. Various expert methods were applied to filter out nighttime, weak and erroneous signals. Sap flow measurements were scaled at the plant level according to plant leaf area estimates corresponding to each sensor. The daily sap flow assumed to measure daily vine transpiration was computed by adding all hourly sap flow rates measured during the day.

Ks Computation: Ks is the ratio between actual and maximum vine transpiration, defined as: $Ks(t) = T(t)/T_{max}(t)$.

Ks represents the level of daily vine water use by reference to its maximal level. Ks=1 reflects a situation when maximal level of vine water use is fully satisfied. When $Ks<1$, daily vine water use is limited. T is daily measured transpiration from sap flow and T_{max} is daily maximal vine transpiration obtained under dry soil condition when soil moisture is non-limiting, as in Allen et al. (2009).

$T_{max}(t)=Kc_B(t)\,ET_{ref}(t)$. ET_{ref} is the reference evapotranspiration and Kc_B a coefficient linearly related to the leaf area index (Picón-Toro et al., 2012). Kc_B determination method is described in Scholasch et al, 2014.

Treatments: Plant equipped with sap flow sensors were at least 10 rows apart to maintain a buffer zone between treatments. ***Traditional treatment***: irrigation is applied according to vineyard historical management practices. Irrigation needs are based on climatic forecast, leaf area visual observations and predawn leaf water potential or stomata conductance but without specific rules to trigger irrigation. ***Experimental treatment (sap flow based)***: Irrigation is triggered according to a Ks threshold value = 40% pre-veraison and 60% post veraison. No irrigation is applied if thresholds are not reached. **Fruit:** 200 berries are sampled every 7 to 10 days on 50 vines surrounding the 2 vines equipped with sap flow sensors to measure sugar concentration, berry weight, and sugar amount per berry. Berry sampling for maturation monitoring started before veraison. Yield was measured at harvest and calculated by dividing amount of crop by the ground area allocated to treatment.

3) Results

A) Site comparison:

Thermal time: we compared thermal time accumulation since 2010 at each location (base 10^0C). **Pre-budbreak** (DOY1 - DOY 60)**:** 2014 shows the highest thermal time accumulation (TT ranges from 112 to 193 ^{0}C.d). **Pre veraison (**DOY 60- DOY 195)**:** the earliest veraison is observed on July 15th (DOY 195). Across all locations, 2013 and 2014 show the highest temperature accumulation (780 to 1098 ^{0}C.d). **Veraison to Harvest** (DOY 195- DOY 288- October 15th)**:** All sites were harvested in September except site NP-K (October 7th) and site PR-H (October 15th). Over that period and across all sites, 2014 is the warmest year. (723 to 1152 ^{0}C.d).

Rainfall: Pre-bud break: November 1st (2013) - March 1st (2014). Over winter, rainfall level in the driest area is around 100 mm (Paso Robles) followed by Napa and Healdsburg (varied between 150 and 320mm). **Budbreak-October 15th** (DOY 60-288): In the driest sites, (Paso robles) cumulated rain amounts between 75 to 93 mm. In Napa and Healdsburg, level of rainfall varied from 120 to 160 mm.

ET_{ref}: over the period DOY 60-288, evaporative demand is the highest in site PR-H and PR-A; it is the lowest in site HB-JP and HB-JT. **Vapor pressure deficit analysis:** We counted the number of days when VPD_{max} > 4 kPa over that period. In PR sites, 61 to 63 days were recorded. In Napa, we observed local variations between sites and number of days varied between 52 days (NP-M) and 23 days (NP-K). In Healdsburg, we counted 17 days.

B) Treatment comparison

Irrigation volume: Table 1 compares the volume of irrigation and the number of irrigation events applied at each location and for each treatment. In the experimental treatment water saving varies between 41% and 100%.

Effect on Ks:

We analyzed vine water use profiles over June 18th to September 15th which is the period of sap flow monitoring commonly shared across all sites. We cumulated daily Ks value to compare treatment effect on vine water deficit (Table 2). **Preveraison**: cumulated Ks is lower in the experimental treatment where less water is applied early season. **Post veraison:** cumulated Ks is higher in the experimental treatment except in site NP-M and HB-JT. **Over the whole period**: even if less water is applied in the experimental treatment, plant water deficit over the whole period is not necessarily more severe under sap flow based irrigation strategy (Ks is higher in the experimental treatment in 4/6 sites).

Effect on Yield

Table 3 shows similar yield levels between the 2 treatments. In site PR-A and site HB-JP, with Syrah and Merlot respectively, we observe a lower yield in the traditional treatment and some visual symptoms of berry dehydration were reported before harvest. Table 2 shows that the level of water deficit post veraison is the most severe in those 2 sites (daily average Ks is lower than 55% post veraison). Yield losses may have been further amplified by late season heat wave events recorded across all locations during the last week of August and over the first 2 weeks of September.

Effect on Sugar accumulation

We track the dynamic variations of sugar per berry, starting before veraison until harvest, to determine whether sugar was actively loading onto the berry at the time of harvest. Table 4 reports average amount of sugar per berry, sugar concentration over the last 3 sampling dates and whether sugar amount per berry is still increasing at harvest based on profile analysis. For Cabernet sauvignon, sugar amount per berry is steady and active sugar loading in the berry stops 2 to 3 weeks before harvest for both treatments. For Syrah and Merlot, sugar amount per berry is still increasing at the time of harvest and had been increasing over the last 3 weeks in both treatments. At any given site, all treatments were harvested on the same day except in NP-M (experimental treatment harvested 4 days earlier). Sugar concentration is similar or higher in the experimental treatment. Sugar amount per berry is higher or lower according to sites. Dynamics of active sugar loading are synchronized between the 2 treatments at each location.

4) Conclusions:

Climatic analysis characterizes 2014 as a drought year, across all sites, particularly before budbreak and after veraison.

We used an analytical framework to monitor in real time vine water deficit at different locations and under contrasted climates and to compare two irrigation treatments. From a few reference sites ("smart points"), the experimental treatment extrapolates vine water needs over larger areas to improve the timing and the volume of irrigation. By providing real time analytics to the decision process, the framework successfully implements more conservative irrigation strategies and maintains or improves vineyard performances.

In the conditions of the study, at least 40% of water savings could be achieved with the experimental treatment.

In the traditional treatment, applying higher irrigation volumes did not increase yield and vine water deficit level was not necessarily less severe, particularly after veraison. In the traditional treatment, yield decline observed with Syrah and Merlot, after the heat waves, may be related to varietal behavior. While Cabernet sauvignon is found to behave in a near isohydric manner (Hochberg et al, 2013), Merlot in an anisohydric manner (Chaves el al, 2010), it is unclear how Syrah behaves after rewatering (Pou et al, 2014). Results suggest that some improvements in agronomic management may be achieved by applying different irrigation regimes to different cultivars in order to maximize crop performances.

Acknowledgments

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5) Literature cited

Allen, R. G., & Pereira, L. S., 2009. Estimating crop coefficients from fraction of ground cover and height. *Irrigation Science*, *28*(1), 17–34.

Chaves, M.M., Zarrouk, O.,Francisco, R., Costa, J M., Santos, T., Regalado, A. P., Rodrigues, M. L., Lopes, C.M. 2010, Grapevine under deficit irrigation: hints from physiological and molecular data. *Ann. Bot.* **105,** 661–76

Hochberg, U., Degu, A., Fait, A. , Rachmilevitch, S. , 2013. Near isohydric grapevine cultivar displays higher photosynthetic efficiency and photorespiration rates under drought stress as compared with near anisohydric grapevine cultivar. *Physiol. Plant.* **147,** 443–52.

Picón-Toro, J., González-Dugo, V., Uriarte, D., Mancha, L. a., & Testi, L., 2012. Effects of canopy size and water stress over the crop coefficient of a "Tempranillo" vineyard in south-western Spain. Irrigation Science, 30(5), 419–432.

Pou, A., Medrano, ., Tomàs, M., Martorell, S., Ribas-Carbó, M., Flexas, J., 2012. Anisohydric behaviour in grapevines results in better performance under moderate water stress and recovery than isohydric behaviour. *Plant Soil* **359,** 335–349.

Scholasch, T., Charnomordic,B., Hilgert N. , 2014. A generic method to analyze vine water deficit continuously, XV Terroir conference proceding, July 7-10, 2014, Tokay, Section 6, pp 244-247.

Site	**Traditional**	**Experimental (Sap flow based)**	**Water saving**
PR-A	88 *(4)*	25 (1)	71%
PR-H	57 *(5)*	27 *(2)*	53%
NP-K	27 *(8)*	0 *(0)*	100%
NP-M	91 *(7)*	50 *(3)*	53%
HB-JP	44 *(12)*	26 *(3)*	41%
HB-JT	53 *(28)*	14 *(2)*	74%

Table 1: *comparison of water volumes applied according to treatment (mm).*

(Irrigations are cumulated from June 1st until harvest date- number of water application in parenthesis).

	Pre veraison: June 18th to July 15th		**Post veraison : July 15th- September 15th**		**Whole period: June 18th- September 15th**	
Site	**Traditional**	**Experimental**	**Traditional**	**Experimental**	**Traditional**	**Experimental**
PR-A	23.81	22.02	33.76	47.60	57.57	69.62
PR-H	26.65	26.30	40.37	46.98	67.02	73.28
NP-K	24.12	23.20	40.37	52.75	75.24	75.95
NP-M	19.90	17.41	51.12	45.13	69.50	62.54
HB-JP	21.92	18.67	31.81	39.92	53.73	58.59
HB-JT	25.26	20.34	49.13	48.24	74.39	68.58

Table 2: *Cumulated Ks*

Site	**Traditional**	**Fruition treatment**
PR-A	6.4	7.7
PR-H	5.2	5.1
NP-K	7.1	7.2
NP-M	4.9	5.0
HB-JP	6.9	7.3
HB-JT	9.2	9.4

Table 3: *Yield comparison (tons/Ha)*

Site	Treatment	Sugar amount (mg/berry)	Sugar concentration (Brix)	Sugar loading
PR-A	Traditional	261.4	25.1	active
	Experimental	261.2	25.9	active
PR-H	Traditional	171.4	24.7	stopped
	Experimental	177.1	24.6	stopped
NP-K	Traditional	270.6	25.9	stopped
	Experimental	273.3	26.9	stopped
NP-M	Traditional	200.5	24.9	stopped
	Experimental	187.8	25.3	stopped
HB-JP	Traditional	188.6	22.9	active
	Experimental	184.2	22.8	active
HB-JT	Traditional	190.0	23.0	stopped
	Experimental	178.9	22.9	stopped

Table 4: *Sugar accumulation (average over the last 3 sampling dates before harvest)*

Comparison of traditional vs. sap flow based irrigation across multiple sites and multiple years: impact on water saving.

Thibaut Scholasch [(1)] ; **Kristina Werner** [(2)]

(1) *Fruition Sciences, SAS. MIBI, 672 rue du Mas de Verchant 34000 Montpellier,France, (2) Kendall Jackson – Stonestreet winery- 7111 CA-128, Healdsburg, CA 95448*

ABSTRACT

By monitoring vine water use continuously, new irrigation strategies can be implemented and compared with traditional irrigation. To evaluate the benefits of a new irrigation approach, we combined an experiment with vineyards across multiple geographic locations along with an experiment across multiple years. First we implemented a sap flow sensor-based approach to irrigation under contrasted locations and climates throughout California. Second by monitoring vine water use continuously, we triggered irrigation based on real time vine water deficit and compared with traditional irrigation. Third, we investigated the temporal stability of the result by testing the carry over effects of sap flow-based irrigation measuring various fruit parameters. Last, we wanted to demonstrate that more conservative irrigation strategies could be adopted, even in a context of drought, while evaluating the consequences of irrigation reduction on yield and sugar loading.

Six vineyard sites were selected and evaluated in a split-treatment trial to compare the effect of two irrigation strategies in Sonoma, Napa and Paso Robles in 2014. At one location, the treatment was implemented for three consecutive years. Under traditional strategy, irrigation was based on empirical knowledge, visual observations and climatic forecasting. Under experimental strategy, we computed a daily vine water deficit index combining sap flow sensors data with climatic data. Irrigations are triggered each time vine water deficit index reaches a threshold value.

Results show that irrigation could be reduced by 40 to 100% in the experimental treatments even in a context of drought. No yield losses were reported and sugar accumulation was observed at a similar rate across treatments. By designing a framework that incorporates plant-sensing data from a selection of reference sites, we can extrapolate irrigation decisions under contrasted soils and climates and over multiple seasons. Our study concludes that plant-sensing irrigation promotes more conservative irrigation and improves vineyard economics.

Keywords: irrigation, drought, Ks, sap flow, vineyard economics

Site Specific Analysis

Site specific report: each vineyard was analyzed separately. Reports were sent to each winemaker or vineyard owner to validate the results in each individual site before synthesizing and summarizing all the results into the final report.

Reports are listed in the following order:

- Site PR-A
- Site PR-D
- Site PR-H
- Site NP-K
- Site NP-M
- Site HB-JP

Site PR-A

Introduction

This is a preliminary report before performing a cross vineyard analysis. Over 6 different vineyards (Sonoma, Napa, Paso Robles) the same split treatment experiment has been conducted and similar data have been collected. Information on block properties, phenology and other historical practices have been compiled in the main report.

This site-specific report summarizes results obtained only in the context of the experiment in your vineyard. We welcome your comments and corrections. The goal is to have your approval before analyzing data from the 6 different vineyards. General conclusions will be discussed in the main report.

Thank you for your collaboration and help during that phase.

1) Water input comparison

Table 1 reports the amount of water applied in each irrigation treatment. To compare irrigation strategies, we reported volumes:

- Automatically from the irrigation gauge. (Water volume was directly measured at the vine level)
- Verbally per the vineyard manager. From the amount of hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (bucket under the dripper to monitor the water filling rate)

Table 1: 2014 Irrigation volume comparison

Site name PR-A	1st Irrigation **	# of events	rain gauge activity (hours)-	volume from rain gauge (mm)	volume verbally reported (mm)
Traditional	6/17	4	24.3	87.55	46.26
Fruition	7/23	1	8.6	25.18	18.92
water savings* (%)				- 71%	-59%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

Figure 1 shows the profile of shoot elongation with time. Active shoot elongation stops around June 9th (as a result of hedging). Main shoot length is comprised between 60 and 70 cm on average. Average shoot length is slightly reduced in the traditional treatment (7.5 cm shorter).

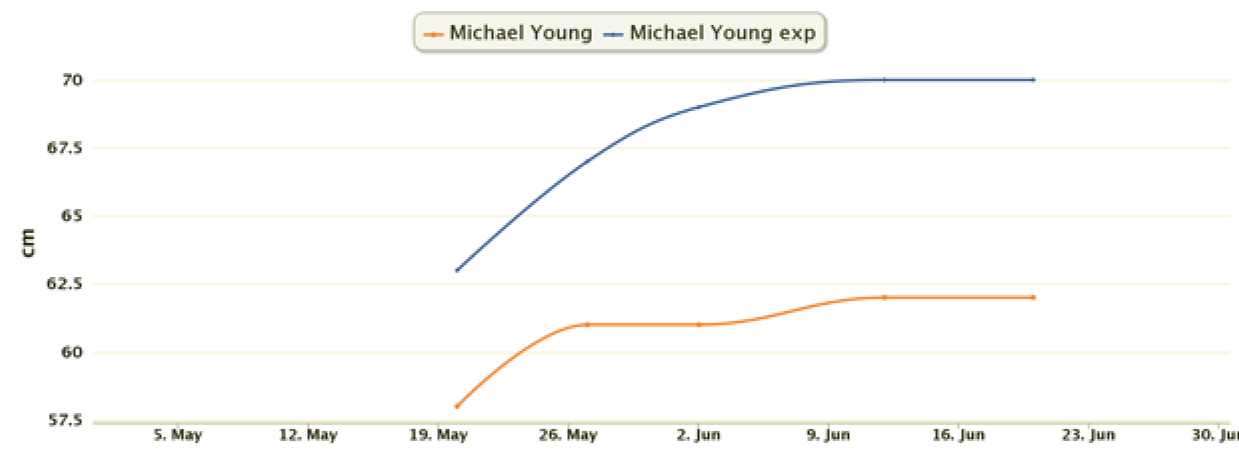

Figure 1: Shoot elongation rate at both smart point locations

B) Plant water use

1) Pressure bomb readings

Predawn water potential variations are reported in Figure 2.

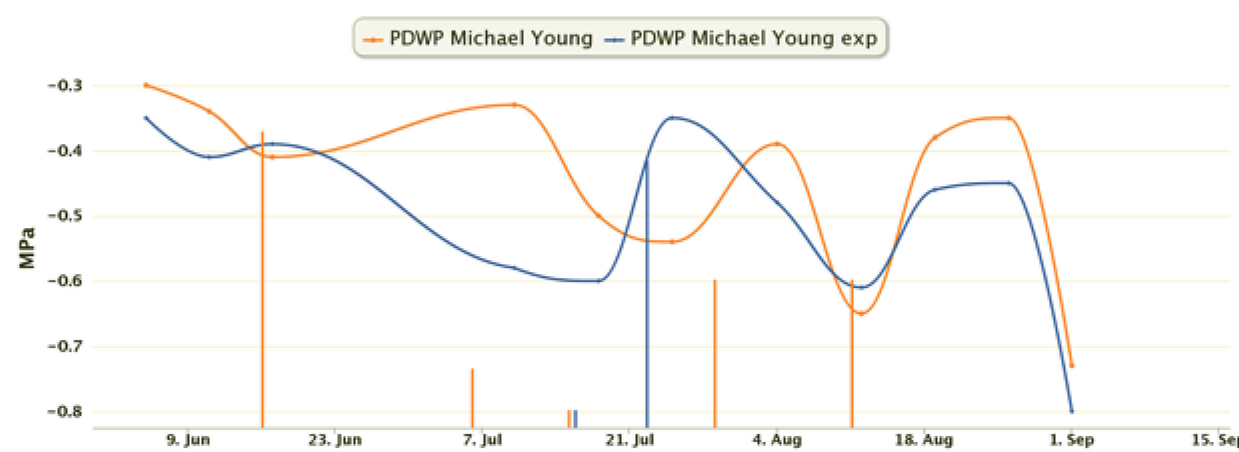

Figure 2: Predawn Leaf Water potential profiles at both smart point locations

Before July 22nd irrigation, we observe more negative values in the Fruition treatment. As expected, predawn water potential values are more negative and reflect a vine water status more limited compared to the traditional treatment. After July 22nd irrigation: water deficit profiles are similar and a sharp decline is observed end of August for both treatments. The brutal decline can be the reflect of a brutal restriction of root water supply or it can also be the reflect of a brutal rise in air water deficit (Vapor pressure deficit ie. VPD) at the time measurements were performed.

2) Sap flow analysis

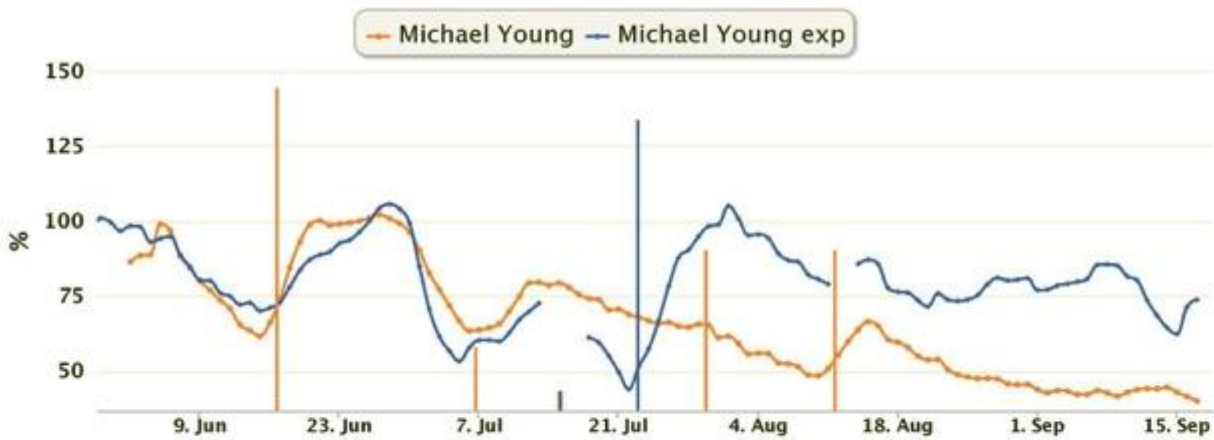

Figure 3: WDI from sap flow

Before July 22nd irrigation, we observe lower WDI values in the fruition treatment. As expected, lower WDI values reflect a vine water status which is more limited in the Fruition treatment since no irrigation has been applied compared to the traditional treatment. After July 22nd irrigation, WDI values increase markedly (+57%) in the Fruition treatment as expected given the large water volume applied (25 mm). In the traditional treatment WDI rises after each irrigation except July 30th. Lack of response after July 30th irrigation shows that irrigation had no effect on vine water status. However the second irrigation on August 12th had an effect on vine water status and WDI increases by 18% after irrigation.

Over the season, a larger amount of water is applied in the traditional treatment, however WDI is on average lower. Consequently, seasonal water deficit is more severe in the traditional treatment. This may seem counter intuitive but in fact this is not in contradiction with the literature. Various authors have reported the following vine responses under higher water supply: water use efficiency gets lower, root water absorption sites are more superficial, drought resistance hormone (like ABA) concentration is lower, diameter of vascular tissue is larger, berry sizing is larger (potentially increasing vine water needs towards the end of the season, etc…).

According to the literature, the higher level of vine water deficit experienced in the fruition treatment (between July 1st and July 23rd) should have positive consequences on maturation profile and phenolics.

C) Fruit response monitoring

1) Pulp composition

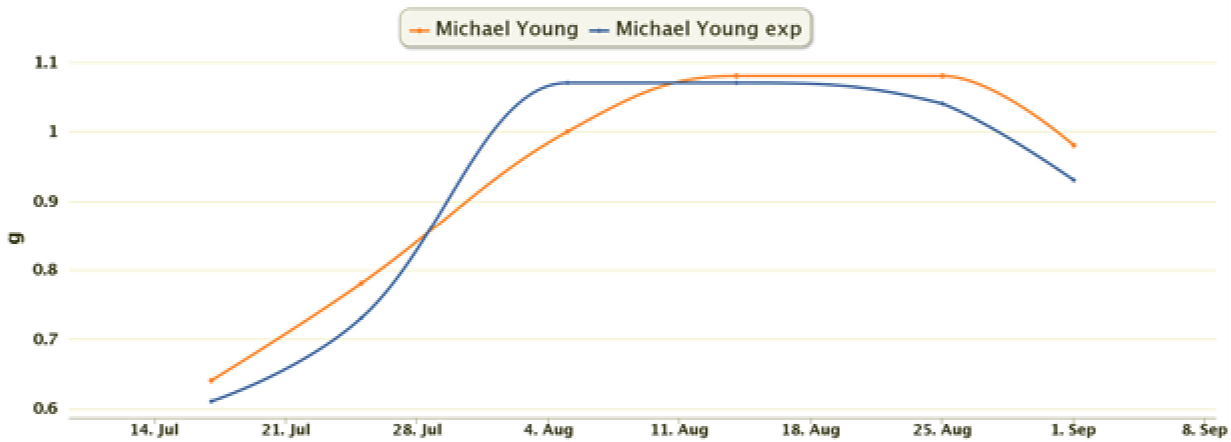

Figure 4: Berry Weight variations

Variations of berry weight with time are reported on Figure 4. A slightly lower peak berry weight is reached earlier in the Fruition treatment. This can be interpreted as a carryover effect from the early season water deficit, which was more, pronounced in the fruition treatment. After August 25th, a sharp decline is observed in both treatments. Berry weight decline affects equally the 2 treatments despite contrasted WDI values (figure 3). Over that period, WDI are high in the fruition treatment (>75%) which confirms that the vine was not experiencing a severe water deficit when berry weight loss occurred.

However adverse climatic conditions can lead to berry volume loss regardless of vine water status. In fact a heat wave was recorded during that period (August 28th- September 1st) with VPD values >4 kPa (figure 5). This result suggests that applying irrigation to minimize berry weight loss caused by late season heat wave is not adapted. Berry weight loss is observed even in absence of water deficit, thus it suggests that it is more efficient to minimize yield loss under a heat spell by modifying vine micro climate (shade cloth, misting, etc..).

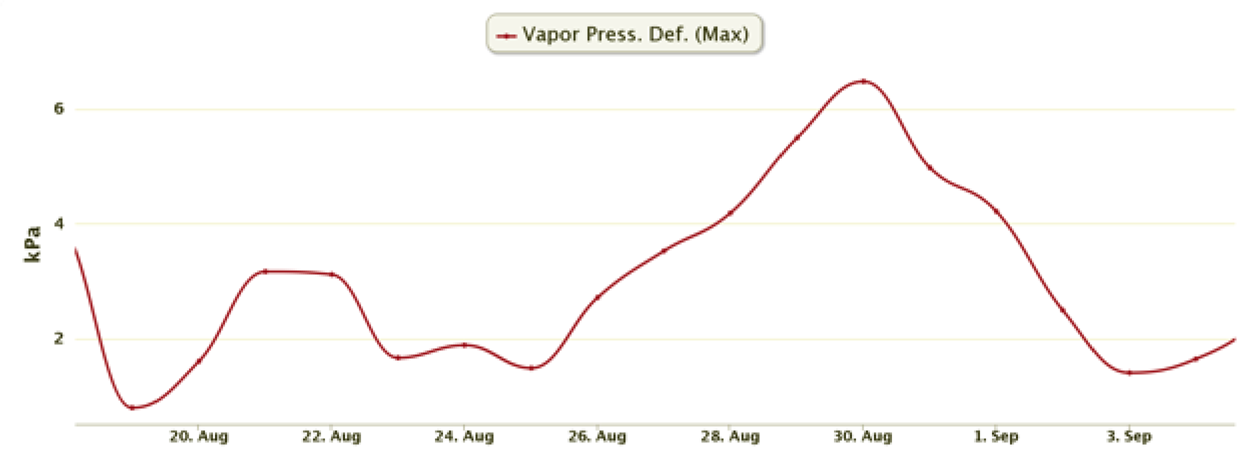

Figure 5: Late season Vapor pressure deficit variations

Sugar concentration increases at a similar rate in both treatments. It is slightly higher in the fruition treatment. This is in agreement with the literature since water deficit early season is expected to hasten the onset of sugar accumulation (Figure 6). We observe a faster rise in sugar concentration between August 25th and September 1st.

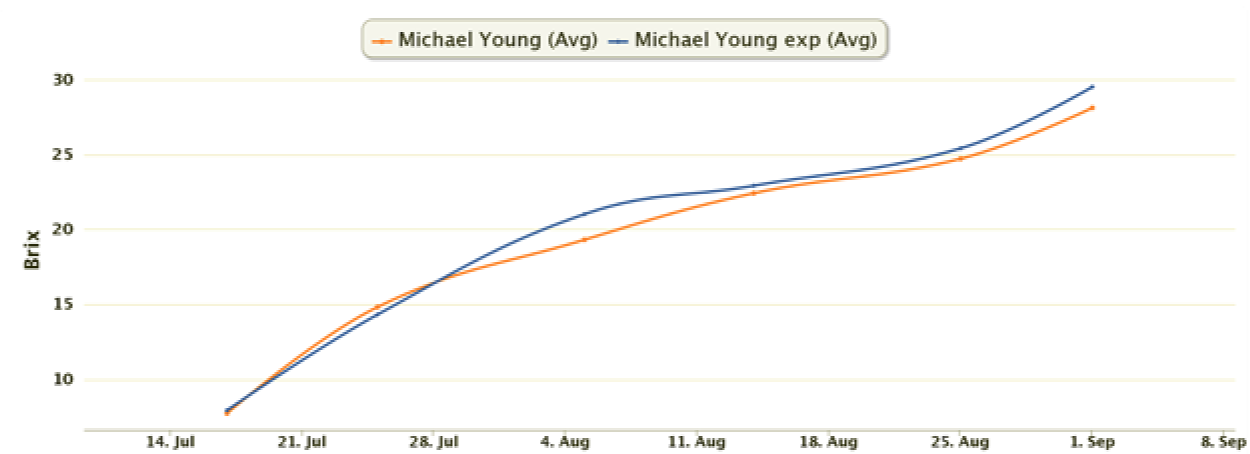

Figure 6: Sugar concentration variations

Active sugar accumulation is expressed in mg of sugar per berry in Figure 7. By tracking the amount of sugar per berry, we can distinguish if rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss. Between mid-July and mid-August, we observe a faster rate of sugar accumulation suggesting an earlier maturation in the Fruition treatment. We observe that the amount of sugar per berry remains the same during the week of August 25th –September 1st. This confirms that the faster rise in sugar concentration over that period is due to berry dehydration caused by the heat wave.

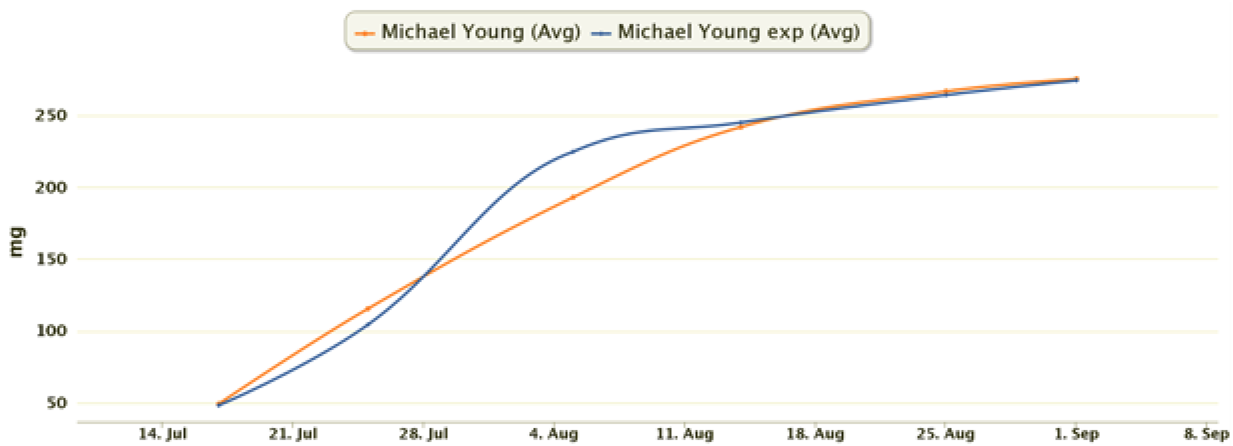

Figure 7: Sugar per berry comparison

2) Skin composition

The analysis of polyphenols shows a higher concentration in the fruition treatment. This is in agreement with our observations of earlier sugar accumulation suggesting an earlier maturation. Results are reported in Table 2 and time variations profiles are displayed in figure 8-9-10.

Table 2: Skin analysis: anthocyanins + polyphenols

Site Name **PR-A**	Treatment	8/25/2014	9/1/2014
Tannin (mg/g)	Fruition	1.16	1.14
	Traditional	1.01	.98
Total Phenolics (a.u./g)	Fruition	38.16	37.78
	Traditional	34.14	33.84
Total Anthocyanins (mg/g) Malvidin-3-glucoside equivalents	Fruition	.60	.59
	Traditional	.54	.53

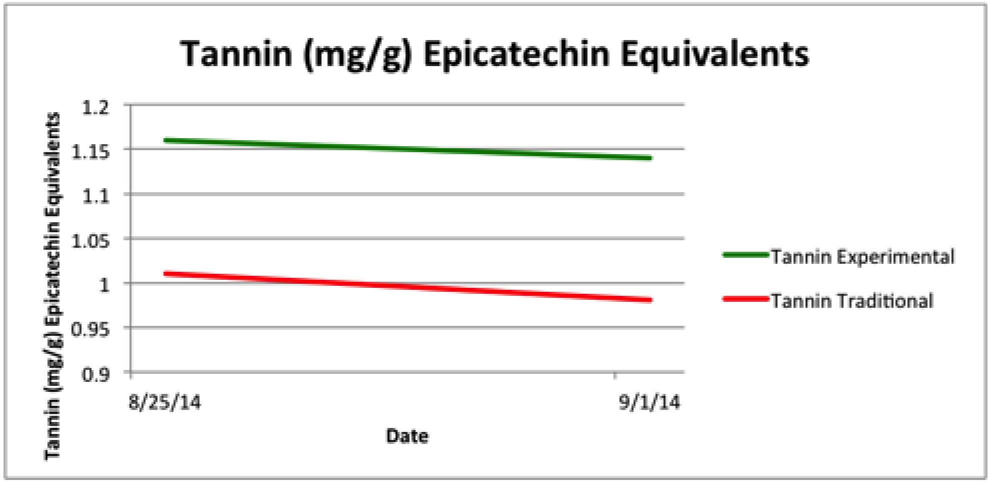

Figure 7: Skin analysis: Tannin

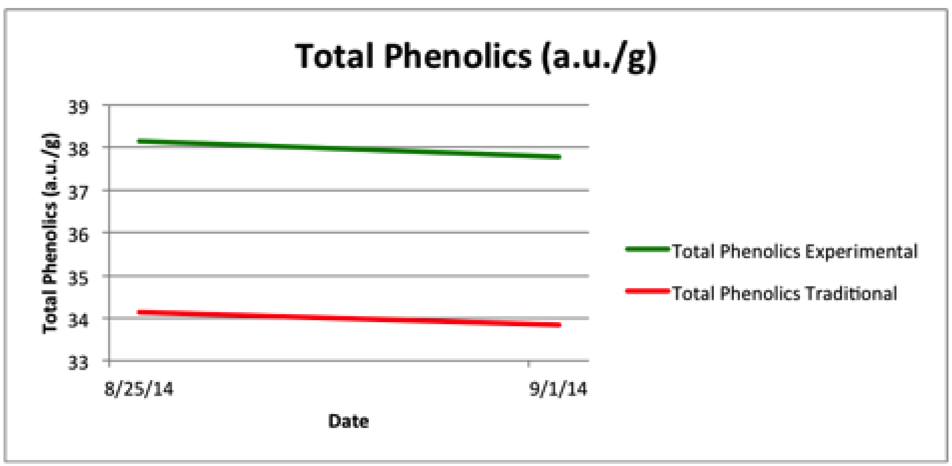

Figure 8: Skin analysis: Total Phenolics

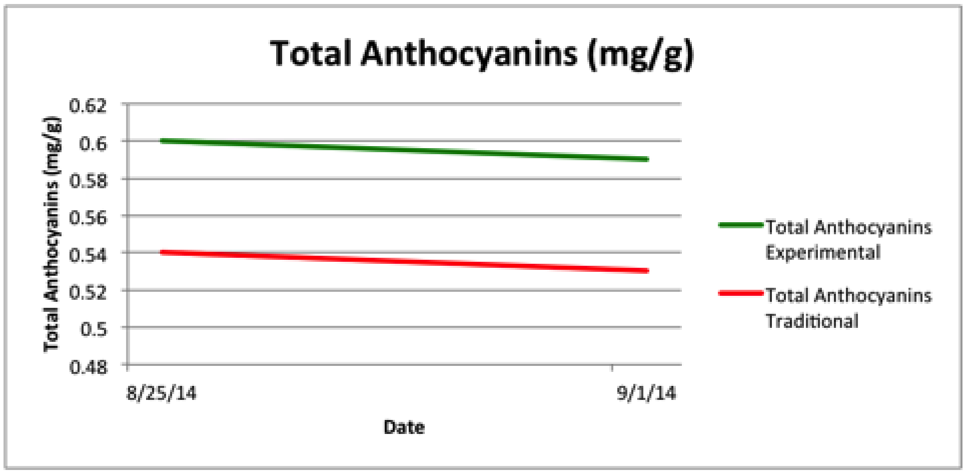

Figure 9: Skin analysis: Total Anthocyanins

3) Vineyard yield

Table 3: Yield Estimate in 2014

Site Name **PR-A**	Tons/acre
Traditional	2.58
Fruition	3.13
Yield variations	+21%

4) Winemaker feedback

on Yield : September 4

"We observe no significant differences in terms of yield. Cluster number per vine is around 15.8 in traditional and 16.5 in fruition. More fruit came out of the Fruition treatment. Despite applying less water we observe no decline in yield."

on fruit quality:

"Average brix coming from combined sample of juice extracted while the fruit was harvested : Traditional 27 Brix vs 26.5 Brix in Fruition it means that contrarily to what one would have expected there is more dehydration in the traditional treatment (coherent with lower yield). "

Note that this is also in agreement with WDI values being lower in the traditional treatment from July 22nd onwards (the vine in the traditional treatment were experiencing more water deficit despite being more irrigated)

Acidity level: TA

Traditional treatment yield a juice concentration at harvest of 5.67g/L of tartric vs. 6.9 g/L in Fruition.

"We observe a better equilibrium in terms of " physiological maturity" in the fruition treatment"

Note: this drives in part the qualitative aspects of the wine.

In conclusion: "no yield difference even if we would have thought that more dehydration should have occurred onto the Fruition treatment. The physiological maturity level is better in Fruition treatment, which suggests that vine suffered less! An asset for wine quality under the fruition treatment"

Site PR-D

1) Water input comparison

This site has been challenging because unfortunately we could not apply a split irrigation treatment in the same vineyard block (block 11). By mistake irrigation was applied uniformly over the 2 treatments on August 10th. Consequently the whole block 11 was considered a Fruition treatment and was compared to block 7B, which was irrigated according to traditional irrigation strategy. Excepted differences in irrigation strategies, block 7B is similar to block 11 (same varietal, same spacing density, same canopy size, same row orientation, similar yield). No sap flow sensors and no irrigation gauges were installed in block 7B. Figure 1 shows the location of block 7B and 11.

Traditionally the vineyard has been irrigated weekly from the 3rd week of July onward. Traditional irrigation guidelines are as follows

- Starting date for irrigation: week of July 21st
- Irrigation frequency: weekly until the first week of September
- Volume of irrigation: 6 gallons per week = 75 mm (6 weeks of irrigation)

In 2014, the block 11 was under a Fruition "plant-based" irrigation experiment with 2 sap flow systems at 2 distinct smart point locations labeled: blank (North) and EXP (South). Initially, one of the 2 sections was going to be irrigated traditionally but this could no longer happen after August 10th.

To compare the Traditional vs. the Fruition treatments, we computed the volume of water used for irrigation as reported verbally by the vineyard manager in block 7B in 2014. From the hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (using a graduated bucket under the dripper to monitor its water filling rate with a timer). Table 1 summarizes the water amount applied in each treatment.


Block 7B
(Traditional)
X
North
X
South EXP
Block 11
(Fruition)

Figure 1: block 11 (Fruition treatment applied in both sections) and block 7B (traditional treatment)

Table 1: 2014 Irrigation comparison

Site name **PR-D**	1st Irrigation **	# of events	Volume from rain gauge (mm)	Volume verbally reported (mm)
Traditional (Block 7B)	7/21	6	n/a	51
Fruition (Block 11 –North)	8/10	2	29.4	29
Fruition- (Block 11- South-EXP)	8/10	2	27.9	28
Water savings (%) *			n/a	-45%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

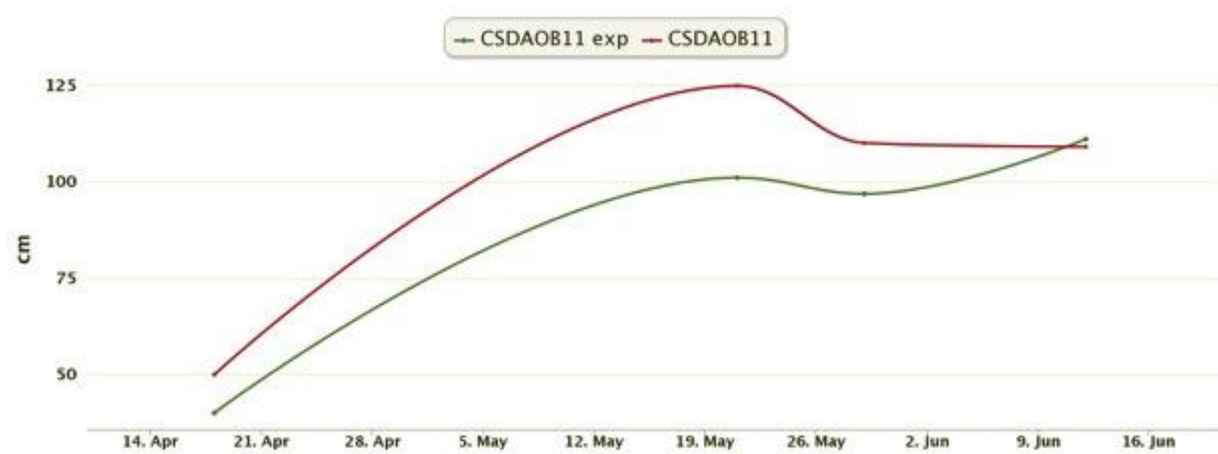

Figure 2: Shoot elongation rate in the Fruition treatment (from the 2 smart points in block 11)

Figure 2 shows the profile of shoot elongation with time at the 2 smart point locations in the fruition treatment. Rapid shoot elongation phase stops after hedging was performed on May 22nd . Main shoots are reaching a similar length (100-110 cm of shoot length on average). Leaf area regrowth is observed in the South-EXP smart point, suggesting a higher water supply and a lower level of water deficit compared to the North smart point.

b) Plant water use

1) Pressure bomb readings

Predawn water potential variations are reported in Figure 3

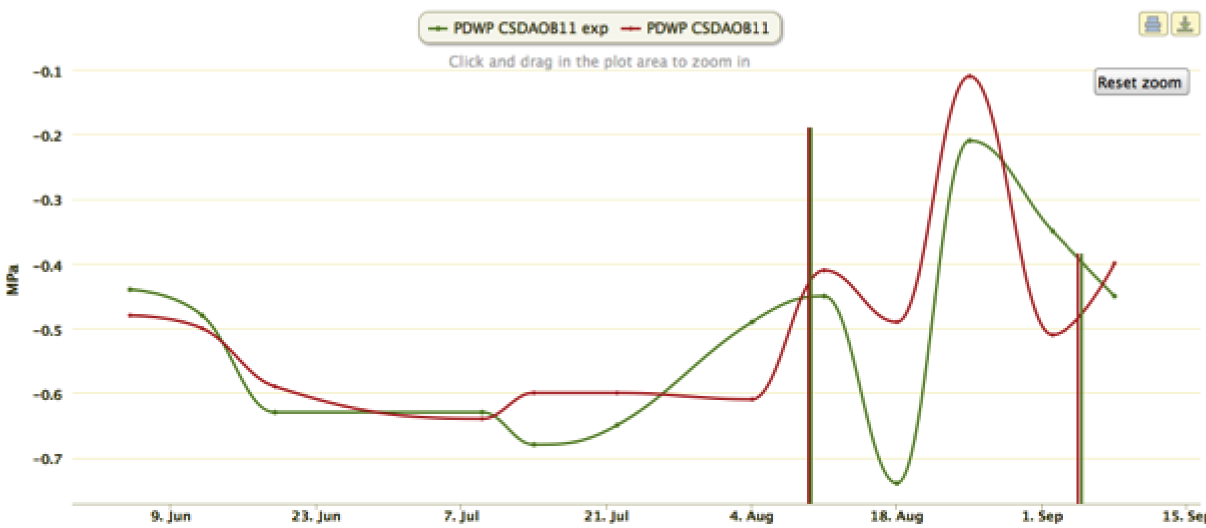

Figure 3: Predawn water potential profiles (Fruition treatment- block 11)

We observe no differences between the 2 profiles until July 9th as expected since the entire block is under the same irrigation regime. On August 4th, water deficit is more pronounced in the North smart point (-0.61 MPa) compared to the South smart point (-0.49 MPa). This difference reflects a more severe vine water deficit in the North smart point before irrigation. This result is in agreement with the lack of shoot regrowth after hedging season suggesting an earlier limitation of water supply (Figure 2).

After irrigation on August 10th, we observe a higher rise in predawn LWP value (+0.2 MPa) in the North smart point compared to the South smart point (+0.05 MPa) while a same water volume is applied. Thus, irrigation has a more pronounced effect at the North smart point. This is in agreement with what has been observed in other experimental sites. After application of a same water volume, the rise in Predawn LWP is more pronounced when water deficit is more severe before irrigation.

A larger rise (>+0.4 MPa) is measured on August 25th in absence of any irrigation at the 2 smart point locations. During the night of August 24th to 25th, nighttime temperatures reach their lowest seasonal values as seen in table 2 causing the predawn LWP value to rise. This illustrates the main limitation of the water potential measurement technique. Even if we minimize the effect of climatic demand variations on leaf water potential by performing measurement pre dawn, nighttime temperature variations are affecting nighttime transpiration significantly, which in turn affect the predawn LWP values. Figure 4 shows that seasonal variations in minimal temperature are spread over a 17 degrees Celsius span, which is the largest of all the sites under experiment. This climatic specificity is due to the topography of the vineyard located on top of a ridge. Following the second irrigation, we observe a rise in predawn LWP values (+0.1 MPa) in one smart point (North) but a decline (-0.1 MPa) in the other smart point. Thus based on predawn LWP profile variations, it is not possible to conclude whether the 2nd irrigation was effective.

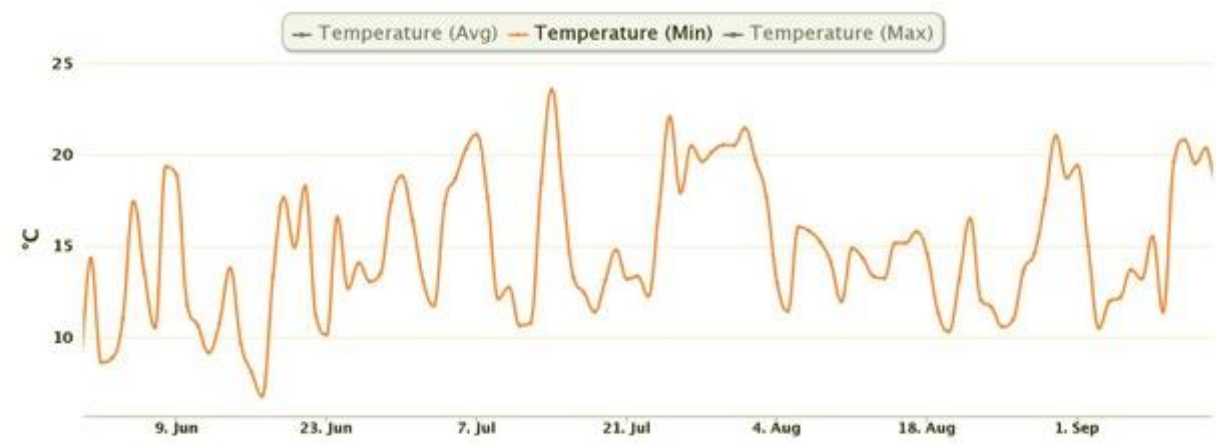

Figure 4: minimal temperature reached during nighttime.

Figure 4 shows a wide seasonal span (17Celsius) between lowest and highest minimal nighttime temperature. Table 2 reports the nighttime temperature when predawn LWP readings are performed.

Table 2: minimal nighttime temperature when predawn LWP readings are performed (from mid-veraison)

Date	July 22	Aug 4	Aug 11	Aug 18	Aug 25	Sept 2	Sept 8
Temperature(C)	13.3	13.0	14.9	15	10.5	15	15.6

Table 2 shows that the rise in predawn LWP values observed on August 25th corresponds to the lowest nighttime temperature. This suggests that predawn LWP is not only influenced by the water status of the plant but is also affected by nighttime temperature.

2) Sap flow analysis

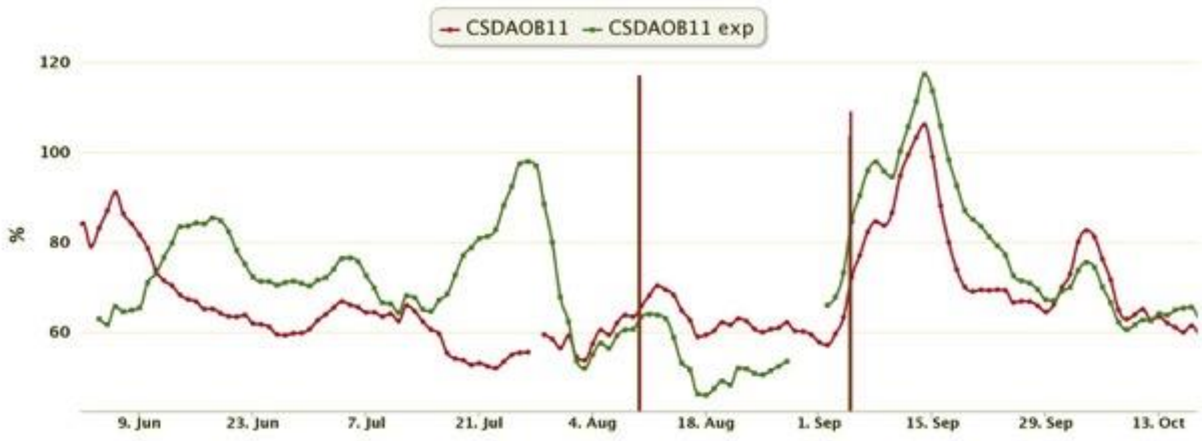

Figure 5: Water deficit index profile (Fruition treatment – block 11)

Throughout the season comparison of the 2 profiles shown in figure 5 reflects a moderate level of water deficit (WDI> 50%) at both smart point locations. Water deficit before veraison is more pronounced at the location of the North smart point.

In the North smart point: WDI steadily decreases to 52% and is maintained above 60% after irrigation. Earlier water deficit is in agreement with the lack of leaf area regrowth observed after hedging.

In the South-exp smart point: a rise in WDI is observed over the period July 15th- July 28th , which confirms the trend seen in predawn LWP. It is unclear what caused the rise in vine water use but it is not irrigation. Consequently the level of water deficit pre-veraison is less limited, which should affect maturation profile.

The first irrigation did not have a strong effect on WDI. However the second irrigation applied before a heat wave (Sept 9th –Sept 17th) induced a larger WDI rise in response to the rise in climatic demand at both locations. Figure 6 shows the Vapor pressure deficit variations characterizing the heat wave over that period.

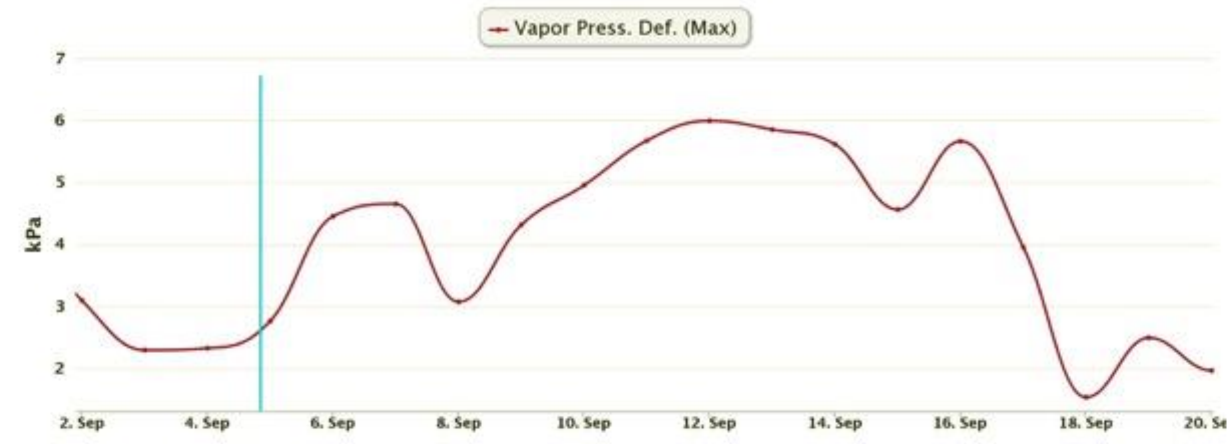

Figure 6: Vapor pressure deficit variations showing the heat wave after the second irrigation

3) Fruit response monitoring

a) Pulp composition

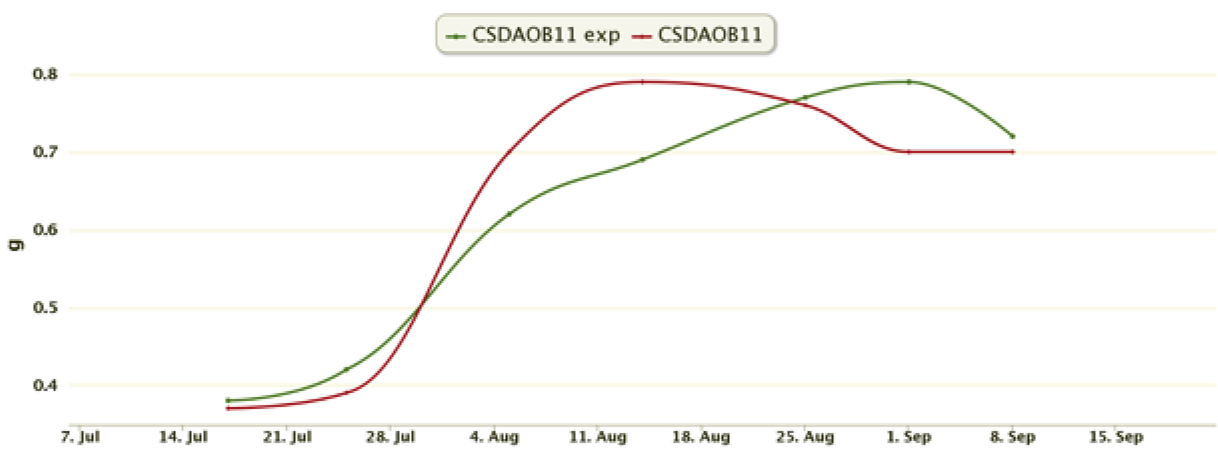

Figure 7 : Berry Weight (Fruition treatment- block 11)

In the North smart point: berry weight increases earlier and reaches a peak earlier. At the south –Exp smart point, berry weight growth rate is slower. At both locations a similar berry weight is reached before harvest (Figure 7). Sugar concentration increases at a similar rate in both treatments (Figure 8).

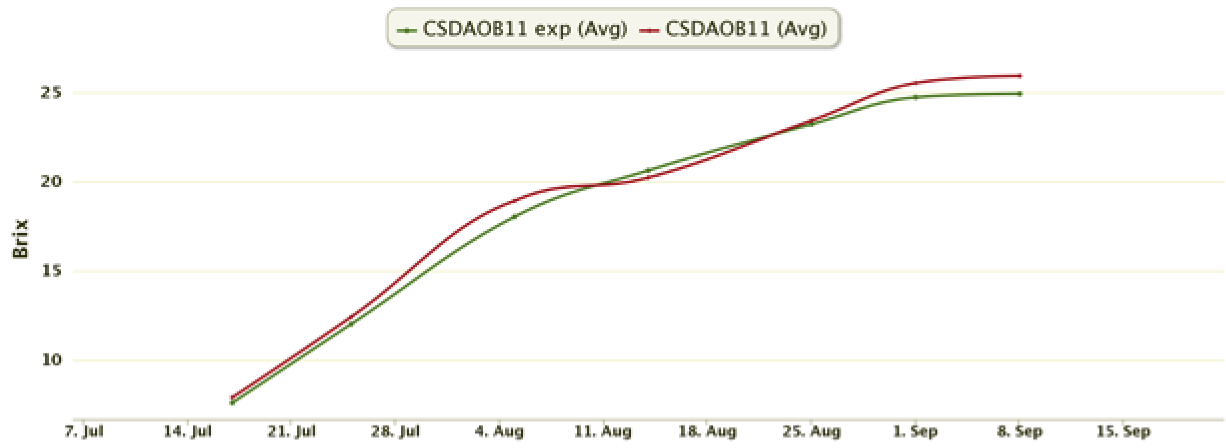

Figure 8: Sugar concentration (Fruition treatment)

Active sugar accumulation is expressed in mg of sugar per berry in Figure 9. By tracking the amount of sugar per berry, we can distinguish if rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss. We observe that the amount of sugar per berry remains steady once amount of sugar per berry reaches a peak. Maximal sugar amount per berry is reached earlier in the north smart point, which is in agreement with the more pronounced level of water deficit experienced pre-veraison. This result is also in agreement with the literature (water deficit preveraison hastens the onset of sugar accumulation).

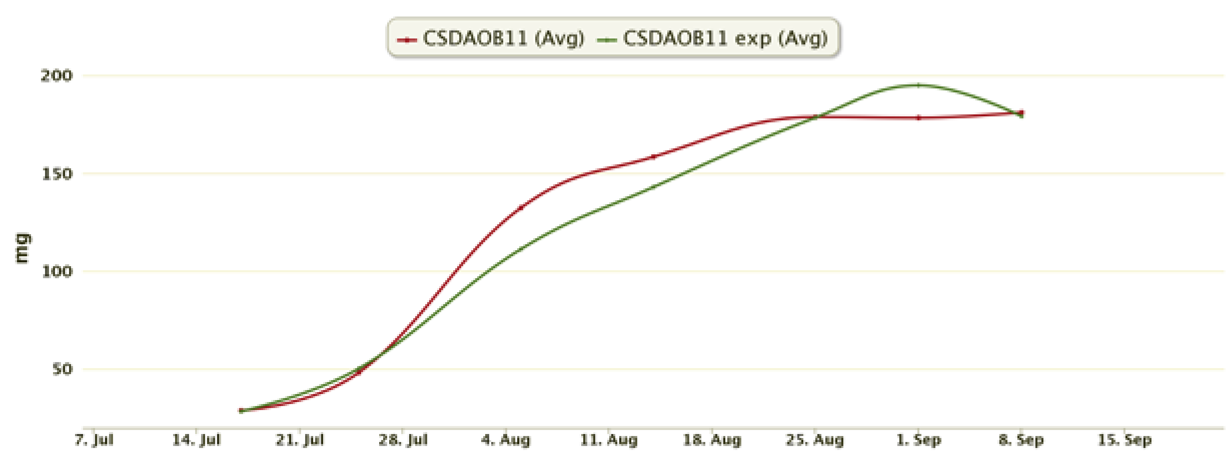

Figure 9: Sugar per berry (Fruition treatment)

Conclusion:

In the north smart point, peak berry weight is reached earlier and active sugar accumulation stops earlier. Those 2 indexes reflect an earlier maturation profile in north smart point, as expected considering the lower WDI pre-veraison.

b) Skin composition

The analysis of polyphenols shows a higher tannin concentration, total phenolics and total anthocyanins at the North smart point treatment. As seen in other vineyards, fruit maturation profile reflects an earlier maturation at the North smart point location experiencing a more pronounced water deficit pre-veraison. Time variations for the polyphenolic profiles are displayed in figure 10-11-12. The effect of lower WDI values pre veraison at increasing polyphenols is in agreement with the literature and our observations at other sites locations.

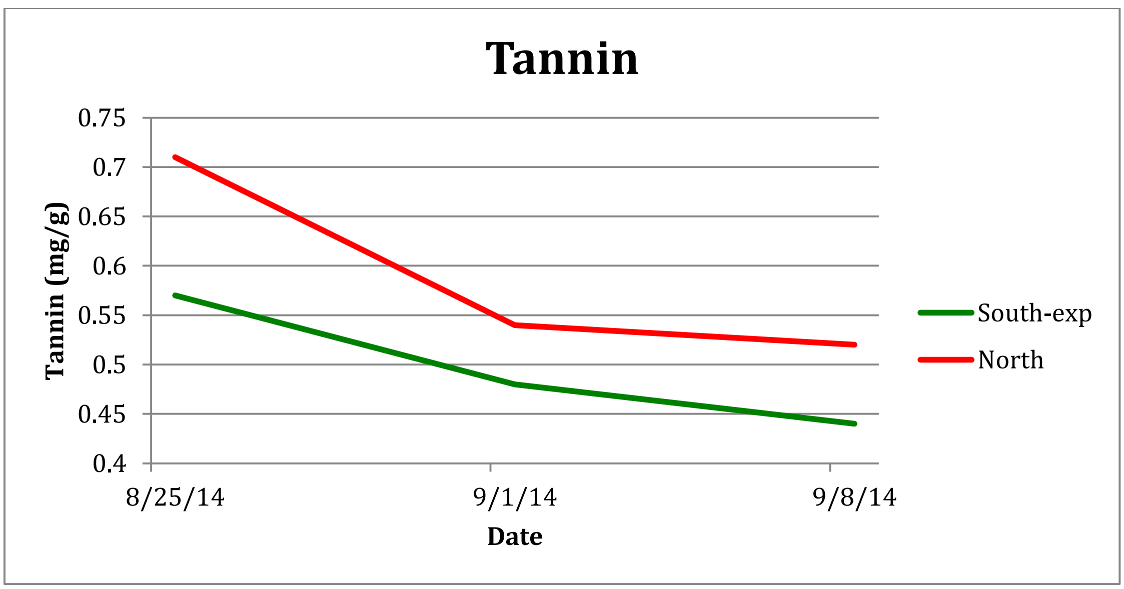

Figure 10: Tannin (fruition treatment block 11)

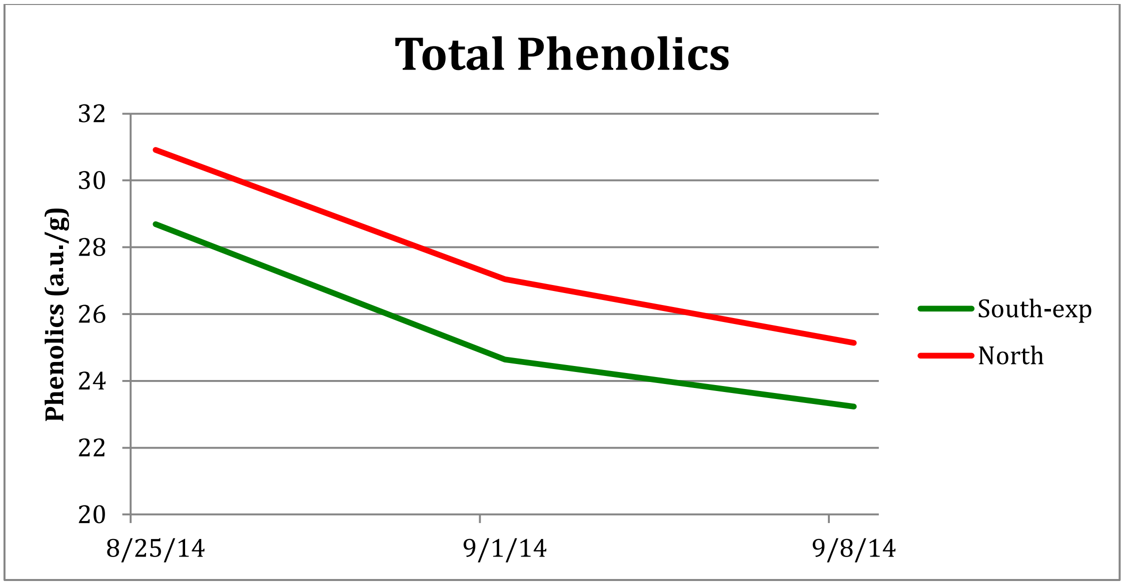

Figure 11: Total Phenolics (fruition treatment block 11)

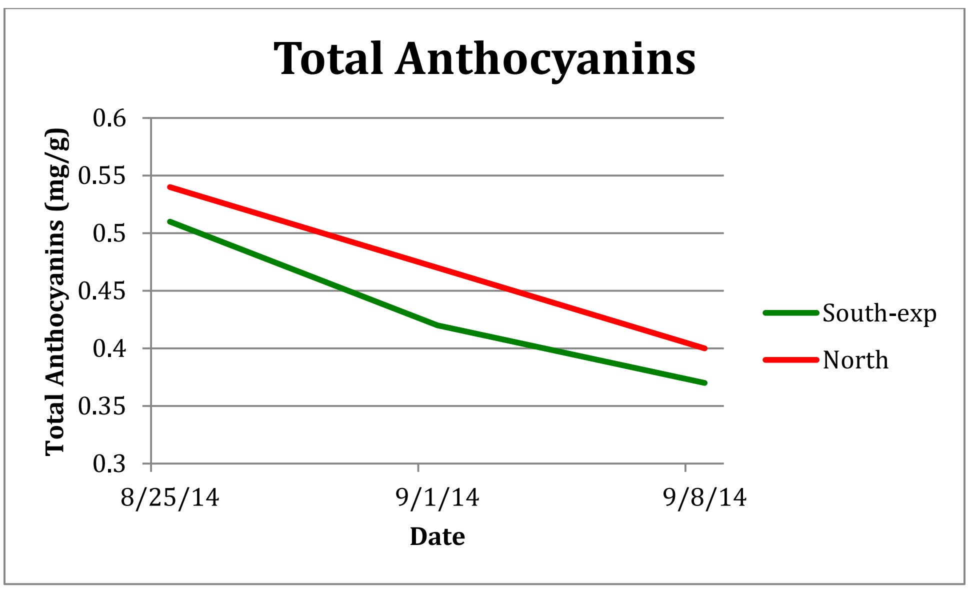

Figure 12: Total Anthocyanins (fruition treatment block 11)

4) Vineyard yield

The Fruition treatment (block 11) and block 7B were harvested on Sept.8th.

Table 2 shows the yield estimate from each treatment in 2014. We observe a lower yield in the Fruition treatment compared to the Traditional treatment. Since the number of clusters per vine (22.8 - average estimated based on 60 vines) is the same for the 2 blocks, we hypothesize that the 2.6% decline in yield is mainly due to a reduction in berry weight. Winemakers often consider that a berry size reduction is desired since it is associated with an increase ratio of berry skin/juice, which in turn increases wine concentration.

Table 2: Yield Estimate in 2014

Site Name **PR-D**	T/acre	per individual vine (kilograms/vine)
Traditional (whole block 7b)	4.67	2.09
Fruition (whole block 11)	4.55	2.03
Yield variations	-2.6%	

5) Winemaker feedback,

On September 8th :

"In 2014, we observe a yield reduction compared to 2013. However, the yield reduction does not seem to be a consequence of the lower irrigation regime. In fact it is rather a consequence of the vintage. Yield reduction is also observed in traditional irrigation regime. Additionally the sections within block 11 where WDI was lower pre veraison shows more polyphenols" …"In the fruition block 11 we have observed a rise of 30% to 40% in phenolics in 2014 compared to 2013" *(which means an improvement in fruit composition and wine quality).*

On October 31st

"In 2013, the maximum amount of anthocyanin block 11 achieved was 780 while in 2014 the highest we achieved was 1,192 resulting in a 52% increase! The ROI increases because this wine makes it into our $100 dollar bottle while before it made it into our $56 bottle. Compared to the wines in 2013, the wine in block 11 is clearly superior. It is more beefy, darker, more intense".

SITE PR-HR

Introduction

This is a preliminary report before performing a cross-vineyard analysis. Over 6 different vineyards (Sonoma, Napa, Paso Robles) the same split treatment experiment has been conducted and similar data have been collected. Information on block properties, phenology and other historical practices have been compiled in the main report.

This site-specific report summarizes results obtained only in the context of the experiment in your vineyard. We welcome your comments and corrections. The goal is to have your approval before analyzing data from the 6 different vineyards. General conclusions will be discussed in the main report.

Thank you for your collaboration and help during that phase.

The vineyard block under treatment is located on a steep slope (Figure 1). The experimental block is divided into 2 areas: the upper part (more subjected to water deficit, less productive) and the lower part (less subjected to water deficit, more productive).

Figure 1: picture showing the downgrading slope of the upper section of the vineyard

1) Water input comparison

Table 1 reports the amount of water applied in each irrigation treatment. To compare irrigation strategies, we reported volumes:

- Automatically from the irrigation gauge. (Water volume was directly measured at the vine level)
- Verbally per the vineyard manager. From the amount of hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (bucket under the dripper to monitor the water filling rate)

Table 1: 2014 Irrigation comparison

Site name **PR-H Ranch**	1st Irrigation **	# of events	volume from rain gauge (mm)	volume verbally reported (mm)
Traditional	6/4/14	5	57.33	63.24
Fruition	8/19/14	2	26.77	28.41
Water savings *(%)			-53%	-55%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

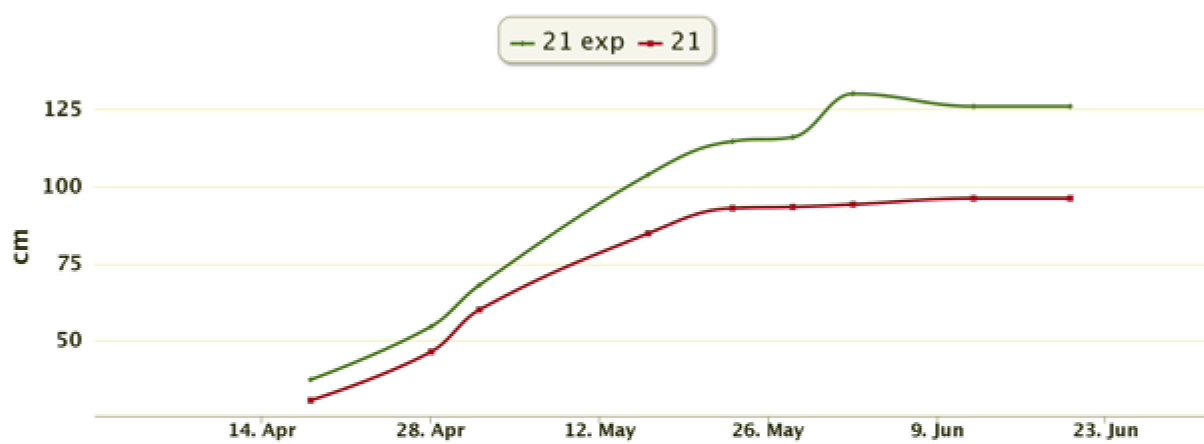

Figure 3: Shoot elongation rate comparison

Figure 1 shows the profile of shoot elongation with time. Rapid shoot elongation phase stops on May 22nd in the traditional treatment; June 2nd in the fruition treatment. Main shoot final length is 96 cm on average in the traditional treatment and 126 cm in the Fruition treatment.

B) Plant water use

1) Pressure bomb readings

Predawn water potential variations are reported in Figure 4.

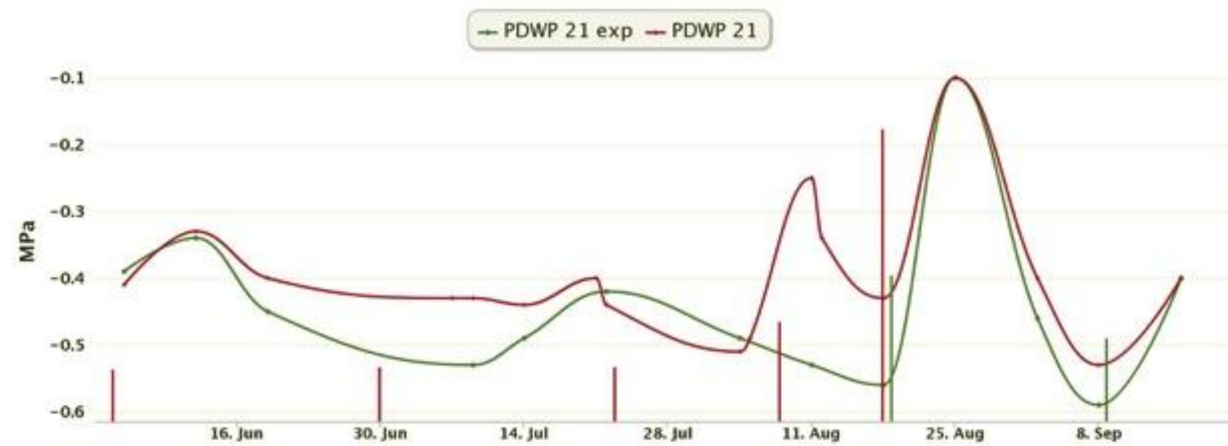

Figure 4: Predawn leaf water potential comparison

Throughout the season, values are comprised between -0.3 MPa and -0.6 MPa thus, the level of water deficit is moderate for both treatments.

2) Sap flow analysis

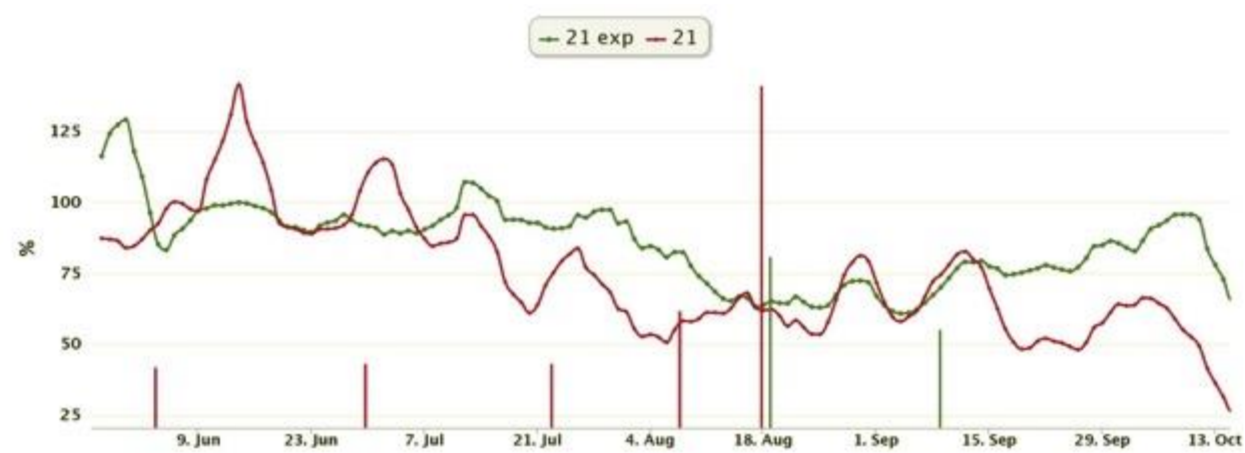

Figure 5: WDI from sap flow

Throughout the season the 2 profiles comparison in figure 5 reflects:

- A low to moderate level of water deficit (WDI> 50%)
- A lower level of water deficit in the fruition treatment, despites a lower amount of water applied.

<u>In the traditional treatment</u>: WDI is above 50% until October 10th. WDI values are dropping faster as the season unfolds, even if a greater amount of water has been applied.

<u>In the fruition treatment</u>, WDI is above 60% over the whole season. The fruition treatment imposed a lower level of water deficit from July 7th onwards.

This suggests that the application of more water earlier in the traditional treatment hastened the onset of water deficit later during the season (as seen in other vineyards). According to the literature, a lack of water deficit early season can be associated with poorer vine water use regulation later on. Early season water deficit has been proven to modify plant vascular system, root hormones synthesis (ABA) and root architecture in a way that improves vine water use efficiency. The gradual and seasonal decline of WDI observed in the Traditional treatment is in agreement with this hypothesis.

Figure 6 displays the vapor pressure variations over August 25th- October 15th. It is interesting to notice that vine water supply is not limiting vine water use during heat wave, particularly late season. In the traditional treatment, while no irrigation is applied, a rise in WDI is observed in response to the heat wave recorded on August 30th, September 12th and October 6th. Similarly WDI increases in the Fruition treatment over that same period. According to literature, such response is consistent with vine experiencing a low to moderate level of water deficit along the season

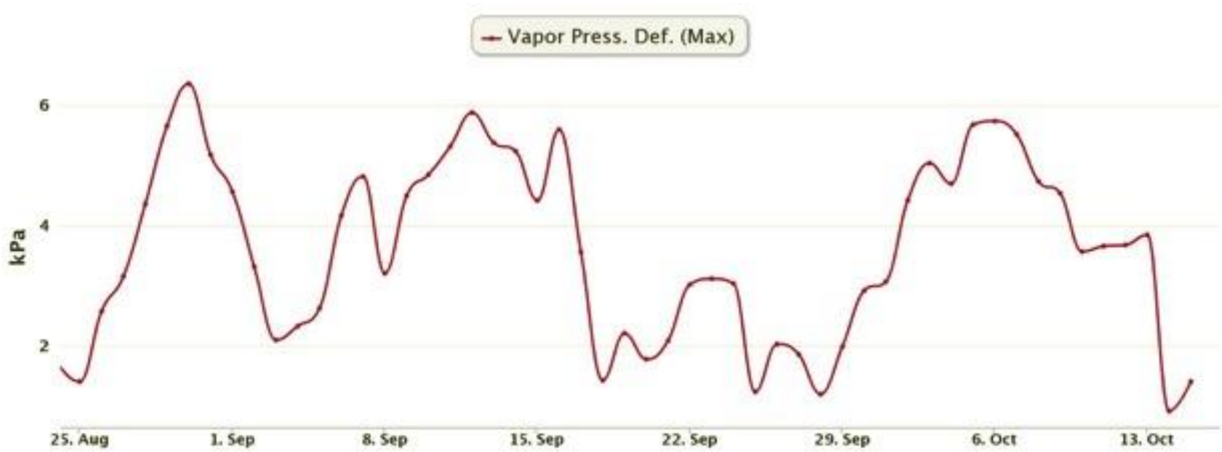

Figure 6: Vapor pressure deficit variations showing 3 peaks of heat waves late season (VPD>4 kPa)

C) **Fruit response monitoring**

1) Pulp composition

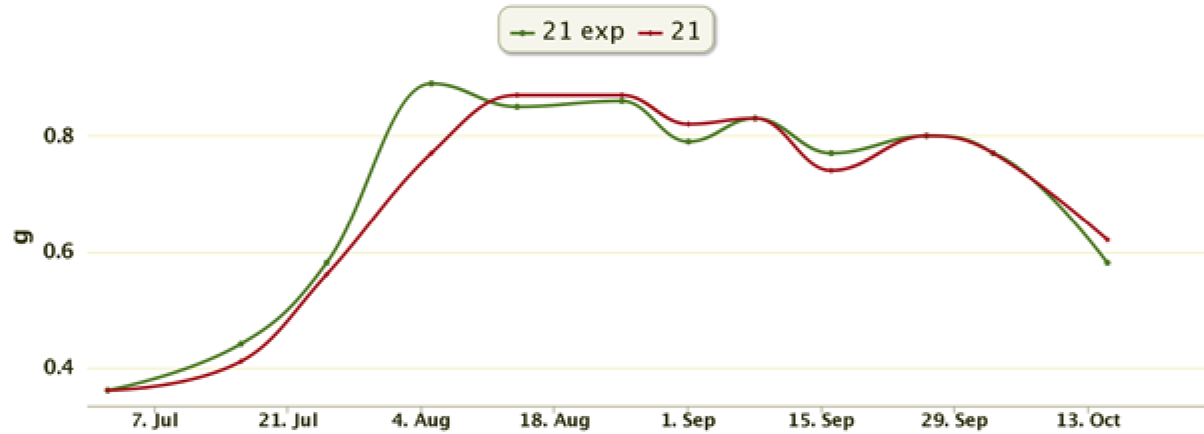

Figure 7: Berry weight comparison

Berry growth curve is similar for both treatments. After reaching a peak between August 5th and august 14th, berry weight declines despite water deficit level being absent or moderate (WDI >50%). We observe that the period during which berry weight declines reflect the footprint of high VPD events (August 30th, September 12th, October 6th).

This suggests that berry weight decline is not related to a lack of water supply but is more likely to be a response to heat wave. This suggests that applying irrigation in order to minimize yield loss under heat spell is not an efficient response. Based on those results, it would be more adapted to mitigate berry weight loss under heat spell by minimizing the high values during the VPD peak (misting, shade cloth,..)

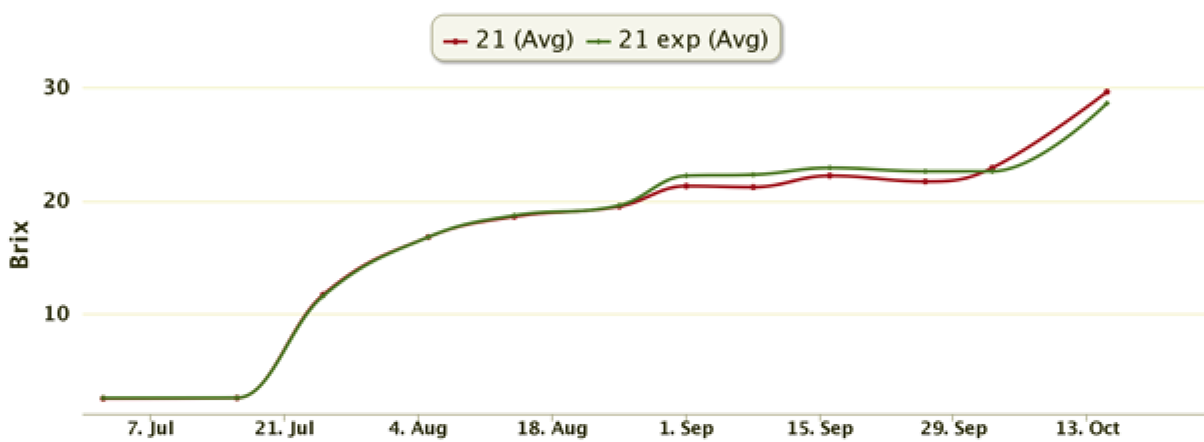

Figure 8: Pulp analysis: Brix comparison

Sugar concentration stops increasing between August 14th and August 25th in both treatment.

Following October 6th heat wave, we observe a rapid increase in sugar concentration (Brix rise more than > 6 degrees)

Active sugar accumulation is expressed in mg of sugar per berry in Figure 9. By tracking the amount of sugar per berry, we can distinguish whether rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss. We observe that the amount of sugar per berry remains steady once the amount of sugar per berry reaches a peak.

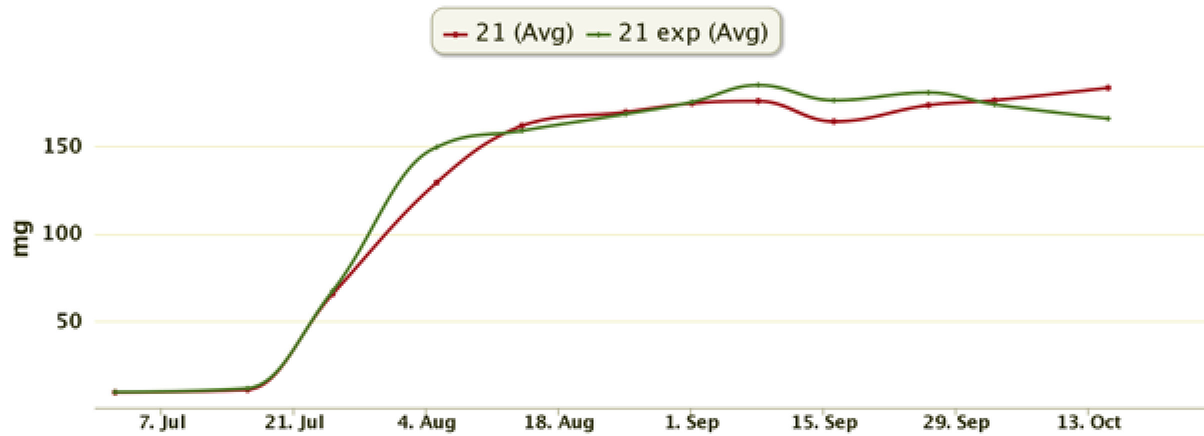

Figure 9: Sugar per berry comparison

Active sugar loading is observed at a fast and steady rate from July 16th until August 14th. Active Sugar accumulation happens at a slower rate after august 14th and stops on September 8th. On September 8th sugar concentration is higher in the fruition treatment (22.3 Brix vs 21.2 Brix).

2) Skin composition

Time variations of polyphenolics, anthocyanins and tannin concentration are reported in figures 10; 11; 12.

Tannins, total anthocyanins, total phenolics are the lowest compared to other sites. This further suggests an abnormal maturation profile.

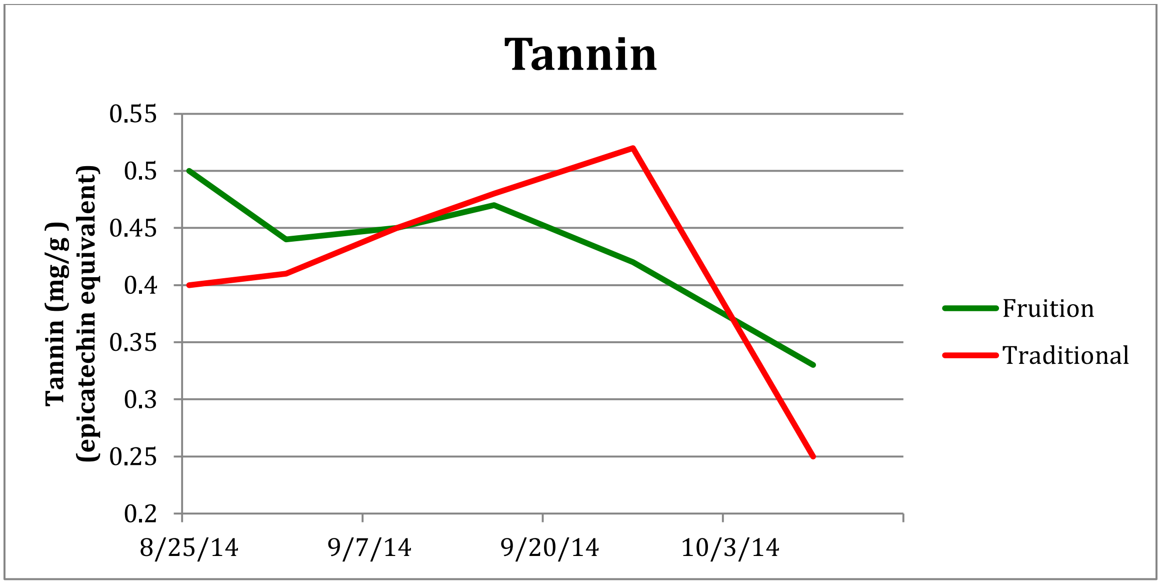

Figure 10: Tannin

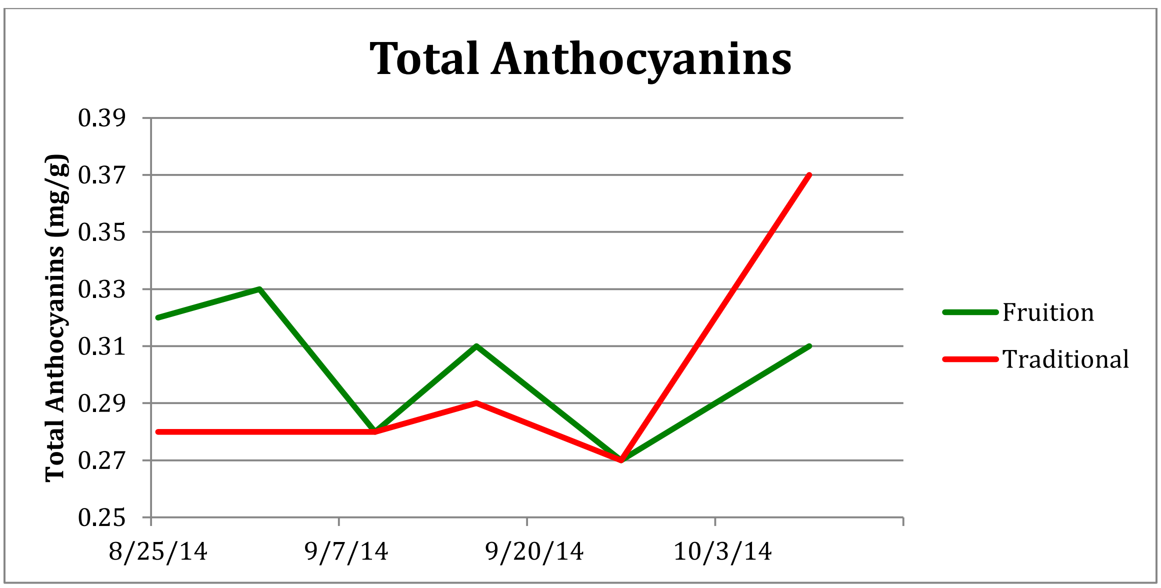

Figure 11: Total anthocyanin

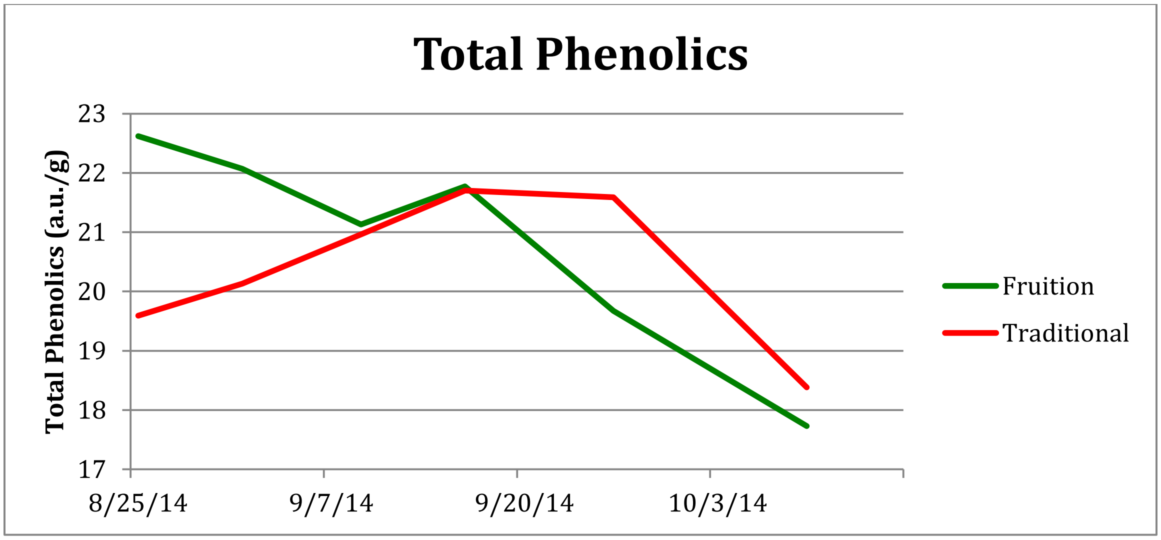

Figure 12: Total anthocyanin

3) Vineyard yield

Table 2: Yield Estimate in 2014

PR-H ranch	yield (tons per acre)
TOTAL TRADITIONAL	**2.12**
TOTAL FRUITION	**2.08**
Yield Variations (Fruition- Traditional)/ Traditional	**-1.8%**

We observe that despite reduced irrigation in the fruition treatment, yield is virtually not affected (-1.8% of variation).

Winemaker feedback on Yield

"**Yields** were relatively similar; the small difference in yield is negligible from a production standpoint. "

Winemaker feedback on fruit quality:

"We found that Fruition block is higher in color than the standard block (80 parts per million higher in color; an 8% increase). Color is the most important aspect of phenolic analysis as the color is where flavor and concentration come from in winemaking. When tasting the blocks individually we gave a slight edge to the Fruition block, however the wines had already begun malolactic fermentation which can make sensory tough. Upon completion of malolactic fermentation we will repeat the sensory tasting."

Site NP-K

Introduction

This is a preliminary report before performing a cross-vineyard analysis. Over 6 different vineyards (Sonoma, Napa, Paso Robles) the same split treatment experiment has been conducted and similar data have been collected. Information on block properties, phenology and other historical practices have been compiled in the main report.

This site-specific report summarizes results obtained only in the context of the experiment in your vineyard. We welcome your comments and corrections. The goal is to have your approval before analyzing data from the 6 different vineyards. General conclusions will be discussed in the main report.

Thank you for your collaboration and help during that phase.

1) Water input comparison

Table 1 reports the amount of water applied in each irrigation treatment. To compare irrigation strategies, we reported volumes:

- Automatically from the irrigation gauge. (Water volume was directly measured at the vine level)
- Verbally per the vineyard manager. From the amount of hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (bucket under the dripper to monitor the water filling rate)

Table 1: 2014 Irrigation volume comparison

Site name **NP-K**	1st Irrigation **	# of events	rain gauge activity (hours)-	volume from rain gauge (mm)	volume verbally reported (mm)
Traditional	7/9/14	8	22 hours 10 mins	27	25.12
Fruition		0	0 hours	0	0
Water savings* (%)				100%	100%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

Figure 1 shows the profile of shoot elongation with time. Rapid shoot elongation phase stops around June 6th. Main shoot length is comprised between 87 and 95 cm on average. Average shoot length is slightly reduced in the experimental treatment (7.0 cm shorter) but difference are not significant (data not shown).

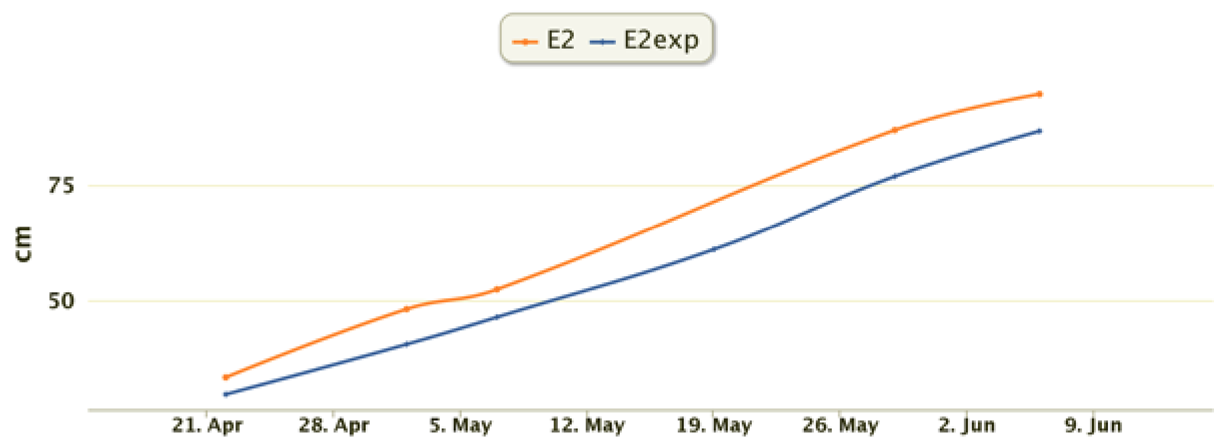

Figure 1: Shoot elongation rate at both smart point locations

B) Plant water use

1) Pressure bomb readings

Predawn water potential variations are reported in Figure 2.

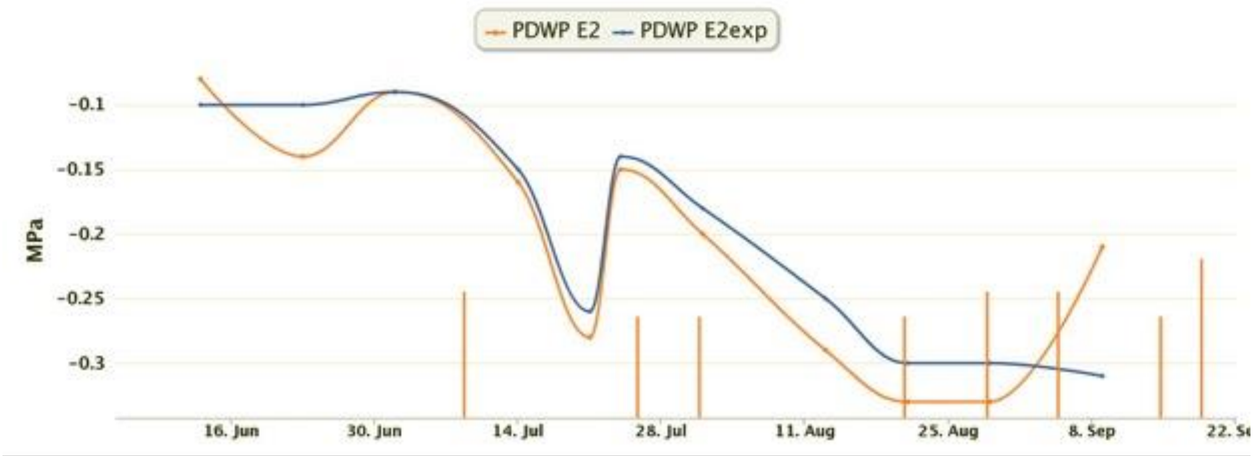

Figure 2: Predawn water potential profiles at both smart point locations

The 2 seasonal profiles reflect an absence of water deficit (predawn LWP values >-0.33 MPa). After August 1st, the traditional treatment reaches more negative values, but differences between the 2 treatments are not significant (data not shown).

Because water deficit is absent when water is applied, irrigations effect is not detected. Thus we do not observe any rise after water application except on September 9th (+0.1 MPa). In fact, it looks like the more water is applied the faster is the decline in predawn LWP. Over the period July 28th -August 25th, predawn LWP is on average lower by 0.05 MPa in the traditional treatment . This is consistent with the hypothesis according to which more frequent irrigations prevent the vine from displaying an optimal stomata conductance regulation (less drought hormones, etc…).

To explain September 9th discrepancy, we observe that compared to other predawn LWP measurement days, September 8th and 9th are characterized by a low climatic demand (cloudy days with VPD = 1.9kPa). We hypothesize that the combination of 2 recent irrigations (August 29th and September 5th) **and** the lower climatic demand lead to higher predawn LWP values in the traditional treatment. This response after irrigation was not observed earlier during the season because climatic demand was higher at the time of the predawn LWP reading. *(in other words the relative effect of the top soil being wet at increasing predawn LWP reflects is stronger when the climatic demand is lower. This is in agreement with scientific literature).*

2) Sap flow analysis

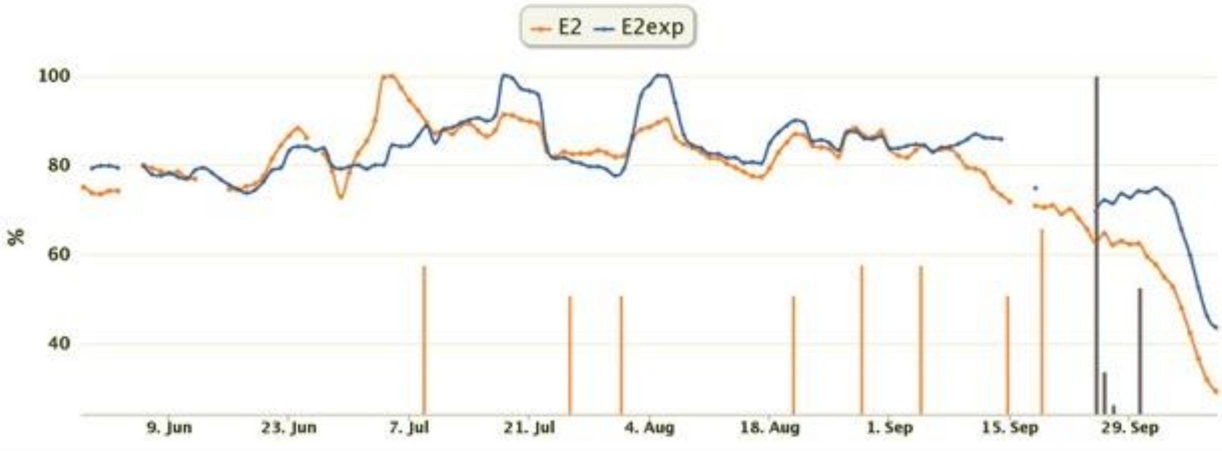

Figure 3: WDI from sap flow

Over the season the 2 profiles reflect an absence of water deficit.

In the **traditional treatment** we observe almost no rise in WDI following irrigation. Over the season, a larger amount of water is applied in the traditional treatment, however seasonal WDI profile is lower from July 8th onward. This may seem counter intuitive but in fact this is not in contradiction with the literature and is in agreement with the trend seen in predawn LWP. Various authors have reported the following vine responses under higher water supply: water use efficiency gets lower, root water absorption sites are more superficial, drought resistance hormone (like ABA) concentration is lower, diameter of vascular tissue is larger, berry sizing is larger (potentially increasing vine water needs towards the end of the season, etc…).

In the traditional treatment we observe a faster WDI collapse from September 8th onwards. WDI values are under 50% from October 4th onwards which means that the vine is experiencing some severe water deficit despite getting more water. This could have some negative effect on berry weight (fruit is harvested on October 8th).

In the **fruition treatment**, WDI starts to collapse from October 4th onwards. On harvest day, WDI is above 50% and we can hypothesize that vine water deficit is relatively moderate.

For both treatments, differences seen in the rate of WDI collapse towards the end of the season can be explained by the following that:

a) Less water is available in the root reservoir

b) Stomata conductance regulation is poorer in the traditional treatment as a result of more frequent irrigations

c) Heat waves increase vine water use thus precipitating the collapse of WDI (figure 4). We observe that the fruition treatment is more resilient to the first heat wave (September 10th- September 13th) and starts to collapse during the second heat wave (October 1st- October 6th). WDI in the traditional treatment starts to collapse during the first heat wave.

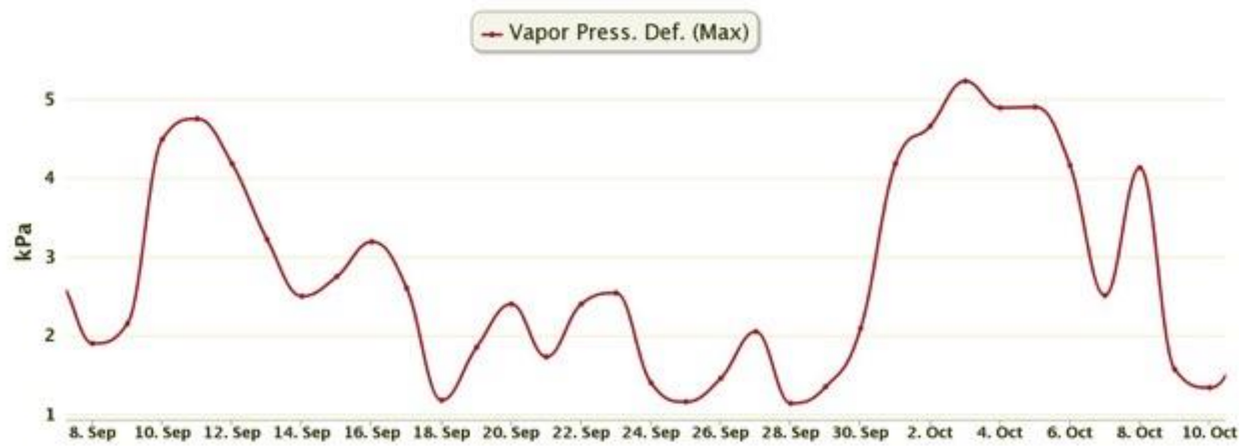

Figure 4: Late season heat wave from Vapor pressure deficit variations

Figure 4 shows the 2 Heat wave periods recorded (VPD >4kPa). Those periods precipitated the collapse of WDI.

C) Fruit response monitoring

1) Pulp composition

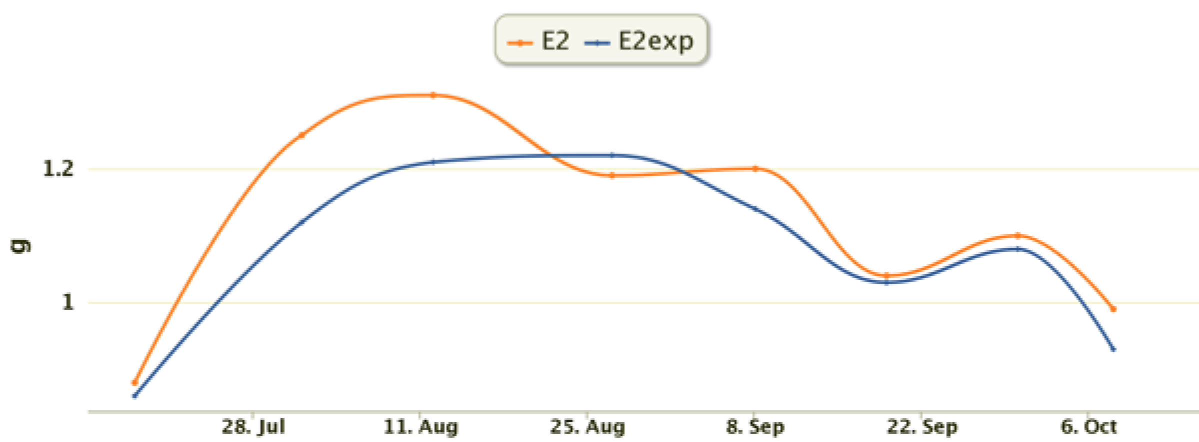

Figure 5: Berry Weight comparison

Variations of berry weight with time are reported on Figure 5. A lower peak berry weight is reached in the Fruition treatment. A decline in berry weight is observed in both treatments. Berry weight decline is sharper in the traditional treatment particularly after the first heat wave (September 10th-

September 13th). On September 19th we observe a 21% drop in berry weight in the traditional treatment and a 16% drop in berry weight in the fruition treatment. The percentage of berry weight loss over the season for each treatment is summarized in table 2

Table 2: comparison of berry weight decline

Treatment	Peak berry weight (g)	Harvest berry weight (g)	Berry weight decline
Traditional	1.31	0.99	-24%
Fruition	1.22	0.93	-24%

Berry weight decline affects equally the 2 treatments despite contrasted WDI values from September 26th onward (figure 3). Over that period, WDI is higher in the fruition treatment. This indicates that the vine was not experiencing any water deficit when berry weight loss occurred. However adverse climatic conditions can lead to berry volume loss regardless of vine water status. This result suggests that applying irrigation to minimize berry weight loss caused by **late season** heat wave is probably not adapted. Berry weight loss is observed even in absence of plant water deficit. Thus during the later season stages, it is probably more efficient to minimize yield loss under a heat spell by modifying vine micro climate (shade cloth, misting, etc..).

Sugar concentration increases at a similar rate in both treatments. It is slightly higher in the fruition treatment (figure 5).

An unusually sharp rise in sugar concentration is observed during the period September 30th-October 8th. (ie. Second heat wave as per figure 4)

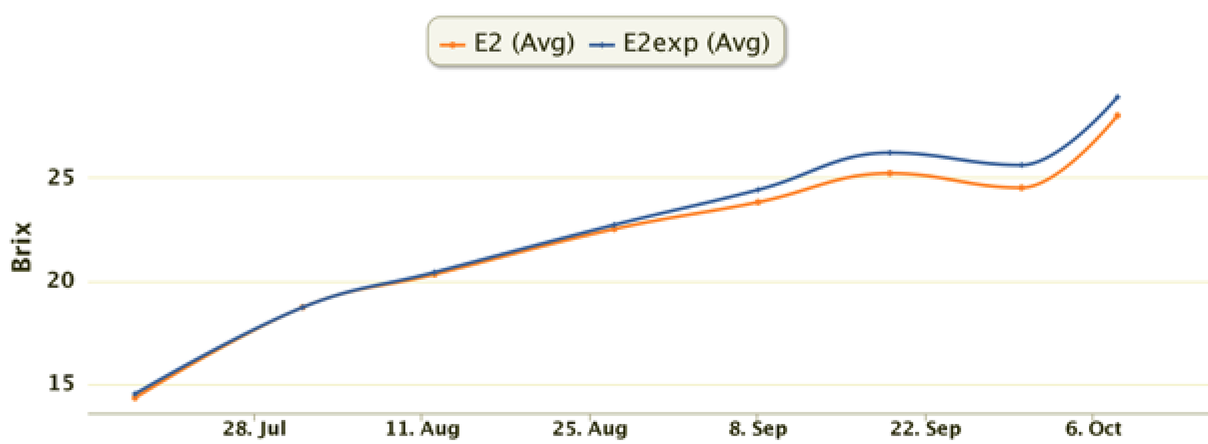

Figure 6: Sugar concentration variations

Active sugar accumulation is expressed in mg of sugar per berry in Figure 7. By tracking the amount of sugar per berry, we can distinguish if rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss.

We observe that the amount of sugar per berry remains steady from August 12th onward in the traditional treatment and from August 27th onwards in the Fruition treatment. We do not observe any rise in the amount of sugar per berry during the period September 30th-October 8th. This confirms that the faster rise in sugar concentration over that period is due **to berry dehydration** resulting from the heat wave.

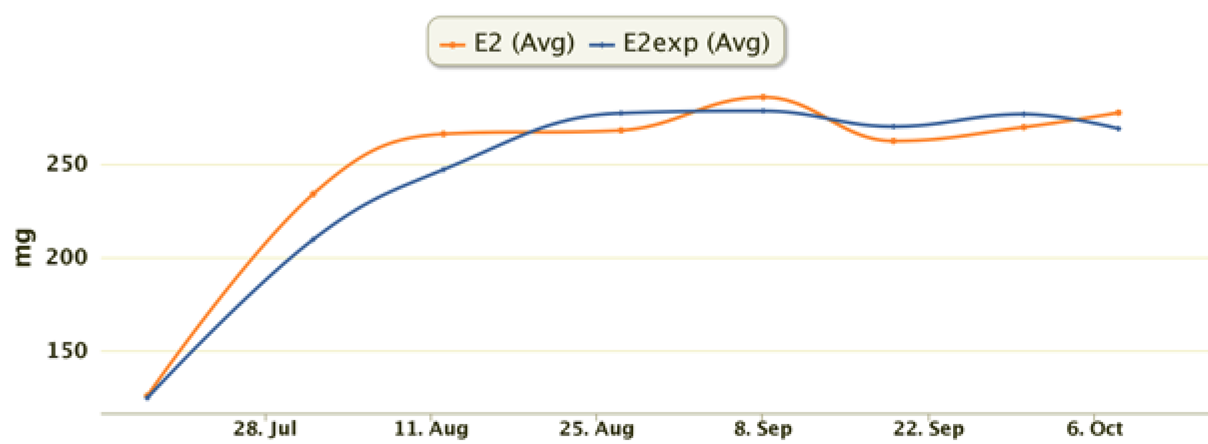

Figure 7: Sugar per berry comparison

2) Skin composition

The analysis of polyphenols shows a higher concentration in the fruition treatment for each sampling date. This is in agreement with winemaker observations reported below. Time variations for the polyphenolic profiles are displayed in figure 8-9-10.

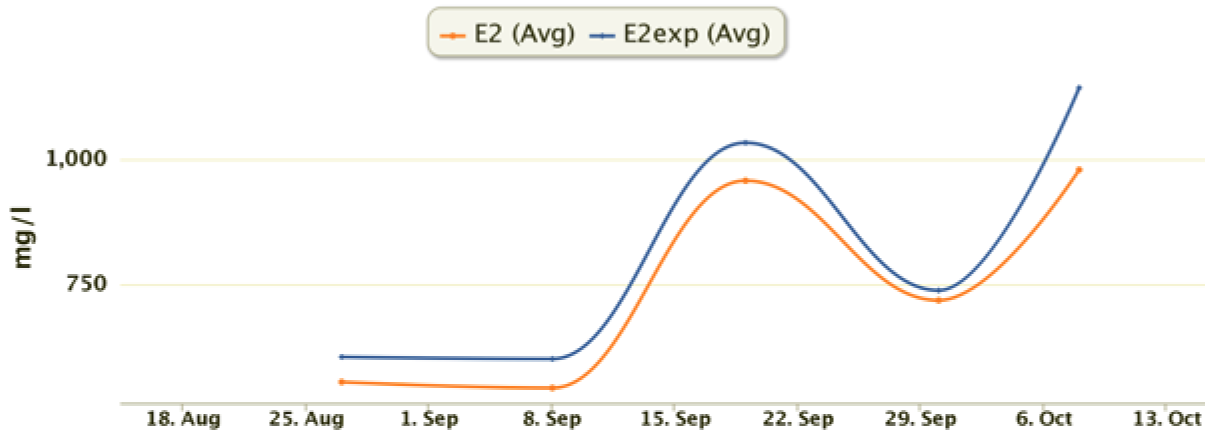

Figure 8: Tannin comparison

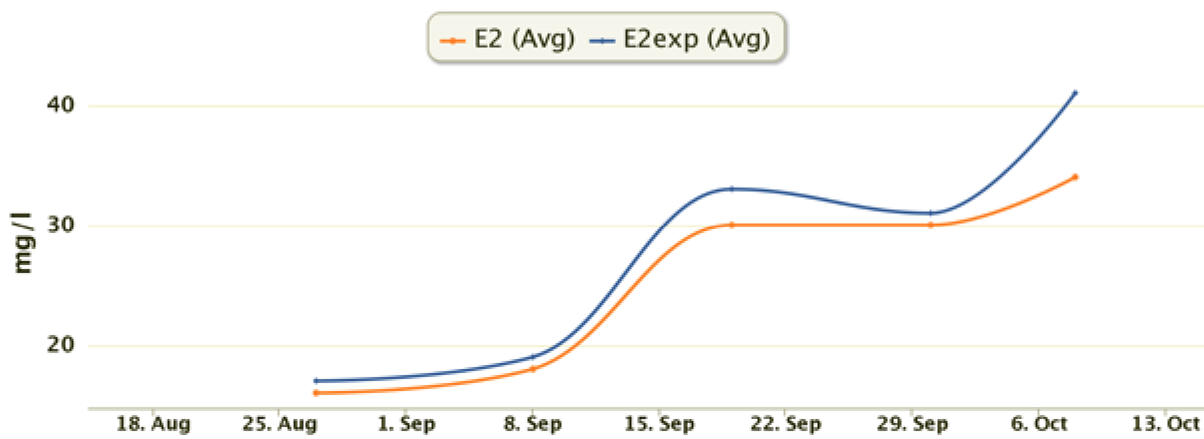

Figure 9: Polymeric Anthocyanins comparison

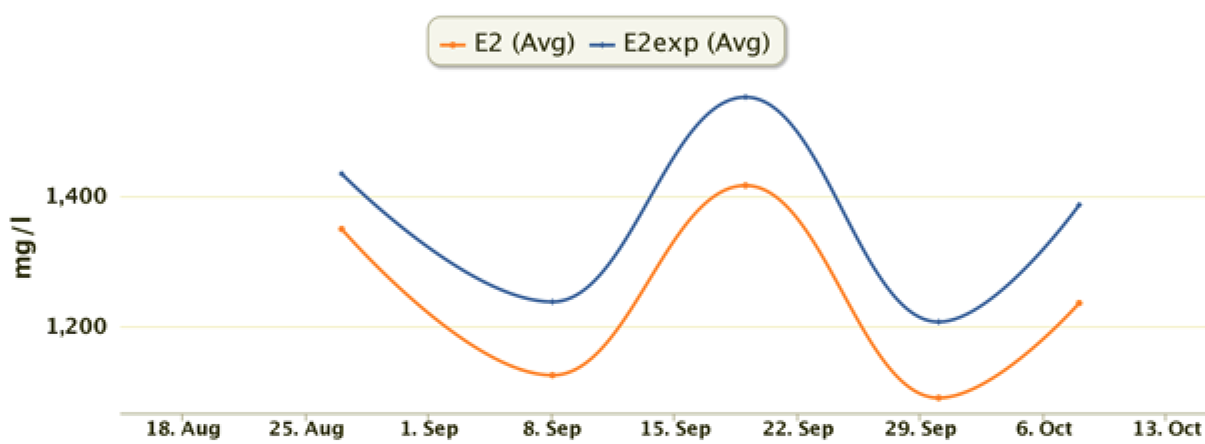

Figure 10: Total Anthocyanins comparison

3) Vineyard yield

Table 3: Yield Estimate in 2014

Site Name NP-K	Tons per acre	per individual vine (kg/vine)
Traditional	2.86	3.94
Fruition	2.91	4.01
Yield variations		+1.7%

The higher yield from the fruition treatment can be interpreted as resulting from a higher resistance to berry weight loss on a larger vineyard scale (even if it does not appear from the smart point data as discussed in table 2). One can hypothesize that in the fruition treatment berry skin may have been thicker (as suggested from the higher polyphenol concentration in the skin). Other physiological mechanisms related to increased drought resistance can be invoked. In particular authors have reported that under a lower irrigation regime berry size reduction will be observed (thus proportionally less volume reduction during heat spell). Other reports have indicated that a higher concentration of drought resistance hormones will be measured in the less irrigated treatment. Lower peak berry weight in the fruition treatment is in agreement with these results.

Winemaker feedback on fruit quality:

"I feel like the tannins came around faster in the non-irrigated and perceived less greenness. Neither wines seem to have IBMP issues but early on I thought that it might be an issue. ".

Note: the perception that there may be an issue with IBMP early on is in agreement with the fact that no water deficit was detected in any treatment before the end of September.

SITE NP-M

Introduction

This is a preliminary report before performing a cross-vineyard analysis. Over 6 different vineyards (Sonoma, Napa, Paso Robles) the same split treatment experiment has been conducted and similar data have been collected. Information on block properties, phenology and other historical practices have been compiled in the main report.

This site-specific report summarizes results obtained only in the context of the experiment in your vineyard. We welcome your comments and corrections. The goal is to have your approval before analyzing data from the 6 different vineyards. General conclusions will be discussed in the main report.

Thank you for your collaboration and help during that phase.

In the following figures, Orange trajectories are for traditional treatment

1) Water input comparison

Table 1 reports the amount of water applied in each irrigation treatment. To compare irrigation strategies, we reported volumes:

- Automatically from the irrigation gauge. (Water volume was directly measured at the vine level)
- Verbally per the vineyard manager. From the amount of hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (bucket under the dripper to monitor the water filling rate)

Table 1: 2014 Irrigation volume comparison

Site name NP-M	1st Irrigation **	# of events	volume from rain gauge (mm)	volume verbally reported (mm)
Traditional	6/26	7	91.05	86.42
Fruition	7/23	3	49.75	40.13
Water savings *(%)			-45%	-53.5%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

Figure 1 shows the profile of shoot elongation with time. Rapid shoot elongation phase stops around June 6th. Main shoot final length is 130 cm on average. Shoot elongation rate is slightly reduced in the traditional treatment in May but differences are not significant (data not shown).

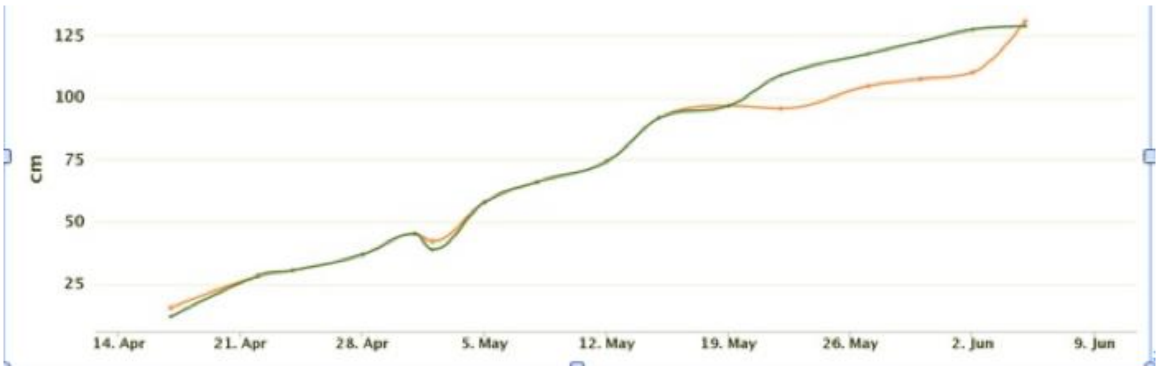

Figure 1: Shoot elongation rate comparison

b) Plant water use

1) Pressure bomb readings

Predawn water potential variations are reported in Figure 2.

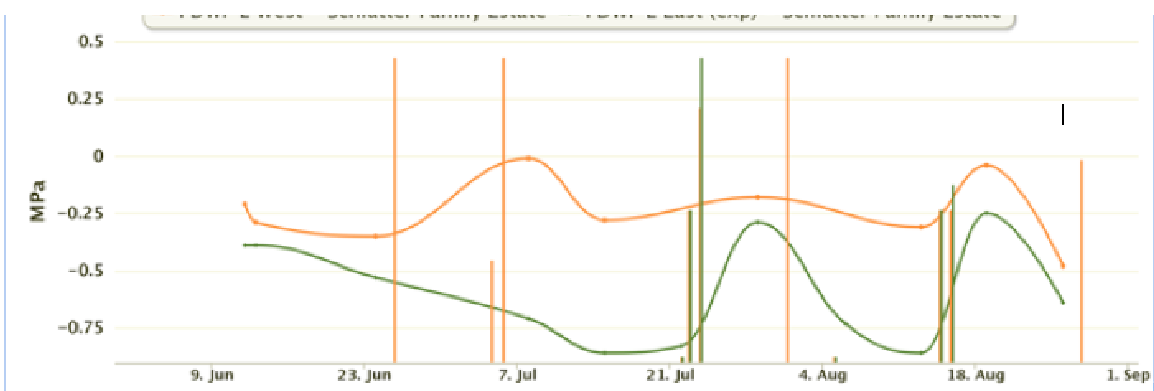

Figure 2: Predawn Leaf Water potential comparison

Throughout the season, values measured in the Fruition Treatment are lower than in the Traditional Treatment. The fruition treatment imposed a higher level of water deficit to the vine.

In the traditional treatment, more frequent irrigations have maintained predawn LWP values above-0.3 MPa until the end of August, reflecting an absence of water deficit over the measurement period. After irrigation predawn LWP rises from +0.1 MPa to +0.3 MPa. Because the most negative predawn LWP values before irrigation are high (>-0.3 MPa) and because the time interval between irrigation date and predawn LWP measurement date are not consistent, the rise observed in predawn LWP varies. (the rise is higher a) when predawn value just before irrigation is more negative, b) 1 to 3 days after irrigation according to water volume applied.

In the fruition treatment, lower irrigation regimes have maintained lower (ie more negative) predawn LWP values (between -0.3 MPa and -0.86 MPa). As expected since water deficit is more pronounced before irrigation, the rise in Predawn LWP values is more pronounced after each irrigation event (+0.4 MPa following July 23rd and August 18th irrigations).

For both treatments, a same water volume was applied on August 15th. Because predawn LWP before irrigation was more negative in the Fruition treatment (ie. vine experiences a more severe water deficit before irrigation), a larger rise is observed (+0.4MPa vs. +0.2 MPa). Consequently, the impact of a same irrigation volume at modifying vine water status is more pronounced in the fruition treatment. *(In other words this suggests that the efficiency of a same irrigation volume is higher in the Fruition treatment)*

2) Sap flow analysis

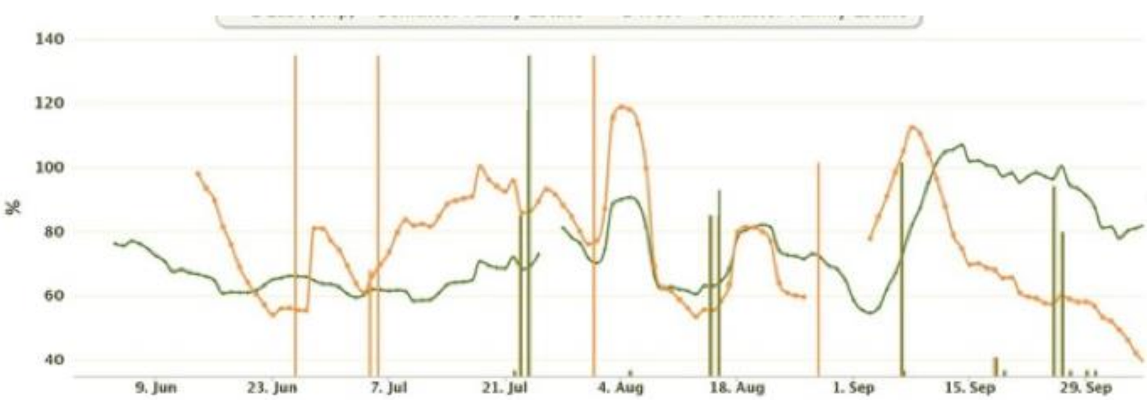

Figure 3: WDI from sap flow

In the traditional treatment: WDI is between 60 and 100% until August 1st and is under 80% thereafter (except over September 1st -September 10th). The rapid decline in WDI observed between September 8th and September 19th may also have some negative impact on berry weight.

In the fruition treatment, WDI varies between 60 and 80% until September 1st and is above 80% from September 7th onwards.

Throughout the season the comparison the 2 profiles in figure 3 reflects:

- A more pronounced water deficit in the fruition treatment until the first irrigation (July23rd).
- A similar level of water deficit over in August
- A lower level of water deficit in the fruition treatment in September.

Duration of irrigation effect in the traditional treatment becomes shorter as the season progresses.

- WDI values are dropping faster as the season unfolds, even if a greater amount of water has been applied.
- Over September 8th-18th, we observe a rapid WDI collapse (WDI drops 50%).
- Higher peak values for WDI are reached immediately after irrigation. This reflects that vine water use increases proportionally more in response to irrigation in the traditional treatment. However in the fruition treatment, after a same irrigation volume is applied, WDI rises at a slower rate (peak WDI is reached September 14th) and drops at a slower rate (only 7% over the same period). This suggests a poorer stomata conductance regulation under more irrigated regimes (as reported in the literature).

As observed in other vineyard sites, the WDI profile suggests that irrigation effect on plant response lasts longer under the fruition treatment. This reflects the carry over benefits of applying a more pronounced vine water deficit early season to improve stomata conductance regulation later during the season.

Scientists have reported several benefits to early season water deficit to improve late season vine water use regulation. Early season water deficit has been proven to modify plant vascular system, root hormones synthesis (ABA) and root architecture in a way that improves vine water use efficiency.

3) Fruit response monitoring

a) Pulp composition

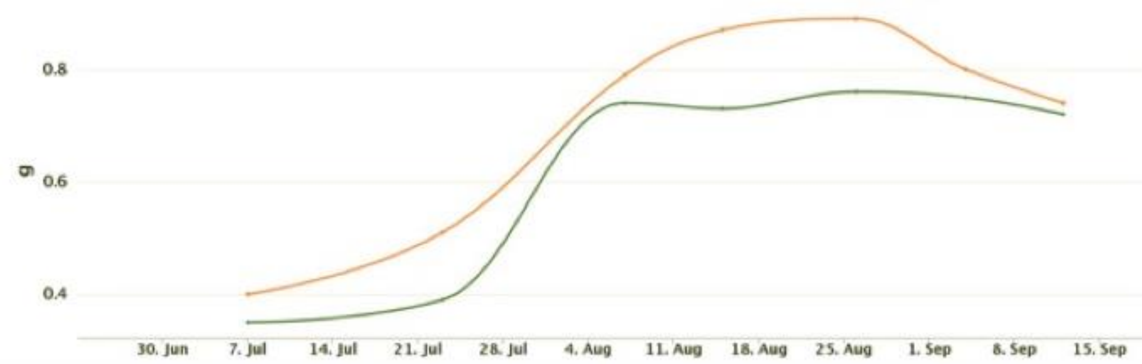

Figure 4: Berry Weight comparison

Berry weight is the same on harvest day for both treatments.

Peak berry weight is higher in <u>the traditional treatment</u> (0.9 g/berry) and is reached on August 26th. Higher berry weight is expected and reflects the effect of a more moderate water deficit preveraison (WDI profile is higher in the traditional treatment in July). However, despites the 2 irrigation events (August 28th and September 7th), berry weight declines from August 26th onwards (-17%).

Berry weight decline is not observed in the <u>fruition treatment</u>. Peak berry weight is reached earlier and remains steady, as expected given the higher WDI values late season (WDI >80% and vine do not experience water deficit).

The lower WDI value late season and the loss of berry weight late season seen in the traditional treatment could result from various factors such as:

1) A lower irrigation efficiency (ie. response to irrigation is shorter)

2) A higher sensitivity to late season heat wave in vineyard where more irrigation is applied earlier (Figure 5)

These results suggest that imposing vine water deficit **early season** may contribute to minimize berry weight loss caused by **late season** heat wave.

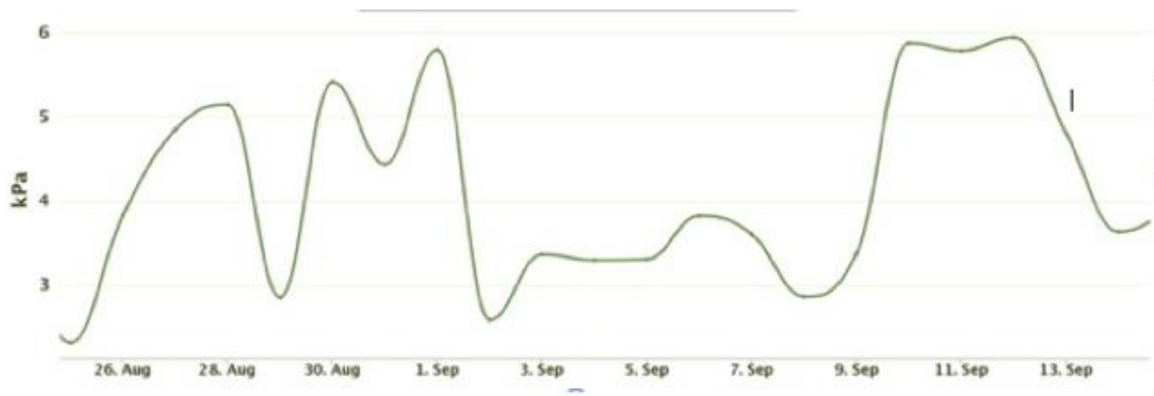

Figure 5: VPD variations (max)

Figure 5 shows 2 heat waves occurring during the period of rapid berry weight decline (VPD >4 kPa during August 27th- September 1st and September 10th -14th).

Sugar concentration increases at a similar rate in both treatments (Figure 6).

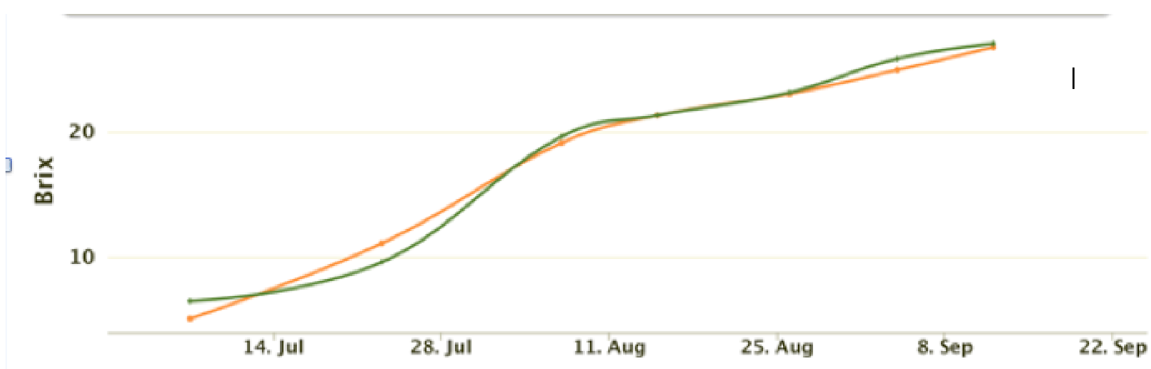

Figure 6: Sugar concentration variations

Active sugar accumulation is expressed in mg of sugar per berry in Figure 7. By tracking the amount of sugar per berry, we can distinguish if rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss. We observe that the amount of sugar per berry remains steady once amount of sugar per berry reaches a peak. Maximal sugar content per berry is reached earlier in the traditional treatment.

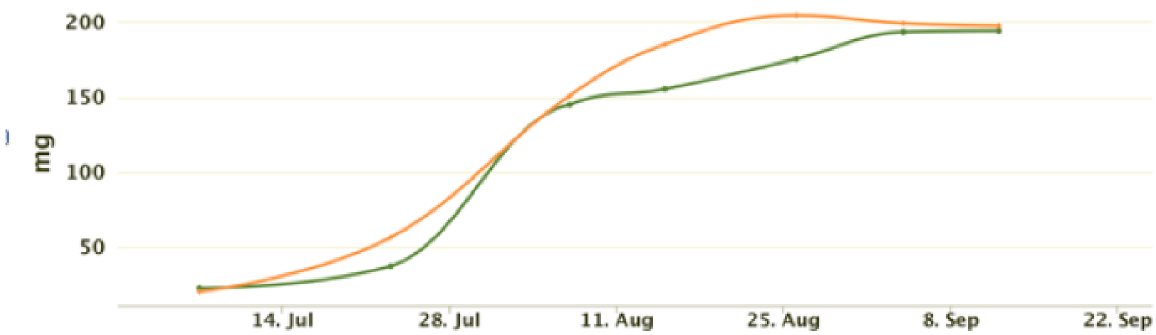

Figure 7: Sugar per berry comparison

b) Skin composition

The analysis of polyphenols shows a higher tannin concentration in the fruition treatment. This is in agreement with winemaker observations reported below. As seen in other vineyards, fruit maturation profile reflects an earlier maturation in Fruition treatment. Time variations for the polyphenolic profiles are displayed in figure 8-9-10.

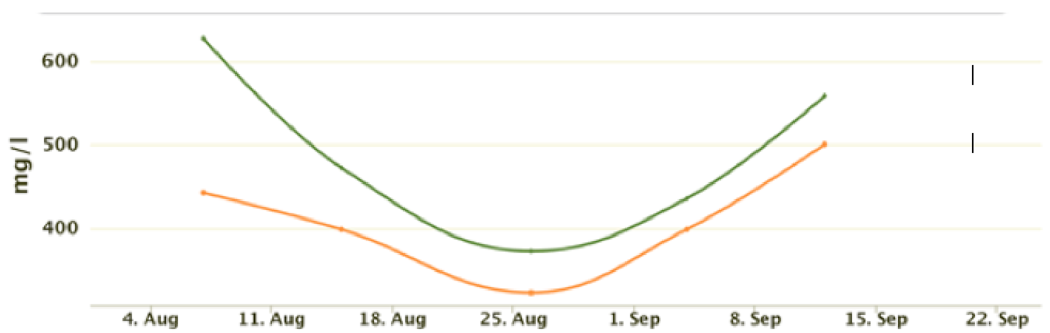

Figure 8: Tannin comparison

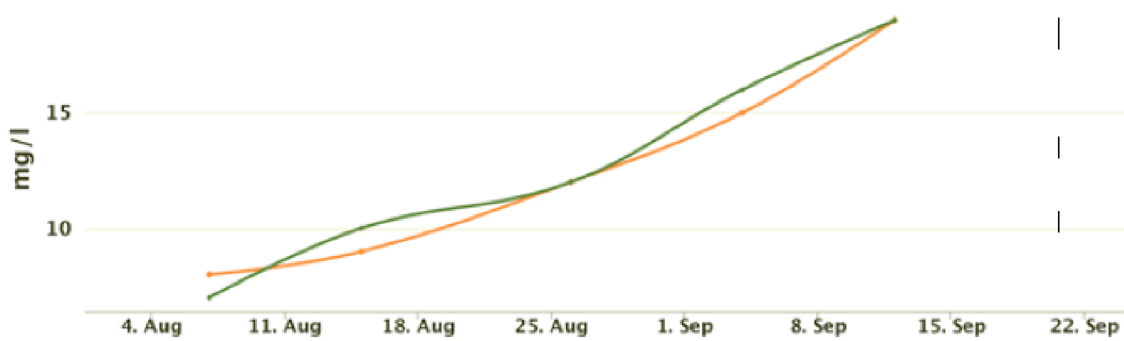

Figure 9: Polymeric Anthocyanins

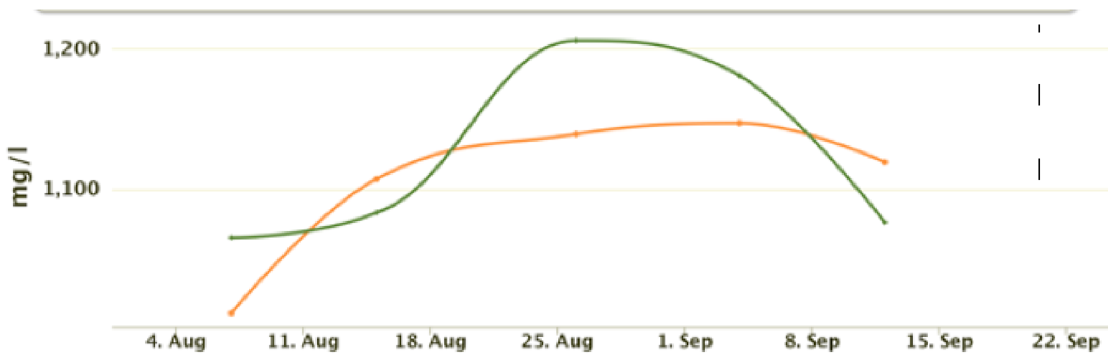

Figure 10: Total Anthocyanins comparison

4) Vineyard yield

Table 2: Yield Estimate in 2014

Site Name **NP- M**	T/acre	per individual vine (kg/vine)
Traditional	1.98	0.91
Fruition	2.03	0.89
Yield variations		-2%

Winemaker feedback on fruit quality:

Winemaker reported the following

On September 18th:

"I observed an earlier maturation in the Fruition treatment. Fruit quality is surprisingly good in the fruition treatment despite having applied less water.".

Site HB-JP

Introduction

This is a preliminary report before performing a cross-vineyard analysis. Over 6 different vineyards (Sonoma, Napa, Paso Robles) the same split treatment experiment has been conducted and similar data have been collected. Information on block properties, phenology and other historical practices have been compiled in the main report.

This site-specific report summarizes results obtained only in the context of the experiment in your vineyard. We welcome your comments and corrections. The goal is to have your approval before analyzing data from the 6 different vineyards. General conclusions will be discussed in the main report.

Thank you for your collaboration and help during that phase.

In the following figures, Orange trajectories are for traditional treatment

1) Water input comparison

The experiment in Site HB-JP took place over one large vineyard block divided into 2 subsections - block 20 and block 21. In 2014, irrigation practices remain traditional in block 20, while the bock 21 was irrigated according to the fruition approach. Unfortunately, on July 21st a short irrigation (<5 mm) was applied by mistake in the fruition treatment.

Table 1 reports the total amount of water applied in each irrigation treatment. To compare irrigation strategies, we reported volumes:

- Automatically from the irrigation gauge. (Water volume was directly measured at the vine level)
- Verbally per the vineyard manager. From the amount of hours during which irrigation was turned on, we estimated the amount of water applied. We converted the hours of irrigation into mm of water applied using the measurement technique described in the main report (bucket under the dripper to monitor the water filling rate)

Table 1: 2014 Irrigation comparison

Site name Site HB-JP	1st Irrigation **	# of events	rain gauge activity (hours)-	volume from rain gauge (mm)	volume verbally reported (mm)
Traditional	6/10	12	57	44 mm	32.01 mm
Fruition	7/22	3	34	26 mm	21.8 mm
Water savings *(%)				-40%	-32%

*(Fruition-Traditional)/Traditional

**Irrigation regimes comparison are considered from June 1, 2014 onwards

2) Plant response monitoring

a) Leaf area

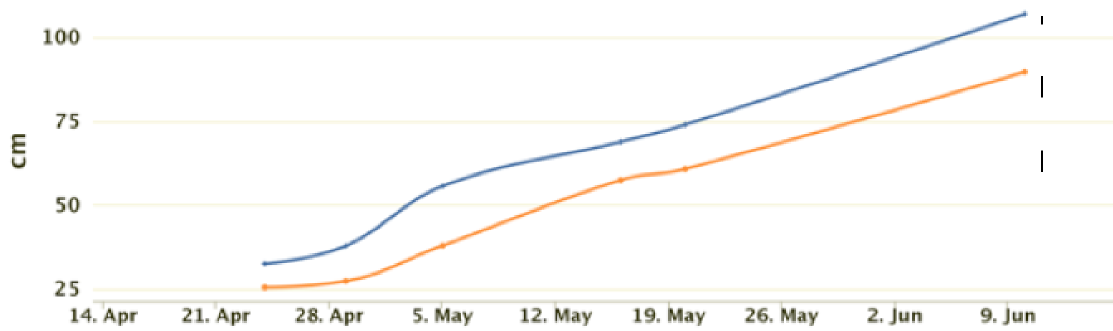

Figure 1: Shoot elongation rate comparison

Figure 1 shows that mains shoot length developed at a faster rate in the fruition treatment. Shoot elongation monitoring stopped on June 10th. A minimal shoot length of 90 cm is reached in both treatments.

B) Plant water use

1) Stomata conductance readings

Predawn water potential variations were not monitored; instead stomata conductance readings were performed according to a protocol (see porometer protocol in attachment). The same 8 leaves were measured each time, all at their natural leaf angle, mostly at 12:00 noon. The four vines selected were within the smart point, including the two vines with the sap flow sensors. Results are reported in Figure 2.

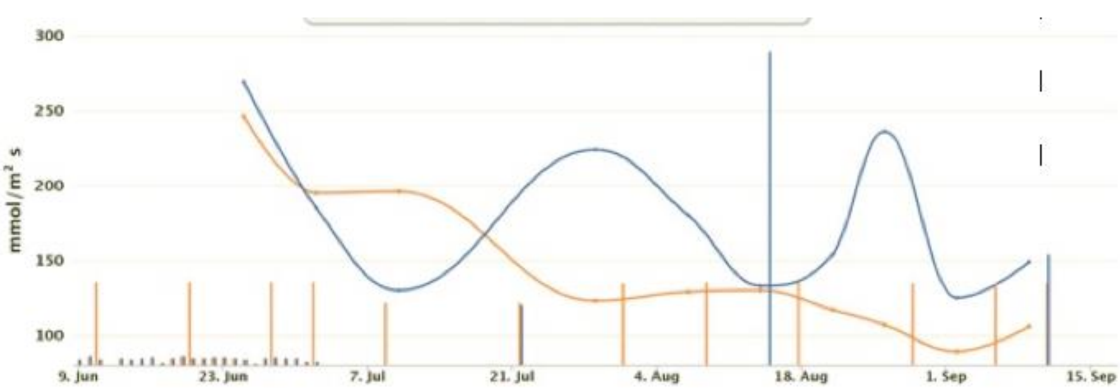

Figure 2: Stomata conductance comparison

Seasonal stomata conductance is higher in the Fruition treatment.

In the traditional treatment, despite frequent irrigation events (12 total over the period) stomata conductance steadily declines over the season. Figure 2 shows that stomata conductance before irrigation, reaches lower and lower values as the season progresses. In August lower values pre-irrigation are around 130 mmoles.m^{-2}.s^{-1}; in September, lower values pre-irrigation are under 100 mmoles.m^{-2}.s^{-1}. Thus, stomata conductance profile shows that the vine is gradually experiencing a more pronounced water deficit and suggests that vine water use regulation is less efficient under the traditional treatment.

Consequently stomata conductance is expected to reach higher values immediately after irrigation (not seen in the data) and lower values before the next irrigation. In practice, this should affect vine transpiration, trigger a faster collapse of vine water use and reduce the effect of irrigation.

This is in agreement with various studies of vine responses under higher water supply. Authors have reported lower concentration in drought resistance hormone (ABA), shallower root system, potentially wider xylem vessels, etc….

In the fruition treatment, the collapse of stomata conductance values as season progresses is less pronounced, suggesting a better stomata conductance regulation (ie. less variations between extremes). Before July 14th, we observe an early decline of stomata conductance in the fruition treatment. After July 22nd irrigation, stomata conductance values remains higher even if less water is applied.

2) Sap flow analysis

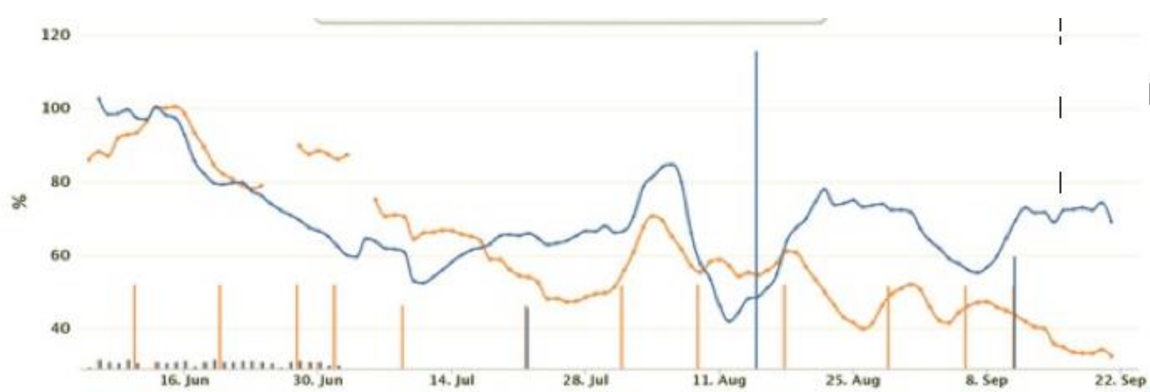

Figure 3: WDI from sap flow

Early season WDI drops more rapidly in the fruition treatment, as expected since no irrigation is applied. After irrigation on July 21st, WDI raises more in the Fruition treatment and is maintained above 50% until the end of the season. The unwanted irrigation applied on July 21st had no effect on WDI, as expected given its low volume (<5 mm).

In the traditional treatment, WDI declines as the season progresses, which reflects that vine is gradually experiencing a more pronounced water deficit level. From July 21st onward, WDI is under 50%. Because more water is applied under the traditional treatment, vine water use regulation is less efficient.

Over the season WDI profiles displayed in figure 3 are similar to stomata conductance profile. There is a good agreement between the 2 methods.

WDI profile suggests that irrigation effect on plant response lasts longer under the fruition treatment (less water is applied but WDI is > 50%). This reflects the carry over benefits of applying a more pronounced vine water deficit early season to improve stomata conductance regulation later during the season. Scientists have reported several benefits to early season water deficit likely to improve late season vine water use regulation. Early season water deficit has been proven to modify plant vascular system, root hormones synthesis (ABA) and root architecture in a way that improves vine water use efficiency.

C) Fruit response monitoring

1) Pulp composition

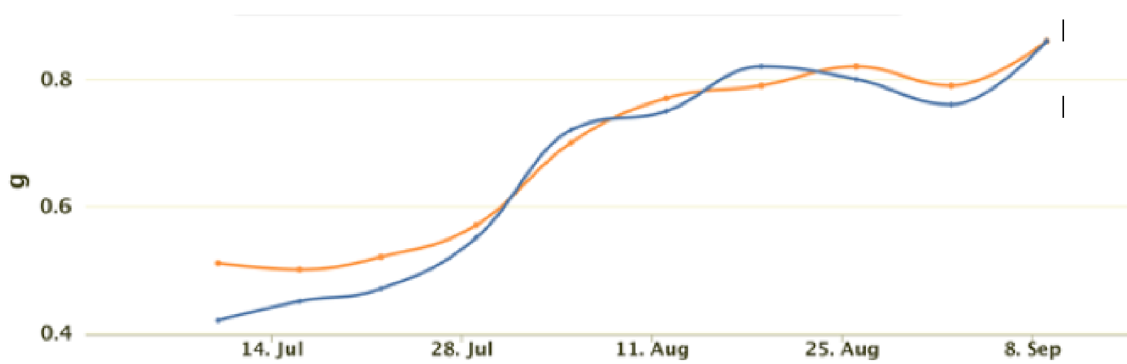

Figure 4: Berry Weight

Berry weight profile is similar for both treatments (Figure 4).

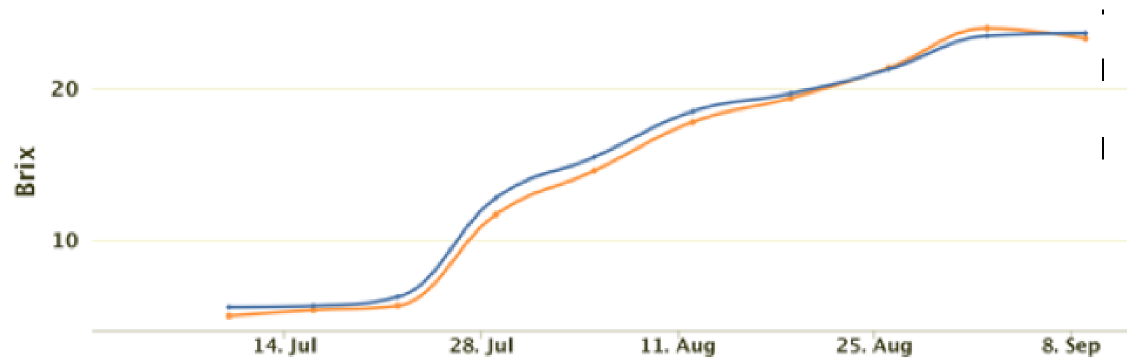

Figure 5: Sugar concentration variations

Sugar concentration increases at a similar rate in both treatments (Figure 5).

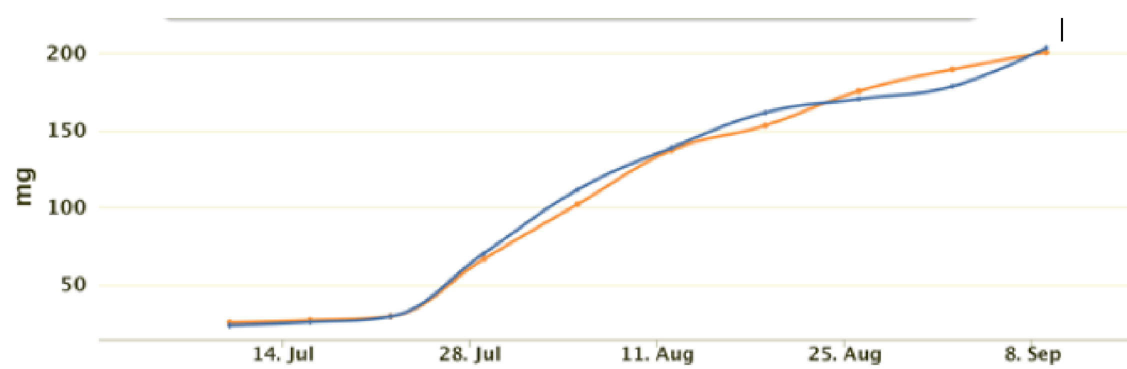

Figure 7: Sugar per berry comparison

Active sugar accumulation is expressed in mg of sugar per berry in Figure 7. By tracking the amount of sugar per berry, we can distinguish if rising Brix values are either due to an active sugar downloading from the phloem into the berry or if it reflects a sugar concentration due to berry water loss. We observe that the amount of sugar per berry reaches a peak on September 9th.

2) Skin composition

The analysis of polyphenols shows a higher tannin concentration and a higher total phenolic in the fruition treatment.

Variations for the polyphenolic profiles are summarized in Table 2 .

Table 2: Polyphenolic Fingerprint Analysis

Site Name **Site HB-JP** **Sample: 9/12/14**	Tannin (mg/g)	Total Phenolics (a.u./g)	Total Anthocyanins (mg/g) Malvidin-3-glucoside equivalents
Block 21 (fruition treatment)	1.43	45.01	.62
Block 20 (traditional treatment)	1.30	40.81	.56
Difference	*+ 10%*	*+9.3%*	*+10.7%*

3) Vineyard yield

Yield comparison is reported in Table 3.

Table 3: Yield Estimate in 2014

Site Name **Site HB-JP**	T/acre	per individual vine (kg/vine)
Traditional	2.80	1.79 kg
Fruition	2.95	1.89 kg
Yield variations		+5.5%

Winemaker feedback on fruit quality and yield:

"Wine quality has been assessed post-drain and Fruition treatment was preferred for its broader and more concentrated mouth feel. Aromatics were more similar."