2011

Sonoma County Water Agency: Vineyard Water Conservation Demonstration Project

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Contents

Executive Summary

An irrigation demonstration project was conducted at Hoot Owl Creek / Alexander Valley Vineyards (HOCV/AVV) during the 2009 growing season. A follow-up demonstration was conducted in 2010. A second site was added at Wildwood Vineyards in 2010 to serve the Sonoma Valley. The HOCV/AVV demonstration consisted of 6 non-replicated irrigation "treatments" illustrating 6 common practices used in drip irrigation of vineyards. Irrigation scheduling was conducted independently of the commercial practice being used in the surrounding vineyard block. In 2010, five of the treatments were initiated at the same time, as substantial late spring rains delayed the irrigation season. A sixth treatment was not irrigated at all, as the target level of plant water status was not reached at any time during the season.

The commercial level of irrigation for the growing season was 2 inches, while the five early-initiated irrigation treatments were irrigated with only 0.9 inches of water, on average and the sixth treatment with no irrigation at all. **Relative to commercial practice, this represents approximately 55% savings for the five irrigated treatments, and 100% savings for the sixth treatment.**

Water savings relative to commercial practice arose partially by delaying the onset of irrigation for as long as possible, but also by using continuously-measured soil moisture to define both the volume and interval of irrigation applications. Soil moisture-based scheduling, paired with frequent plant water status monitoring, allowed for efficient irrigation applications that further reduced irrigation needs for this demonstration vineyard.

The water savings summary is summarized below for the 2009 and 2010 seasons along with estimates of energy savings, energy cost savings and CO_2-equivalents of savings due to energy use reduction:

	Per Acre Savings				
Treatment #	**Gal./Acre**	**In./Acre**	**\$/Acre**	**kWh/Acre**	**lbs. CO_2/Acre**
2009 Data					
1 to 4	68015	2.5	**$ 19.16**	**108**	**127**
5	70767	3.3	$ 25.56	144	170
6	90763	4.0	$ 30.69	172	204
2010 Data					
1 to 5	29,869	1.1	$ 8.43	48	56
6	54,308	2.0	$ 15.33	87	102

When extrapolated over the estimated 60,000 acres in the geographic region of interest (Russian River Basin), the estimated total savings were as follows:

Treatment #	Acre-ft.	$	kWh	Tons CO_2
2009 Data				
1 to 4	12,524	$ 1,149,389	6,456,154	5,099
5	13,031	$ 1,533,796	8,615,377	6,804
6	16,713	$ 1,841,315	10,342,723	8,169
2010 Data				
1 to 5	5,500	$ 504,762	2,835,264	2,239
6	10,000	$ 917,749	5,155,025	4,071

The irrigation treatments were not accompanied by any yield difference in 2010, and all treatments produced approximately 5.5 Tons/Acre.

The Wildwood vineyard site was provided as a demonstration site primarily for discussion purposes. Soil moisture and plant water status were monitored at three sites, each of which had different characteristic soils. The irrigation methods used by the vineyard manager are critiqued in this report, to be viewed as constructive criticism.

A vineyard cooling demonstration project compared conventional impact sprinklers against the use of large pre-irrigation applications in anticipation of heat events. The overhead sprinklers were pulsed on and off at intervals of 30 minutes. This method saved water over the typical practice of leaving the system running for the duration of the heat episode. Canopy air temperature was reduced 6°F and cluster temperature was reduced 3°F, on average, during the cooling episodes. Irrigating the day before a heat wave had minimal, if any impact on cooling of fruit, as cluster temperature differences were seen to be less than 1°F different than those that were irrigated per standard practice. While pulsing the overhead sprinklers appears to be an effective means of water conservation, proper trellis design, minimization of leaf removal, and especially row orientation are non-active ways to reduce fruit damage under heat episodes.

Alternative frost protection methods (to overhead irrigation) were investigated, though 2010 was a poor year for evaluation of frost protection methods, due to few episodes. Measurements of air temperature at several levels demonstrated the effect of conventional wind machines and cold air drains on vineyard air temperatures. Both systems caused air temperatures to rise after they were activated, though temperatures continued to fall after they were running for a period of time. Wind machines and, perhaps, cold air drains may be effective frost protection methods, though they will be ineffective for frost conditions that are not radiation (i.e. advective). A frost blanket idea was also tested, but was found to be ineffective as well as impractical.

Project Execution and Results

Irrigation Demonstration: Hoot Owl Creek / Alexander Valley Vineyards

An irrigation demonstration project was conducted at Hoot Owl Creek / Alexander Valley Vineyards during the 2010 growing season, for the second year in a row. The demonstration was conducted in a Cabernet Sauvignon Vineyard trained to a Scott-Henry trellis system on O39-16 rootstock. Row Spacing was 8 feet and vine spacing 6 feet. The demonstration consisted of 6 non-replicated irrigation "treatments" illustrating 6 common practices used in drip irrigation of vineyards. The irrigation scheduling was conducted by Mark Greenspan (viticulturist) of Advanced Viticulture and was based on current best practices, with some modifications per the individual treatments.

Treatments and Measurements
The treatments consisted of the following:

1) A single 1 gallon per hour (gph) emitter per vine (others had two ½ gph emitters installed per vine)
2) Relatively low volume irrigations conducted at relatively frequent intervals (same intended volume as the other irrigation treatments but applied in a different manner)
3) Relatively high volume irrigations conducted at relatively infrequent intervals (other irrigation regimes were based on this schedule except for #3)
4) Irrigation per #3, but during daytime hours (all others were irrigated at night)
5) Irrigation scheduling intended to maintain vines at approximately -13 bars of midday leaf water potential
6) Irrigation scheduling intended to maintain vines at approximately -15 bars of midday leaf water potential

Each treatment was applied to one row of grapevines. Treatment names were marked at the endposts and map was situated in the vineyard during the field demonstrations (**Figure 1**). Each treatment featured a 5 foot long AquaSpy soil moisture probe (which were donated by the company). Each probe contained 12 soil moisture sensors at 4 inch intervals. These sensors were connected to a Ranch Systems transceiver node, which provided the telemetry function for these sensors. (Real-time data were made available to the general public via an internet portal). For ease of interpretation, sensors within 1 foot intervals were averaged in the software for their visualization. Additionally, a flow gauge was installed in each irrigation line to measure current and accumulated flow and to notify the operator (Mark Greenspan) of any water flow (or lack thereof) that did not coincide with the scheduled irrigation events.

Irrigation events were controlled by the Ranch Systems network, with in-line water valves connected to an always-pressurized water source. Each treatment had its own valve connected to a Ranch Systems control and telemetry node. The irrigation events were scheduled by programming them through the Ranch Systems online software (accessible only by the operator).

Weekly measurements of vine water status (leaf water potential and stomatal conductance) were measured in each treatment using field instrumentation. The measurements were posted for access via the internet on Advanced Viticulture's web site.

A two-dimensional grid of soil moisture devices was installed below a drip emitter in the Short/Frequent irrigation treatment to obtain a picture of the vertical and horizontal extent of the wetted soil following an irrigation event. Eight soil moisture sensors (Watermark) were installed at 1, 2, and 3 foot depths right below an emitter, 9 inches laterally from an emitter and 18 inches laterally from an emitter (only 8 sensor ports were available, so the 1 foot depth was not included at the 18 lateral location). The Watermark sensors, which measure soil matric potential, were connected to a Ranch Systems telemetry node, for inclusion in the data stream via the same web portal.

At selected times, soil moisture profile data were extracted from the matric water potential measurements to construct profile plots of the two-dimensional soil moisture status. The results are discussed below.

Building on the concepts outlined in the vineyard water use best management practices (see Appendix), the emphasis was on the following aspects of irrigation management:

1) *Irrigation Initiation*: Begin the irrigation "season" as late as possible into the year by observing shoot elongation rates, combined with plant water status measurements.
2) *Irrigation to match the root zone*: Explore soil and rooting patterns in each vineyard and adjust irrigation volumes to match the soil and root depth of the vineyard. Measurements of soil moisture within the soil profile provides an ideal means to achieve this goal.
3) *Water status monitoring*: Monitor vine water status (stress levels) and adjust irrigation intervals such that the vines operate in a water-use-efficient mode (i.e. partially closed stomata) while avoiding excessive stress.

Project Observations

Irrigation Initiation

Irrigation commenced per the decision of the viticulturist, primarily when shoot tips exhibited slowed or stopped growth (except for treatments #5 and #6). As vine water status measurements were already being made, values of about -11 bars of midday leaf water potential were being sought as a secondary guideline for the season's irrigation initiation.

The 2010 season featured an unusually high amount of rainfall during the spring, and substantial rainfall occurred until mid-to late May (**Figure 5)**. The late rainfall made it difficult to slow shoot growth and delayed the need for irrigation until early September, which was 2-3 weeks later than 2009. Hence, total irrigation volume applied in 2010 was likely reduced below that of "normal" due to the spring rainfall pattern, and was even

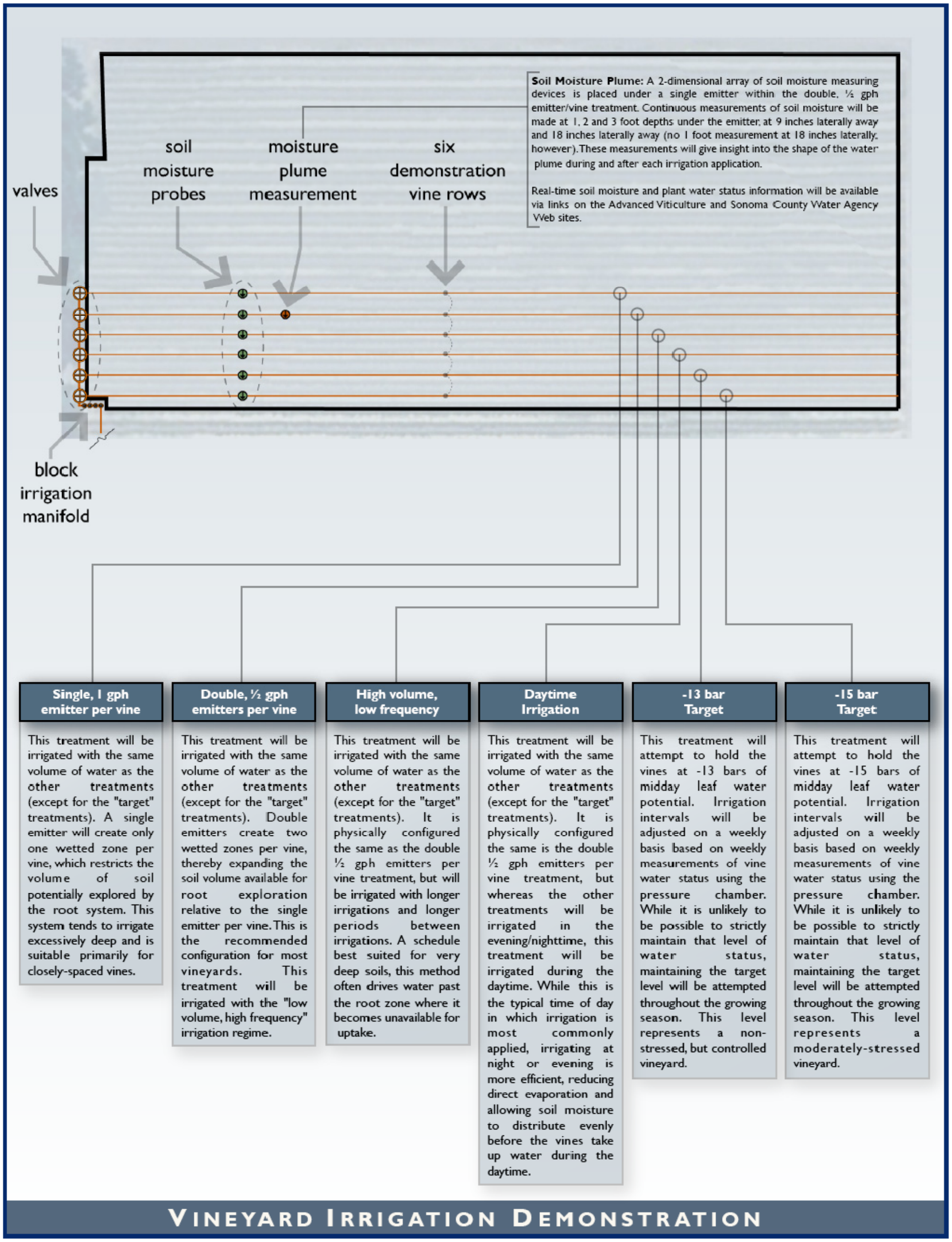


Figure 1: Treatment map and description for the irrigation demonstration. Water flow sensors were located at the same location as the soil moisture sensors.

lower than the 2009 irrigation needs, which was also below normal. Nevertheless, it was instructive to demonstrate to growers that irrigation initiation does not need to be made during the same calendar time period each and every growing season.

Another message to growers about irrigation initiation is that drip irrigation, although the most efficient means to apply irrigation to vineyards, provides water to a very small proportion of the potentially-active root zone (water plume measurements appear later). Because the north coast typically receives ample winter and spring rainfall (even in a drought year) to provide ample soil moisture reserves for most vineyards until at least early summer, root systems will remain active within a relatively large volume of soil until drip irrigation commences. Once drip irrigation has begun, the root system tends to flourish in the wetted soil volume, while the remainder of the root system tends to go into dormancy. Within a relatively short amount of time (roughly two weeks), the root system morphs into one that is primarily active under the emitters. This creates a vineyard that is dependent upon drip irrigation during the remainder of the season. It also reduces the soil nutrient pool largely to the small wetted zone, thereby restricting uptake of nutrients from the larger soil reserve. For these reasons, it is beneficial to avoid drip irrigation until absolutely necessary to do so.

Irrigation began on September 10, 2010 and ceased after the large rainfall on October 24, 2010. It was an unusually short irrigation season.

Irrigation to match the root zone

Once irrigation begins, it is important to irrigate with appropriate practices tailored to each vineyard. The primary variable is the depth of the root system. This was demonstrated using a backhoe pit, situated near and about the trunk of a typical vine in the vineyard. The root system was evaluated visually and the root system was determined to be approximately 3.5 feet deep (**Figure 2**). There were roots extending to 4 feet of depth, and perhaps even a few further down below the soil pit. Yet, the majority of the root system appeared to lie within the 3.5 foot soil depth. The soils at this location are alluvium, with a clay loam texture. There were no obvious impediments to root growth observed in the soil.

It was determined that, based on soil observations, that irrigation depth would be targeted to the 3-4 foot soil depth for the majority of the irrigation treatments, except for treatments #1 (single 1GPM emitter) and #3 (low volume, low frequency). The 2009 demonstration taught us that the longer and less frequent irrigation approach was more appropriate than the short/frequent approach. The deep, heavy soils are amenable to the deeper irrigations and soil moisture depletions following an irrigation showed us that we were irrigating too frequently and not deeply enough in 2009. Hence, the deep/infrequent approach was used for 2010. However, errors were made during the first two irrigations of the low volume, high frequency treatment, as it was irrigated with the same volume as the other treatments, preventing us from applying the irrigation properly. This was an operator error, and is regrettable. However, we had already learned that it was not the most effective method to irrigate this vineyard, so the lesson had already been learned.

The very short irrigation season in 2010 left little time to correct the irrigation scheduling error in time for a meaningful result.

Total soil moisture in the profile (between 0 and 4 feet) appears in **Figure 3**. All treatments jumped to about 13 bars in a short period of time, so all of the treatments, except for the -15 bar treatment, commenced irrigation on the same date. The total soil moisture charts are useful from an operations standpoint. Once the proper volume of applied water has been determined from the individual depth readings (to be discussed), the irrigation timing uses the total soil moisture information to schedule subsequent irrigation events. This is done by irrigating when the soil moisture returns to the same value as it was at the time just before the prior irrigation event. With several different measurements taking place, all sites did not return to the prior level at the exact same time. The -13 bar treatment was chosen as the primary guide for determining irrigation intervals and it can be seen that the soil moisture followed a repeatable pattern of wetting and drying without accumulation or depletion of soil moisture over a period of several weeks. This appears to be close to the ideal irrigation application for this particular site.

Soil moisture profile charts, by depth, appear in **Figure 4a** through **Figure 4c** for the six irrigation treatments. Because of our experience with irrigation at this site in 2009, an irrigation volume of 6 gallons per vine was applied to treatments receiving irrigation. It was found that this irrigation volume wetted all treatments down to the 3 foot level, which was close to the target depth for irrigation infiltration. In most treatments, the soil moisture was not wetted to the 3-4 foot level, suggesting that we could have irrigated slightly more, say 7 gallons per irrigation. Irrigation did infiltrate down to that level in the single 1GPH emitter treatment, indicating that irrigation can travel that far in this soil. However, because of the very short irrigation season in both 2009 and 2010, we were still slightly off of optimal irrigation volume. A larger application of water than 7 gallons (7 hours) would have allowed us to stretch the irrigation interval by 1-2 days. The irrigation interval for the 6 gallon volume was nominally 12 days, suggesting that the ideal minimal irrigation schedule for this vineyard would be 7 hours at 14 day intervals. The interval would probably vary during the growing season based on evaporative demand. Note that irrigating in this manner eliminates the need for reference evapotranspiration (ETo) measurement or estimation of crop ET using crop coefficients, as the actual moisture depletion is measured using the soil moisture sensors.

The high volume/low frequency soil moisture measurements did not show the same amplitude of soil moisture fluctuations as did the other treatments. This may have to do with an obstruction in the path of infiltration, causing some water to divert away from the axis of the soil moisture probe. This is evident in that there are no spikes in the soil moisture at any level following an irrigation event, even at the shallowest level. Spikes are indicative of saturation followed by rapid drainage, which is a normal feature to observe in continuous soil moisture readings. Hence, this probe should be re-situated if it were to be used for irrigation management going forward. However, even with the probe in its current location, irrigation scheduling would not have differed dramatically as the irrigation depths were identifiable and the moisture levels in the total profile repeatedly returned to the previous level prior to each irrigation event.

Likewise, the High Volume/Low Frequency irrigation treatment was irrigated with the same amount of water (nominally), but with twice the volume and twice the interval between irrigations. The higher volume of irrigation pushed water down to the 40-48 inch depth, but not to the 52-60 inch depth to a great extent. Once again, under many other vineyard conditions in the north coast, soils tend to be shallower and/or lighter, and optimal irrigation strategies may not include the deeper irrigation regimes.

Although a brief irrigation period, the methodology shown here indicates the usefulness of continuous soil moisture measurements at successive depths, down the bottom (or below) the root zone. The method is relatively simple, relies on trial and error, and self-calibrates for every situation.

As in 2009, the -15 bar treatment never reached its threshold level of water stress, so was not irrigated at all during the 2010 growing season.

Figure 2: Examination and discussion of the vine's root zone during the demonstration field day on August 20th, 2010.

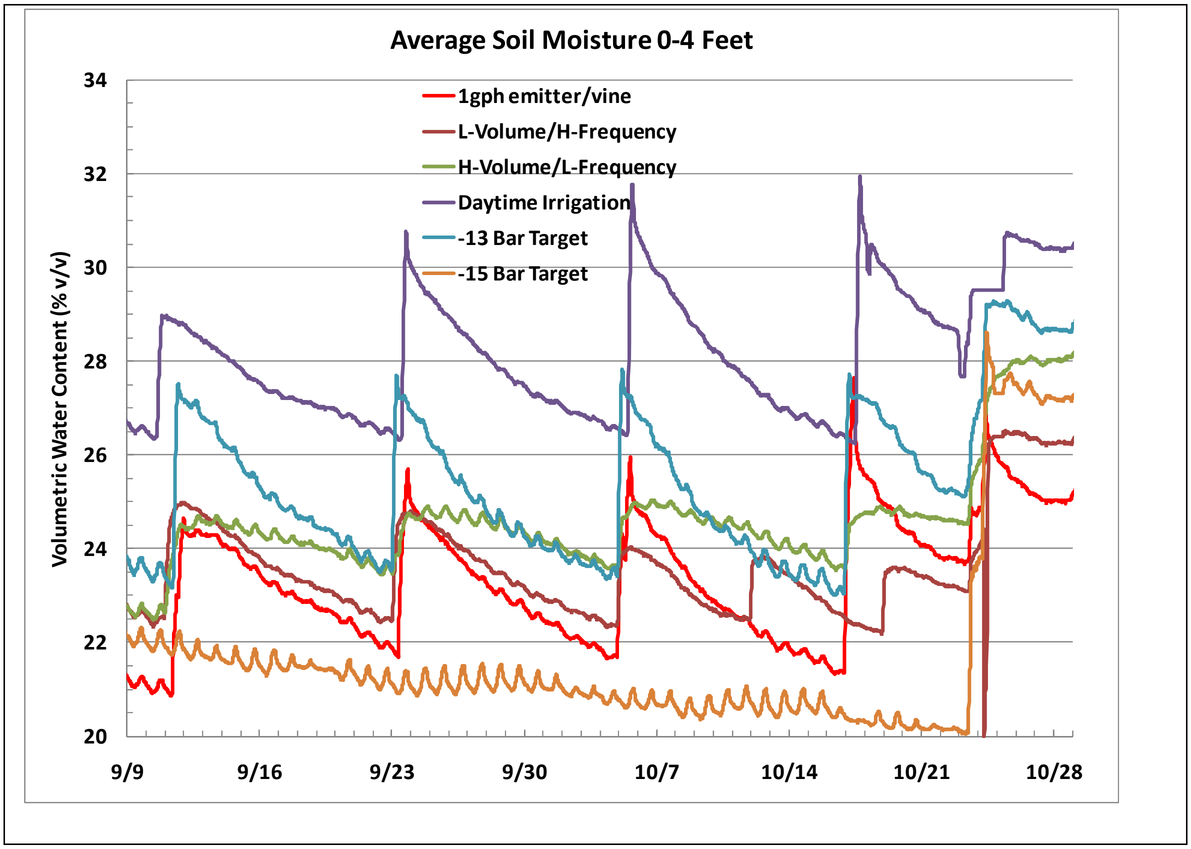


Figure 3: Average volumetric water content between 0 and 48 inches depth for all of the treatments during the irrigated period.

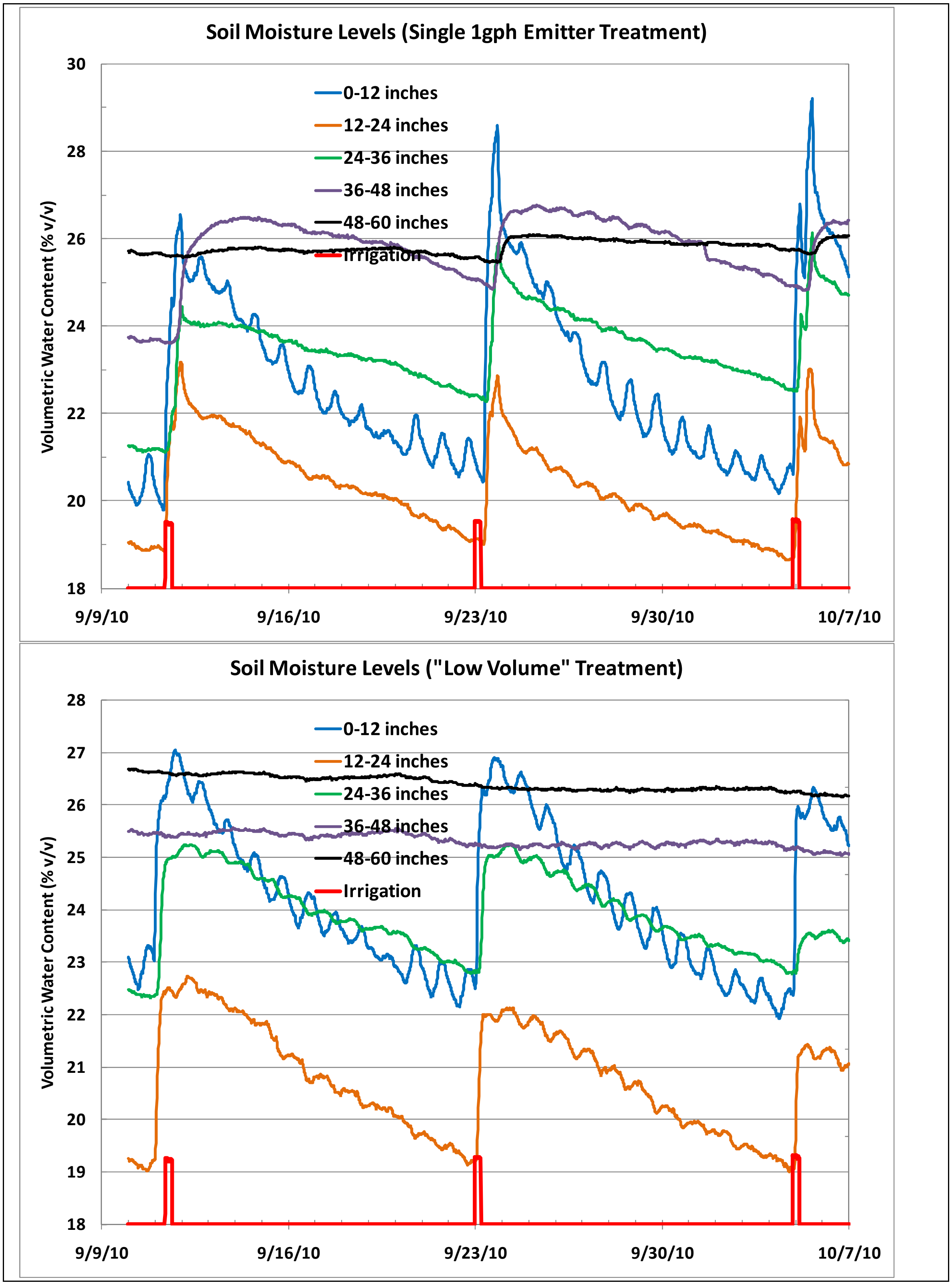


Figure 4a: Volumetric water content of the soils below the emitter in the (1) Single 1GPH emitter per vine treatment and the (2) low volume, high frequency treatment (irrigations were mis-applied for (2))

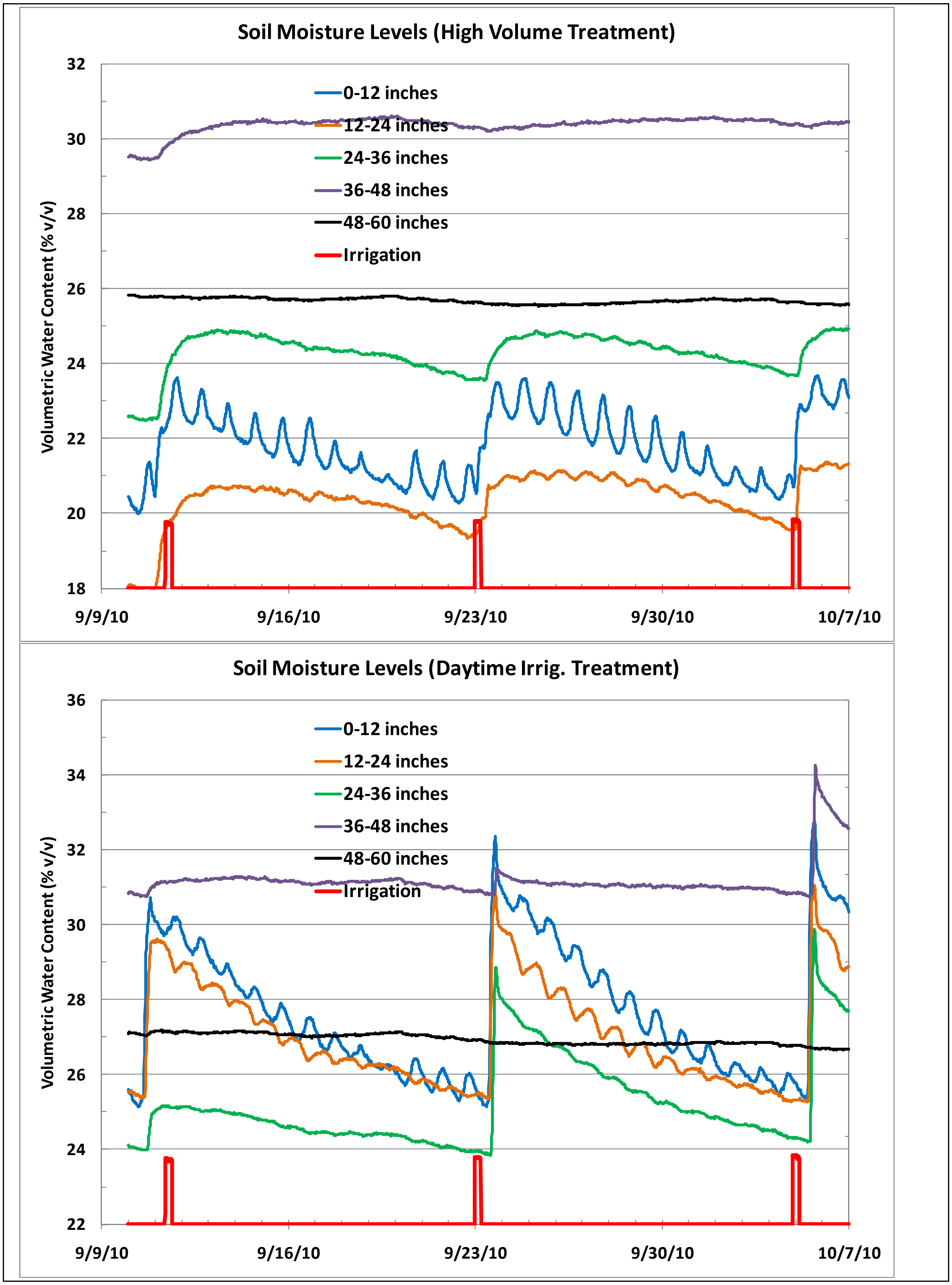


Figure 4b: Volumetric water content of the soils below the emitter in the (3) High Volume/Low Frequency treatment and the (4) Daytime irrigation application treatment.

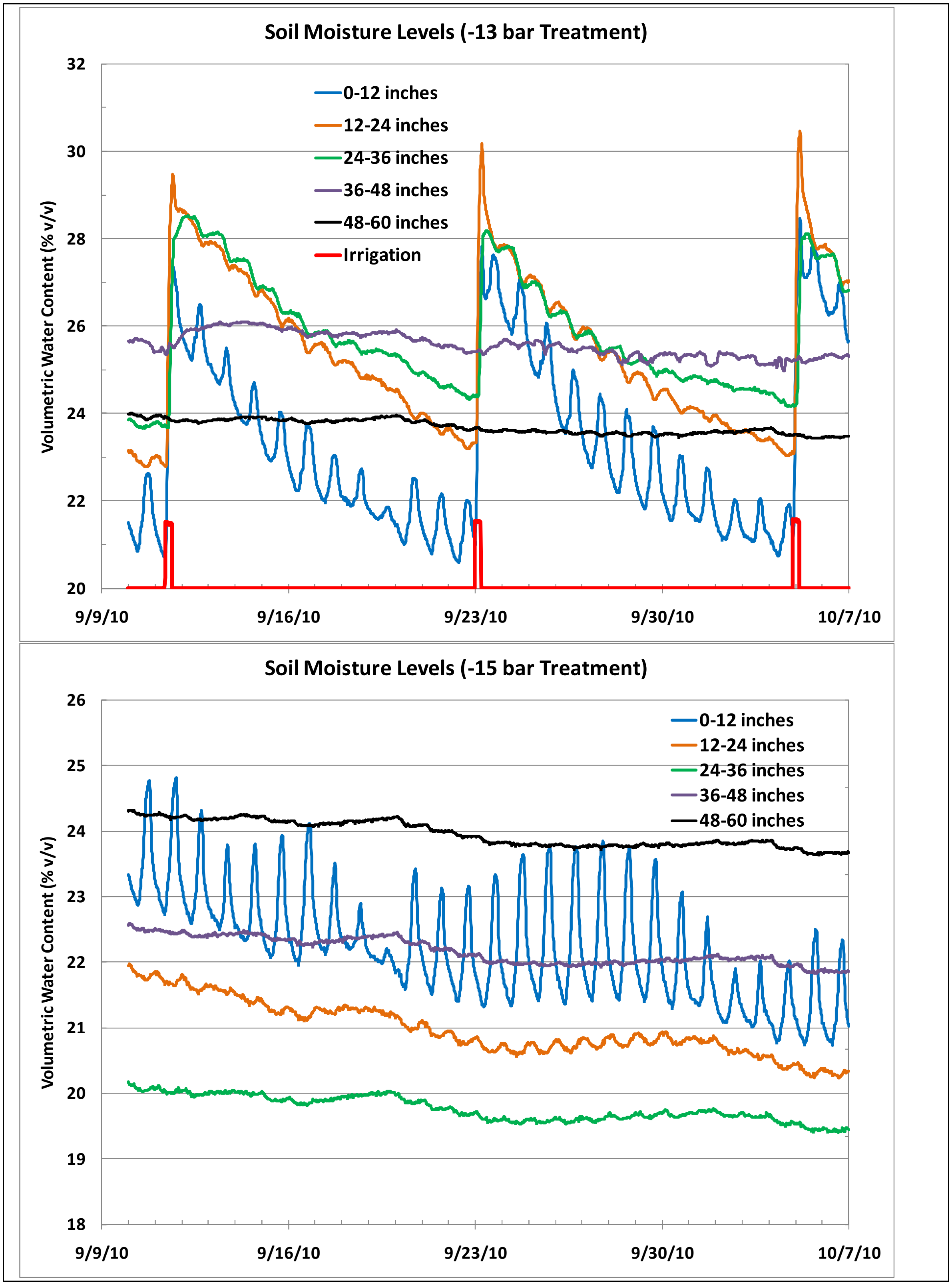


Figure 4c: Volumetric water content of the soils below the emitter in the (5) -13 Bar Target treatment and the (6) -15 Bar Target irrigation treatment (which was never irrigated in 2009 or 2010).

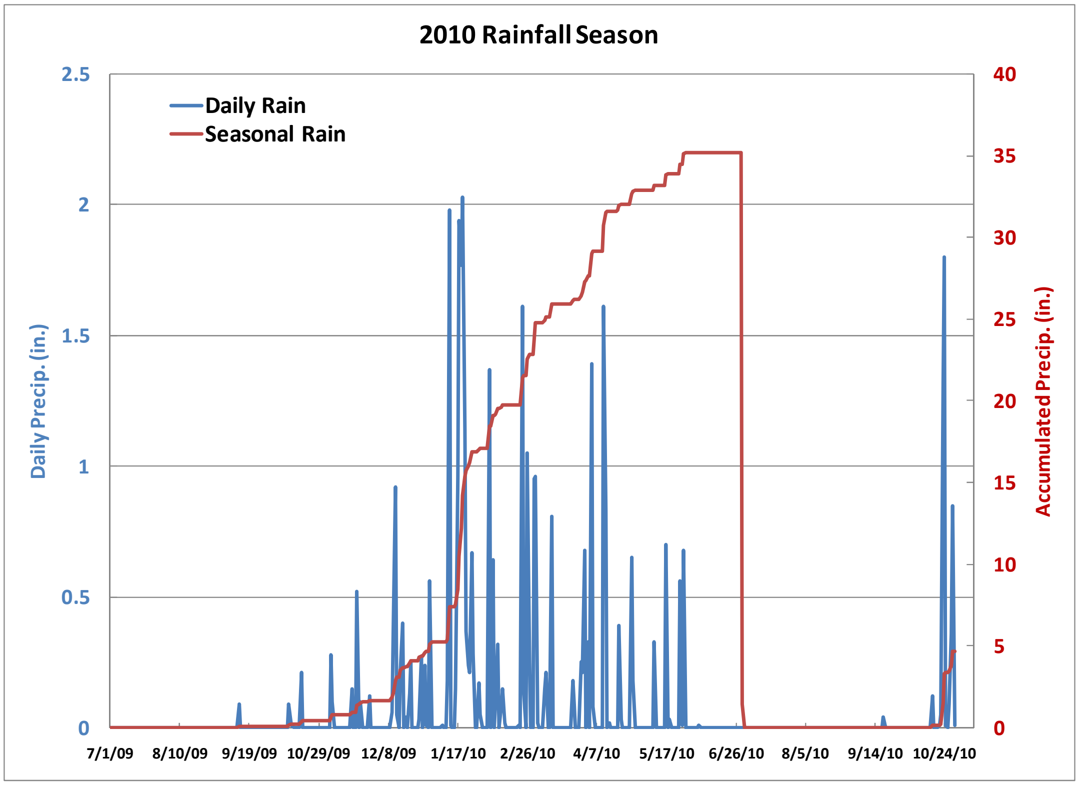


Figure 5: Daily and accumulated precipitation for the HOCV/AVV site in 2010.

<u>Soil Moisture Plume Measurement</u>

As part of the demonstration project, a two-dimensional grid of soil moisture sensors were installed below and near a drip emitter to assess the depth and lateral extent of the wetting pattern following irrigation events. Sensors were placed at 12", 24" and 36" depths directly below a drip emitter and at the same depths 9 inches lateral distance from the same emitter. Additionally, sensors at 24" and 36" were placed 18 inches of lateral distance from the emitter (only 8 data logger ports were available so the 12" depth was not included at 18 inches lateral distance). From these data, wetting profiles were constructed using spatial interpolations of the measured data. Example profiles appear in **Figure 6**, showing the 2-dimensional soil wetting and drying pattern before, during, and at the end of a 12-day irrigation cycle. Soil moisture during the entire irrigation period is shown in **Figures 7-9**, for 0", 9" and 18" lateral distance from emitter, respectively.

It was found that the irrigation practice, as modified for the 2010 season based on 2009 experience, wetted soil down to the 3 foot depth, close to saturation. Likewise, the moisture plume extended to the 9 inch lateral distance, but was sensed primarily at the 24 inch depth. Little soil moisture wetting occurred at 12 inch depth 9 inches laterally from the emitter, though the irrigation did have influence by way of capillary movement of water within the soil matrix. There was absolutely no wetting sensed 18 lateral inches from the emitter at any depth or at the 36" depth at 9 lateral inches. The limited size of the wetting pattern was very enlightening in that it represents a very small volume of wetted soil compared to the entire soil volume available to the vines (6 feet by 8 feet by 3 feet depth). Hence, drip irrigation, while an efficient delivery method, dramatically reduces the soil moisture pool available to the vines. Vine roots are very ephemeral in that they emerge and go dormant in a relatively short amount of time. Drip irrigation tends to shift the rooting patterns from the "natural" rain fed state into a confined soil volume, thus adding potential nutrient and water stresses on the vines. It is important to carry the message to growers that irrigation should be forestalled as late as possible into the growing season in order to mitigate the inherent stresses induced from drip irrigation.

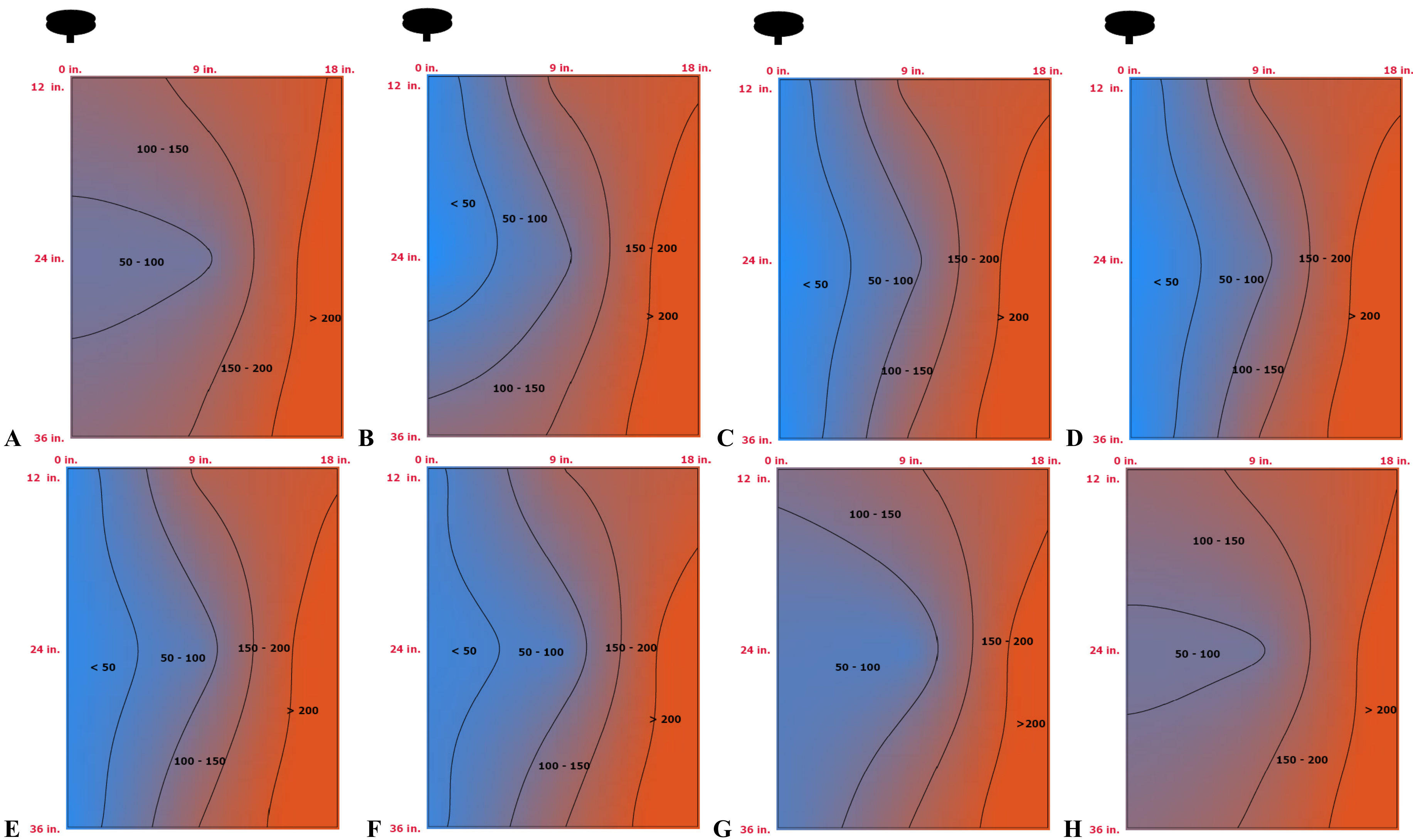


Figure 6: Example semi cross-section of the soil moisture pattern below an emitter during and after a 3 gallon (6 hours) irrigation application. A-F represent time values relative to the onset of irrigation (0, 4h, 8h, 2d, 4d, 8d, 12d, respectively). Values are in centibars of soil matric potential (lower values = more freely-available moisture). Upper level is 12 inches below the soil surface. A represents the soil condition immediately prior to the irrigation and H represents the soil condition immediately prior to the subsequent irrigation event.

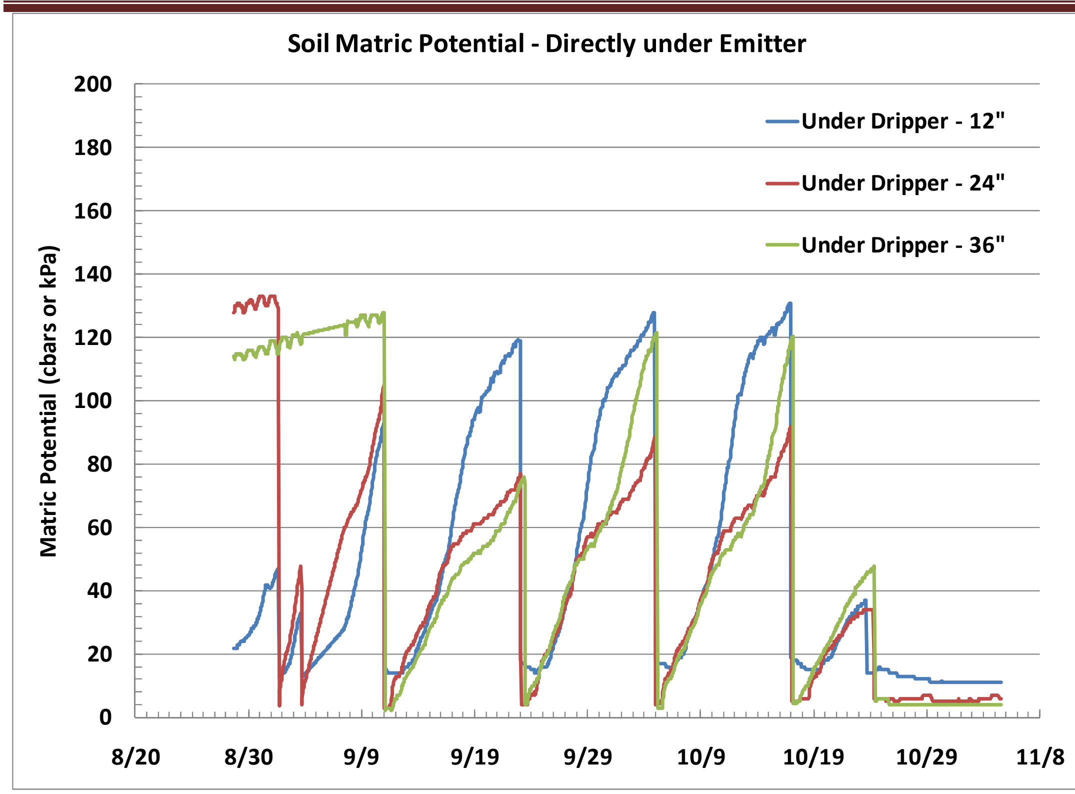


Figure 7: Soil moisture (matric potential) profile during the irrigation period of soil directly below a drip emitter. Values dropped to approx. 0 cbars following the rain at the end of the period.

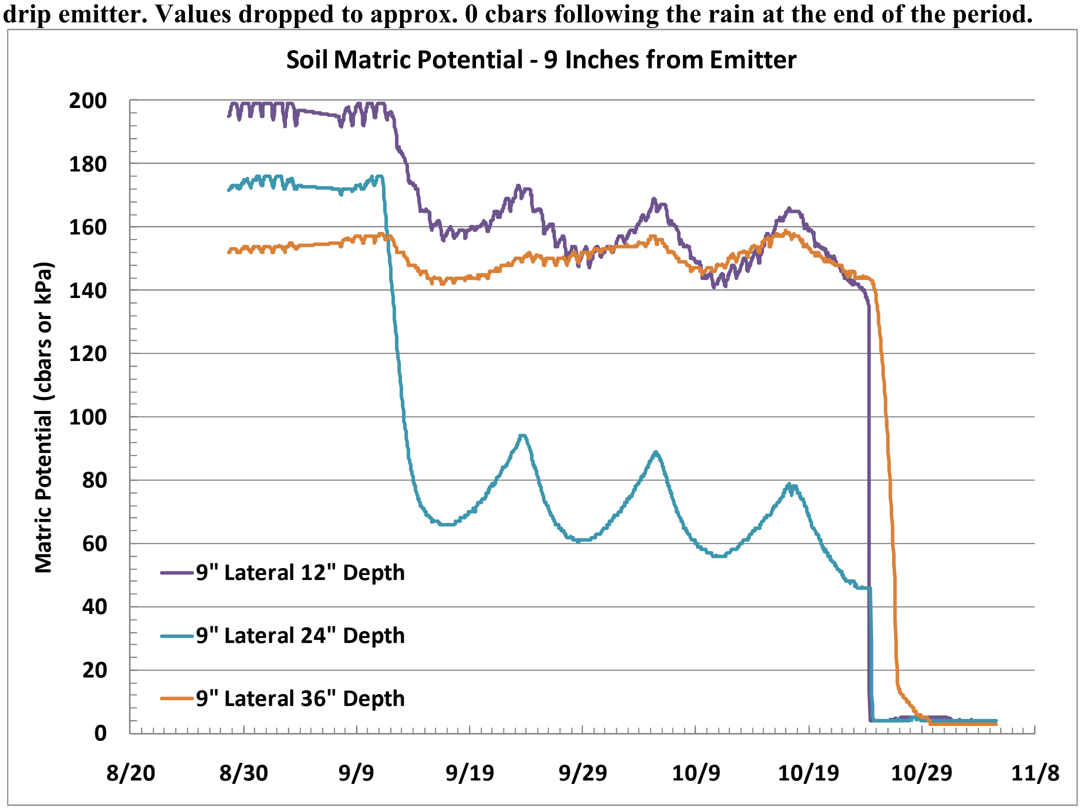


Figure 8: Soil moisture (matric potential) profile during the irrigation period of soil 9 inches laterally from a drip emitter. Values dropped to approx. 0 cbars following the rain at the end of the period.

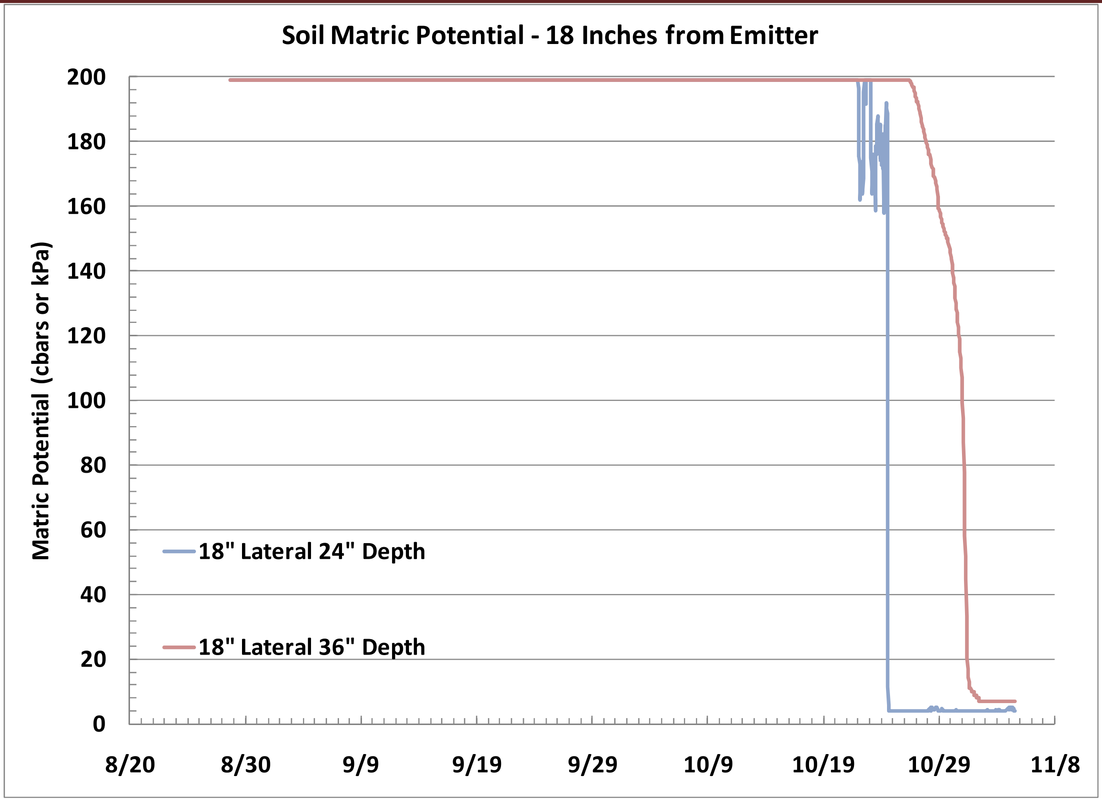


Figure 9: Soil moisture (matric potential) profile during the irrigation period of soil 18 inches laterally from a drip emitter. Moisture plume did not reach the sensors 18" from the emitter during the series of irrigation applications.Values dropped to approx. 0 cbars following the rain at the end of the period.

Vine Water status monitoring

Weekly measurements of vine water status were made throughout the season, from June through October and on days when irrigation was not being applied. For reference, a plot of phenological states, using the Modified Eichorn-Lorenz system[1] is shown in **Figure 10.** Veraison occurred on August 6, at which time the shoot tip ratings were indicating a stopped growth condition. Irrigation was delayed past this stage because midday leaf water potential measurements did not indicate sufficient levels for initiation. Weekly midday leaf water potential measurements (using the pressure chamber) appear in **Figure 11**. Note that more negative values of leaf water potential indicate more stress (i.e. lower energy state of water in the plant's xylem vessels). Data are displayed as two-period moving averages to reduce transient changes in measurements which distract from the overall trends.

With little exception, the leaf water potential values of the treatments did not reach excessive stress levels, with levels remaining above -14 bars, and mostly remaining around -12 bars. This was truly an unusual year in that the levels remained rather high (i.e. less negative) than they normally do during any given time period. Note that the

[1] Pearce, I. and B.G. Coombe. Grapevine phenology. In. Viticulture: Volume 1 – Resources. Winetitles, Adelaide, Australia. p.153.

threshold for irrigation initiation was not reached until early September, at which time the values varied over a 2 bar range despite not being irrigated. It is most interesting to note that the -15 bar treatment, which did not receive any irrigation, did not get overly stressed during the measurement period. In fact, the level of water potential rose to about -12 bars towards the end of the season, which was about the same as the levels measured in the irrigated treatments, except for the 1GPM emitter/vine treatment, which was consistently less stressed by this evaluation method.

Midday leaf stomatal conductance values, as measured with the leaf porometer, are shown in **Figure 12**. Stomatal conductance values tend to exhibit greater variability than do leaf water potential values because of its sensitivity to environmental conditions, although the variability amongst these measurements tended to decline as the season progressed. This growing season was unusual in that the substantial spring rainfall, coupled with very mild early summer temperatures, caused relatively high stomatal conductance values. For best wine quality of many red varieties, including Cabernet Sauvignon, it is desirable to have stomatal conductance levels decline to about 150 mmol m^{-2} s^{-1} by veraison and hold between 100-150 mmol m^{-2} s^{-1} until harvest. However, we

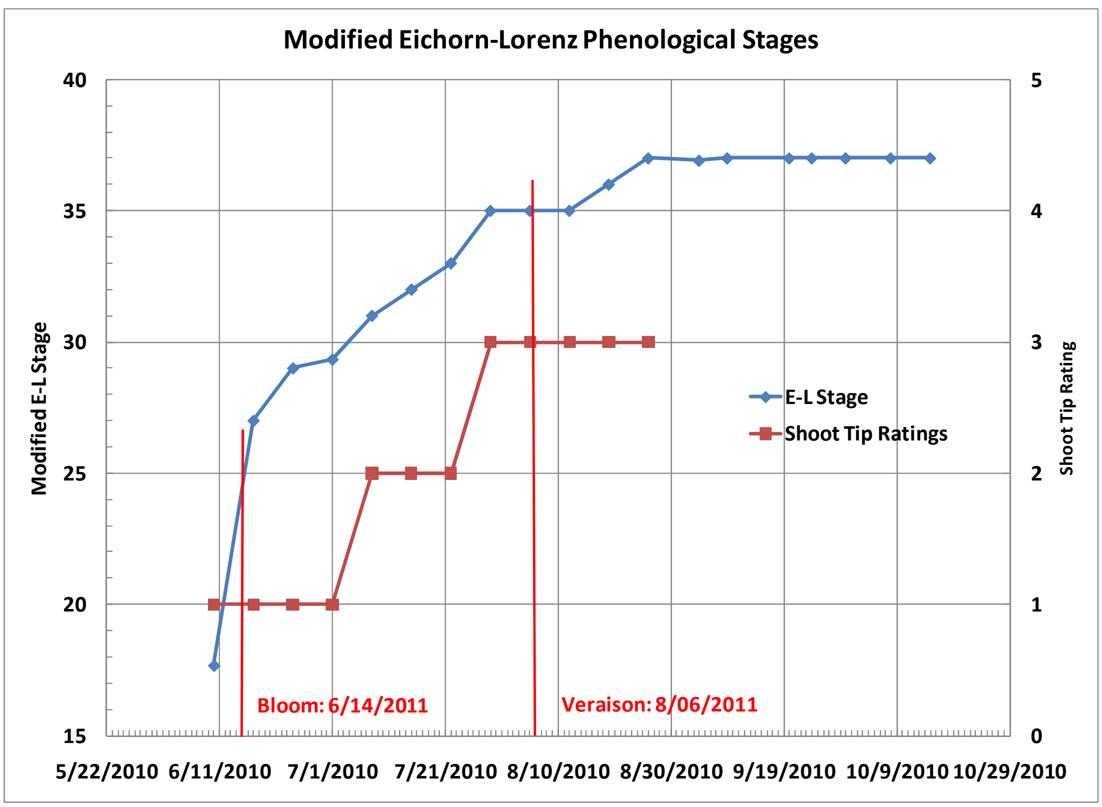


Figure 10: Plot of Modified Eichorn-Lorenz growth stage and shoot tip rating (see appendix for reference). Bloom and veraison dates are indicated. A shoot tip rating of 3 indicates stopped vegetative growth, which is used as one of the triggers for irrigation initiation.

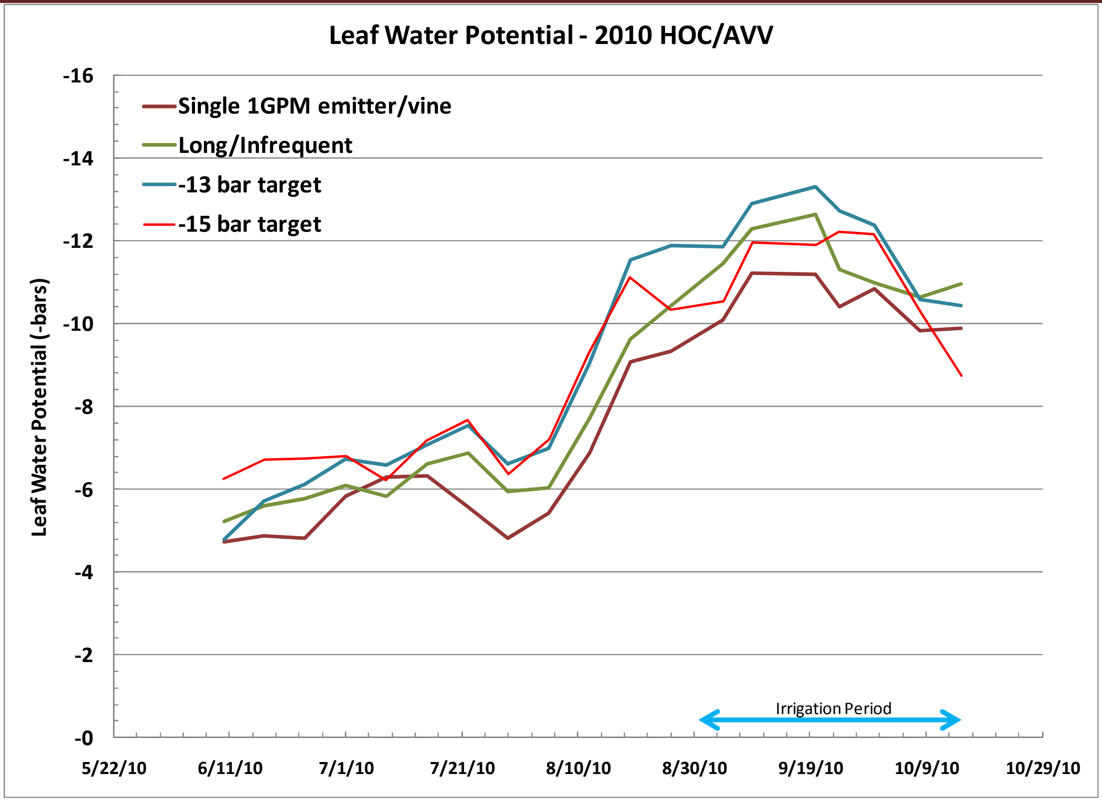


Figure 11: Midday leaf water potential measurements made at weekly intervals. Leaf water potential values above -10 bars indicates excessive water availability, between -10 and -12 bars indicates limited water resources, between -12 and -15 bars indicates moderate to mild water stress and below -15 bars indicates severe water stress. In order to improve clarity, values shown represent a 2-period moving average. Arrow bar at the bottom indicates irrigation time period.

did not reach 150 mmol m^{-2} s^{-1} in any treatment in 2010, though that level was approached near harvest. The single 1GPM emitter per vine treatment tended to show lower stomatal conductance values than the others before irrigation started. It is unclear, but possible, that that was a carry-over effect of the 2009 irrigation regime. If so, then the single 1GPM emitter regime may be desirable at this particular site, which is unusual as most sites (having lighter or shallower soils) benefit from additional emitters per vine so as to spread out the irrigation to cover a greater soil volume. Nevertheless, the lower stomatal conductance of that treatment was probably responsible for the higher (less negative) leaf water potentials measured for that same treatment.

Plots of monthly averages of leaf water potential and stomatal conductance are shown in **Figure 13**. There are not distinct tendencies for any one treatment to be different from the others, though the single 1GPM emitter/vine treatment, as mentioned before, is consistently less negative than the others, at least until October. The most interesting finding is that the -15 bar treatment, which was never irrigated, was not different from the irrigated treatments, suggesting that irrigation was not necessary this season for this block. Even more interesting is the average stomatal conductance of the -15 bar treatment, which was consistently higher than the other treatments. Because this treatment was adjacent to a Chardonnay block, it is possible that there was some influence of the chardonnay irrigation on that treatment, though that is unlikely. Because this demonstration was not a replicated field experiment, it is not possible to know whether or not it is an anomaly. However, the stomatal conductance was higher in that treatment well before irrigation commenced for the season, suggesting that it is not a consequence of the treatment. Note that the 2010 season was a very unusual year for this particular measurement. The reason for the high stomatal conductance values measured in 2010 here and elsewhere in the north coast was likely a result of the unusually cool weather following the extended spring rainfall season.

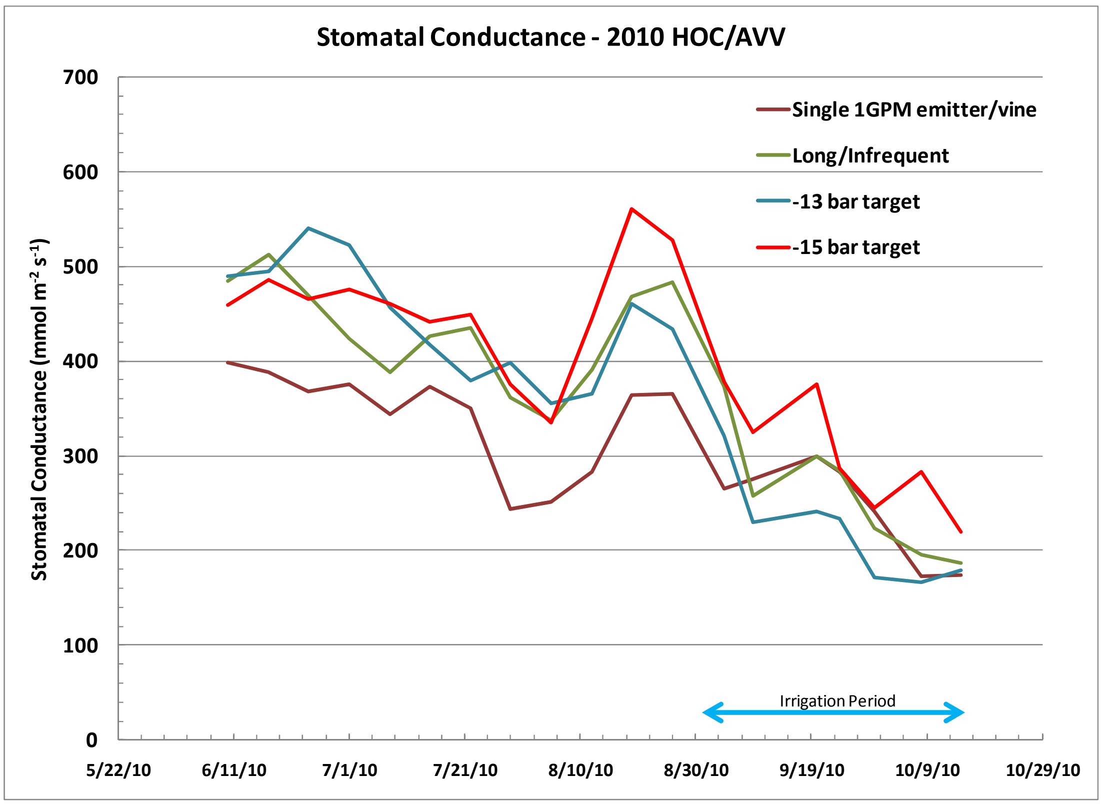
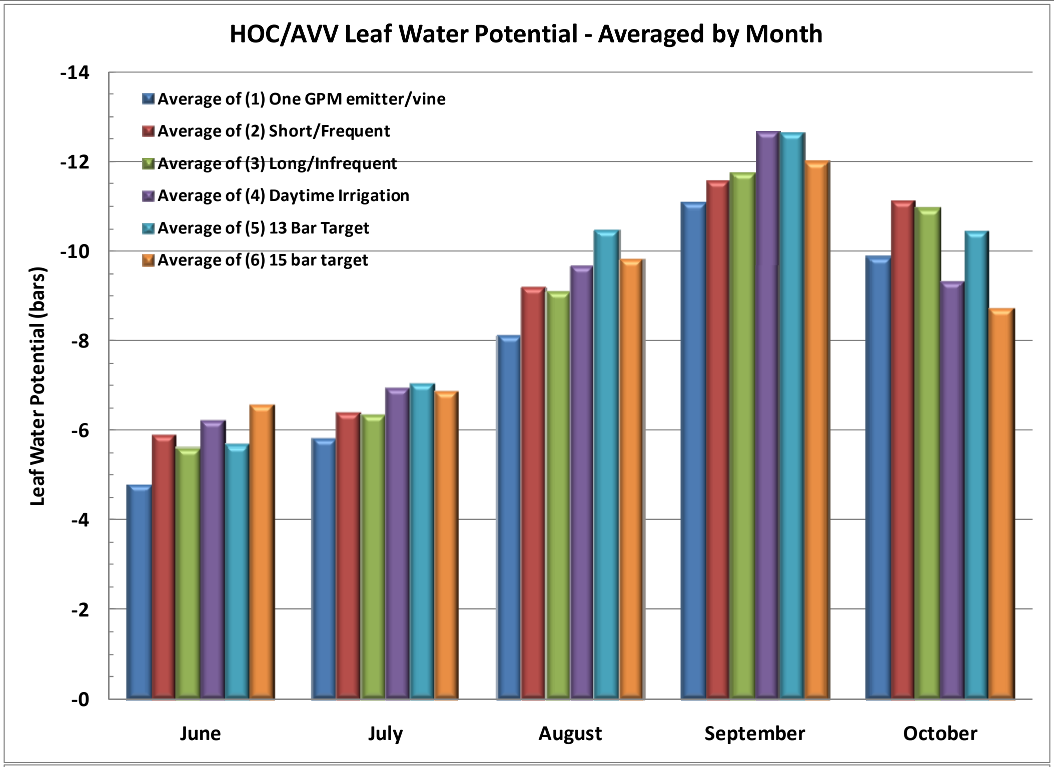


Figure 12: Midday stomatal conductance measurements made at weekly intervals. Values within 100 to 200 mmol m^{-2} s^{-1} indicate water-use-efficient conditions while those below 100 mmol m^{-2} s^{-1} indicate excessive water stress. In order to improve clarity, values shown represent a 2-period moving average. Arrow bar at the bottom indicates irrigation time period.



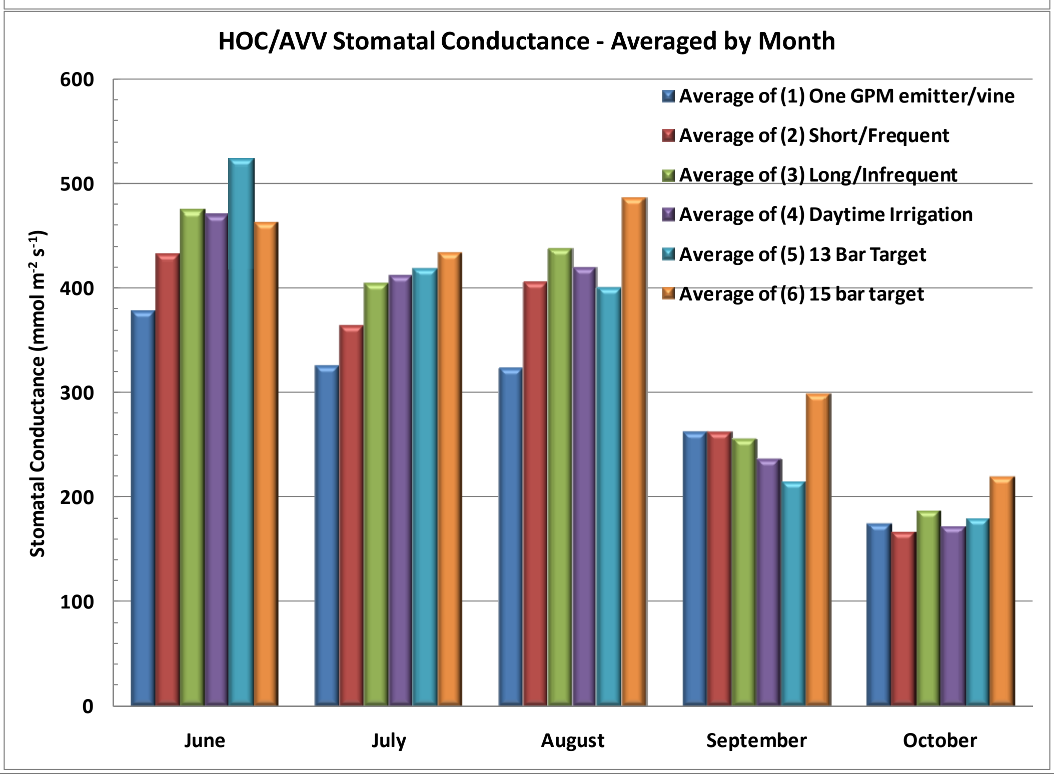


Figure 13: Monthly average values of vine water status measurements made during the growing season. More negative levels of leaf water potential (above) indicate greater stress while lower levels of stomatal conductance (below) indicate greater stress.

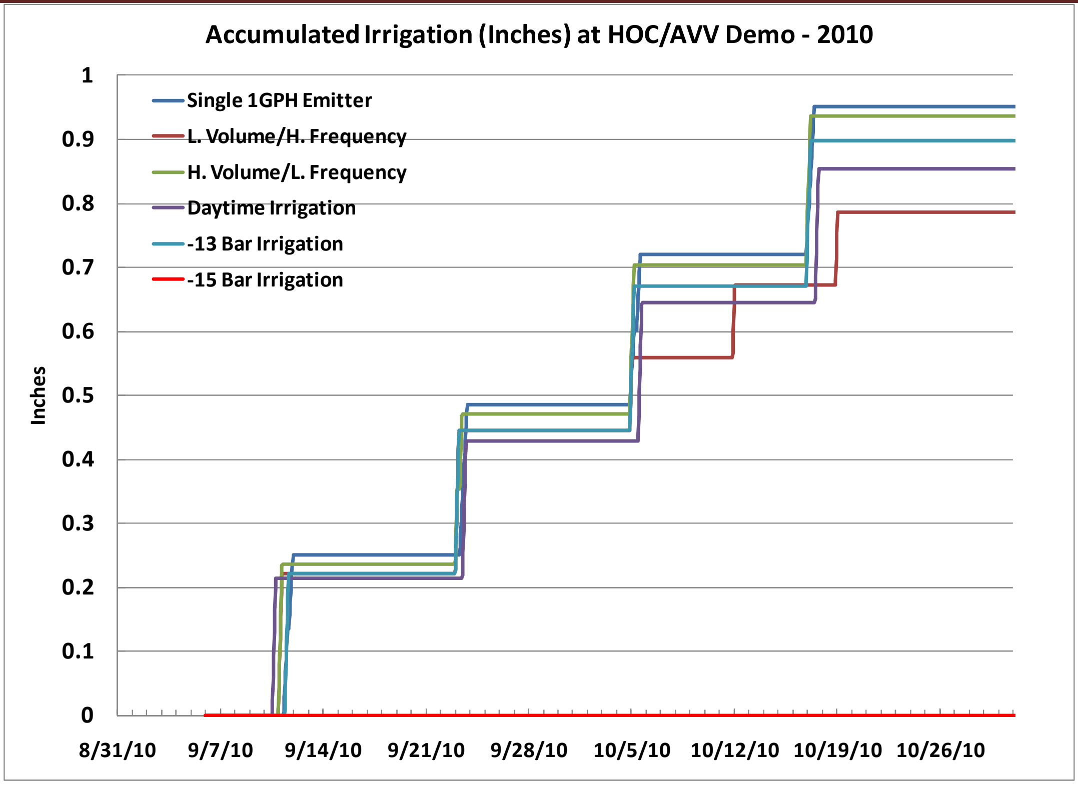


Figure 14: Accumulated irrigation volumes during the growing season for the six irrigation treatments at HOCV/AVV.

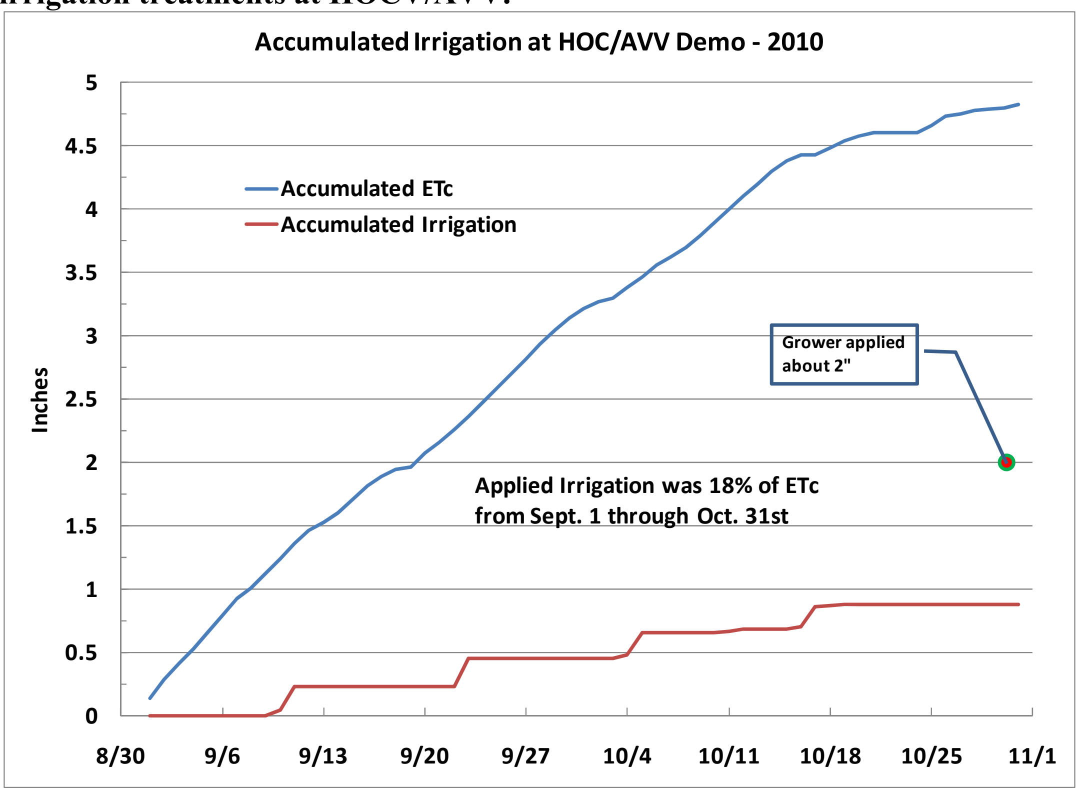


Figure 15: Accumulated ETc and accumulated irrigation for the 2010 irrigation period for HOCV/AVV demonstration site.

Net Water Applications and Savings from Commercial Practice

Accumulated rrigation application volume, measured by flow meters within each of the treatment rows, is shown in **Figure 14**. Because of some valve opening/closing failures, and the short irrigation season, the total volumes differed somewhat among the 5 irrigated treatments. Total irrigation applied ranged from 0.8 to 0.95 inches, effectively, with an average application of 0.9 inches. Compared to ETc during the months of September and October, the irrigation applied represents only 18% of crop ET (**Figure 15**). This is much lower than most would consider necessary using ET as a basis for irrigation. It points out the value of the soil moisture based approach to irrigation scheduling, which led to a substantially lower application volume than would have probably been used. For reference, the surrounding block, connected to the main irrigation system, received approximately 2 inches of irrigation.

The vineyard manager is well-informed of best irrigation management practices and, indeed, the volume of water applied in this block (2 inches) was not at all excessive per the standard practice for Alexander Valley (about 6 inches, though probably more typically 3-4 inches in 2010). Using soil moisture monitoring devices and plant water status monitoring devices, irrigation volumes in the demonstration project were markedly lower than the commercial practice. The -15 bar treatment, of course, was not irrigated at all. **This represents a savings of about 55% from standard practice for treatments #1-5, and 100% savings from the -15 bar treatment.**

Water savings relative to commercial practice arose largely by delaying the onset of irrigation for as long as possible. This is a practice that is particularly effective in climates with high levels of off-season (i.e. winter) rainfall, such as the California north coast wine growing region. Irrigation initiation occurred on September 10th in the demonstration block. It should be noted that the relatively high spring rainfall allowed for a late irrigation start. In fact, the commercial vineyard began its irrigation season three weeks later than usual for this reason.

Besides delaying the onset of irrigation, the use of soil moisture monitoring devices paired with frequent plant water status monitoring, allowed for efficient irrigation applications that further reduced irrigation needs for this demonstration vineyard.

Energy costs for pumping were $15.33/acre (87 kWh) for the commercial irrigation practice versus and average of $8.43/acre (48 kWh) for irrigation treatments #1-5.

The water savings summary is summarized below along with estimates of energy savings, energy cost savings and CO_2-equivalents of savings due to energy use reduction[2]:

[2] 0.718 kg CO_2 per kWH electricity per US EPA

	Per Acre Savings				
Treatment #	**Gal./Acre**	**In./Acre**	**$/Acre**	**kWh/Acre**	**lbs. CO_2/Acre**
2009 Data					
1 to 4	68015	2.5	**$ 19.16**	**108**	**127**
5	70767	3.3	$ 25.56	144	170
6	90763	4.0	$ 30.69	172	204
2010 Data					
1 to 5	29,869	1.1	$ 8.43	48	56
6	54,308	2.0	$ 15.33	87	102

When extrapolated over the estimated 60,000 acres in the geographic region of interest (Russian River Basin), the estimated total savings were as follows:

Treatment #	**Acre-ft.**	**$**	**kWh**	**Tons CO_2**
2009 Data				
1 to 4	12,524	$ 1,149,389	6,456,154	5,099
5	13,031	$ 1,533,796	8,615,377	6,804
6	16,713	$ 1,841,315	10,342,723	8,169
2010 Data				
1 to 5	5,500	$ 504,762	2,835,264	2,239
6	10,000	$ 917,749	5,155,025	4,071

The reduced irrigation levels relative to commercial irrigation did not have an impact on yield in 2010. Estimated yields in the harvested treatments was the equivalent of 5.5 T/Acre, and was the same in the adjacent row that was irrigated per commercial practice.

Potential quality differences

Treatment	Material	Alcohol %	Lactic Acid (mg/L)	Malic Acid (mg/L)	Ammonia (mg/L)	NOPA-N (mg/L)	pH	Brix	TA (g/100ml)	Tannin (mg/L)
Commercial Practice	Must				87	100	3.45	22.9	0.56	454
-13 Bar Target	Must				58	77	3.41	23.7	0.57	466
-15 Bar Target	Must				70	85	3.38	23.7	0.59	517
Commercial Practice	Wine	13.92	85	1460			3.71		0.59	1754
-13 Bar Target	Wine	13.88	85	1400			3.68		0.60	2008
-15 Bar Target	Wine	14.08	73	1419			3.70		0.64	2177

Table 1: Must and wine composition of small-lot wines (non-replicated)

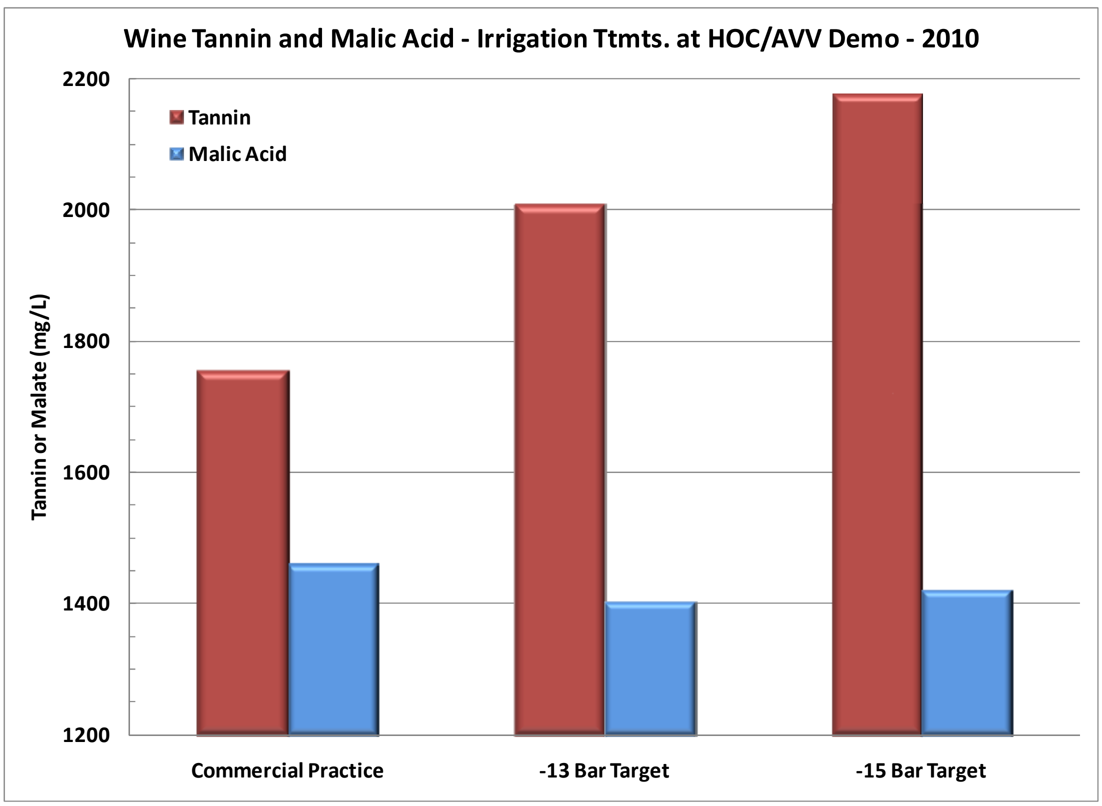


Figure 16: Total tannin and malic acid for small-lot wines made from two of the irrigation treatments along with vines adjacent to the demonstration plot irrigated per commercial practice.

While water conservation was the primary emphasis of this demonstration project, irrigation conservation has the side-benefit on wine grapes of potential improvements in wine quality. Successive sampling and chemical analyses on fruit (see Appendix) indicated no differences among the treatments. Small-lot experimental wines (approx. 120 lbs. of fruit each) were made from some of the treatments. Since 5 of 6 treatments were irrigated similarly this year, we chose the -13 bar target treatment to represent the majority of treatments, the -15 bar target treatment to represent an un-irrigated treatment, and the adjacent row outside of the demonstration to represent commercial practice.

At the time of writing of this report, the wines were in bottle, but not yet ready for sensory evaluation. Results of a bench tasting and any subsequent evaluations will be appended to this report. Composition of the must and wines are shown in **Table 1**. The primary components of interest are illustrated in **Figure 16**. Malic acid is slightly higher in the commercial practice treatment, while it is nearly the same in the other two treatments. Because the two treatments in the demonstration were irrigated quite differently (actually, the -15 bar target was not irrigated), this components is probably not significant. On the other hand, the total tannin level seems to be inversely related to the level of irrigation. Commercial practice, with the highest irrigation amount, had the lowest tannin levels while the non-irrigated -15 bar treatment had the highest. Tannin is often associated with wine quality, thus the least-irrigated treatments appear to have the highest potential for wine quality.

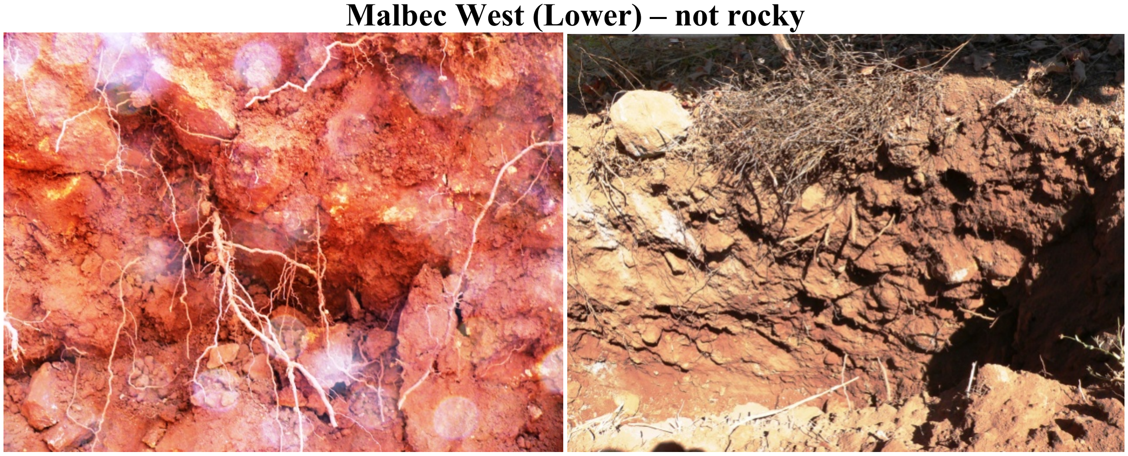
Irrigation Demonstration: Kunde/Wildwood Vineyards

The second demonstration site was added to support wine growers in the Sonoma Valley. The goal of this demonstration was not to apply specific treatments, but to monitor soil and plant water status during the growing season in three different soil and vine conditions. Feedback was provided to the grower at the end of the project. Three sites were monitored during this project:

1) A Malbec block with two different soil types. The lower portion of the block has a loamy to clay loam soil with very few, if any coarse fragments.
2) The same Malbec block as in (1), but at the top of the hill, whose soils were comprised of many coarse fragments (rocks) throughout the profile. The irrigation lines ran through both sections of the vineyard, so both soils needed to be irrigated the same.
3) A Zinfandel block on O39-16 rootstock. Block was terraced and the vines have had problems with stress late in the season, leading to problems attaining maturity.

Figure 17: Photos of soils from the three Kunde/Wildwood vineyards demo sites

Malbec West (Lower) – not rocky



Malbec East (Upper) – rocky soils

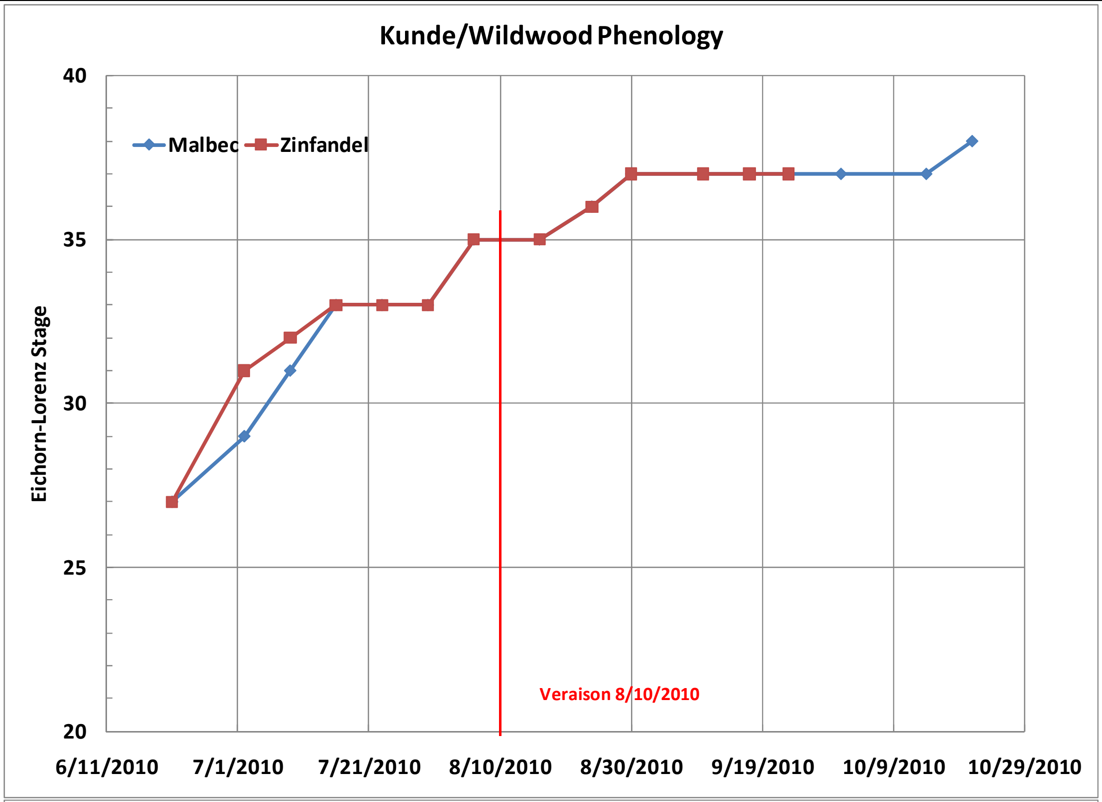

Zinfandel – gravelly clay loam soils; terraced

In each of the locations, a soil moisture probe was installed. The soil moisture probes were made by AquaCheck and are based on the same capacitance principle as the Aquaspy units used at the HOCV/AVV demonstration site, where water content is sensed using principles of dielectric constant. These probes have built-in data loggers, were logged at ½ hour intervals and off-loaded at weekly intervals. 48" probes were used at the Malbec site and a 40" probe was used at the Zinfandel site. The 48" probe has six sensors positioned at 8" intervals, starting at 8" below the soil surface. The 40" probe also has 6 sensors, with one sensor at 4" depth, and the other 5 at 8" intervals beginning at 8" of depth. Weekly measurements of leaf water potential, stomatal conductance, shoot length and shoot tip rating were made during June through October.

The phenology of the monitored sites, as well as the average shoot lengths appears in **Figure 18**. Both blocks reached veraison around the 10^{th} of August. Shoot lengths appeared to become shorter before veraison, but that was due to hedging of the vines. Thus, the natural termination of shoot growth was impossible to determine from this measurement.

Shoot tip ratings (**Figure 19**) showed that the shoots ceased growth before veraison (ceased growth = rating of 3). While the rocky section of the Malbec exhibited slowing growth a week prior to the lower, non-gravelly section, they both stopped growing at approximately the same time. Had the vines not been hedged, it stands to reason that the gravelly side would have stopped before the non-gravelly side due to greater availability of water in the non-gravelly side. On the other hand, the Zinfandel ceased its growth about 1 week prior to the Malbec.

Plots of total soil moisture for the two Malbec sites are shown in **Figure 20a**. Note that the values are not calibrated (which is not necessary), so the actual levels of the two site are not important – only the shape of the curves are important.



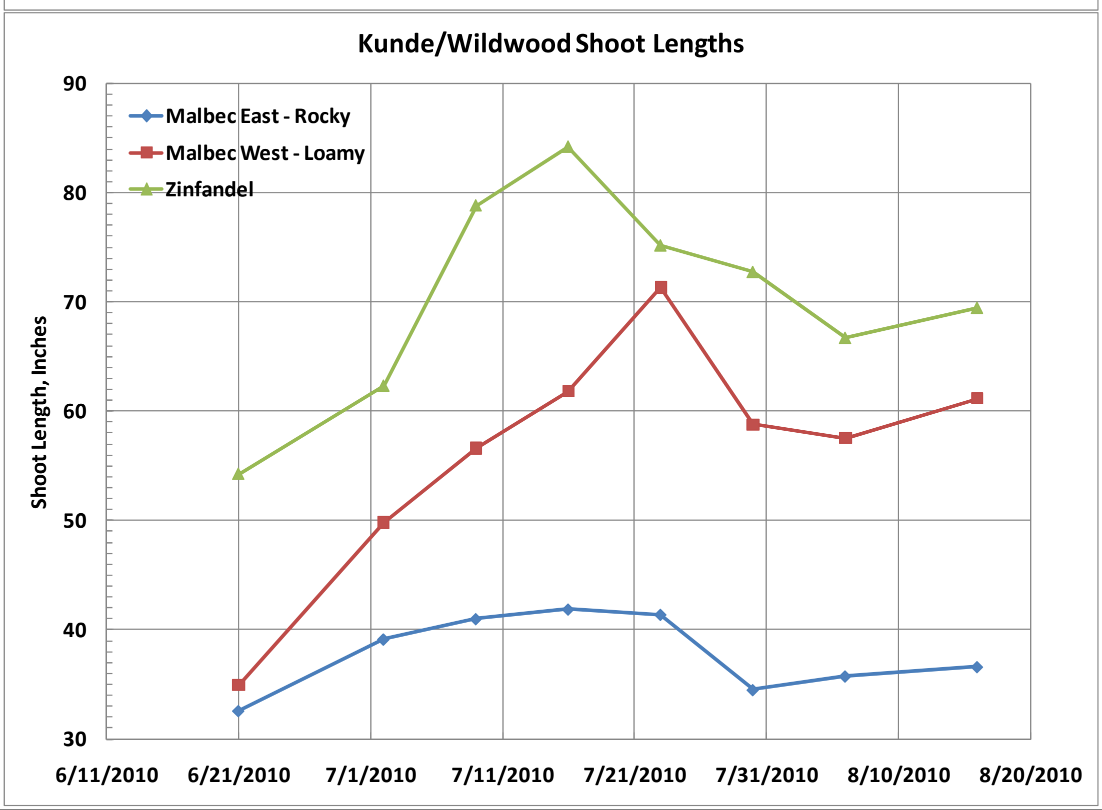


Figure 18: Modified Eichorn-Lorenz development stage (above) and average shoot length (below) for the Malbec and Zinfandel at the Kunde/Wildwood demo sites.

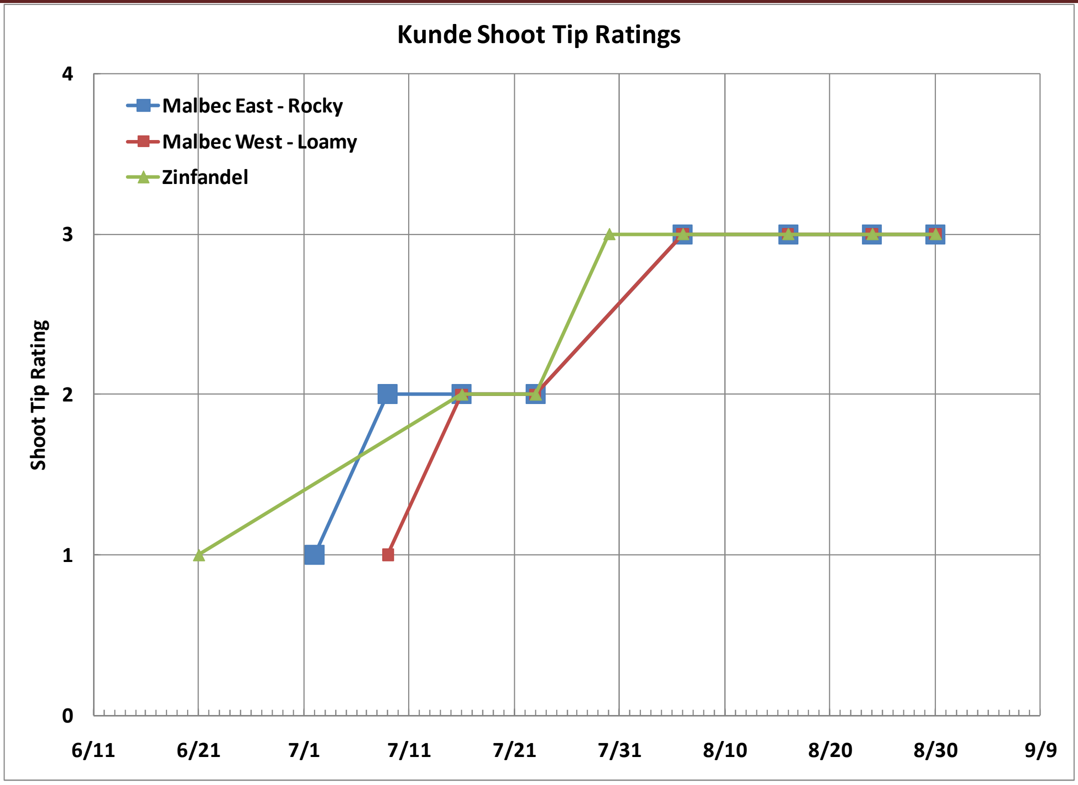


Figure 19: Shoot tip growth ratings for the Malbec and Zinfandel at the Kunde/Wildwood Vineyards demo sites. A rating of 3 indicates ceased shoot growth.

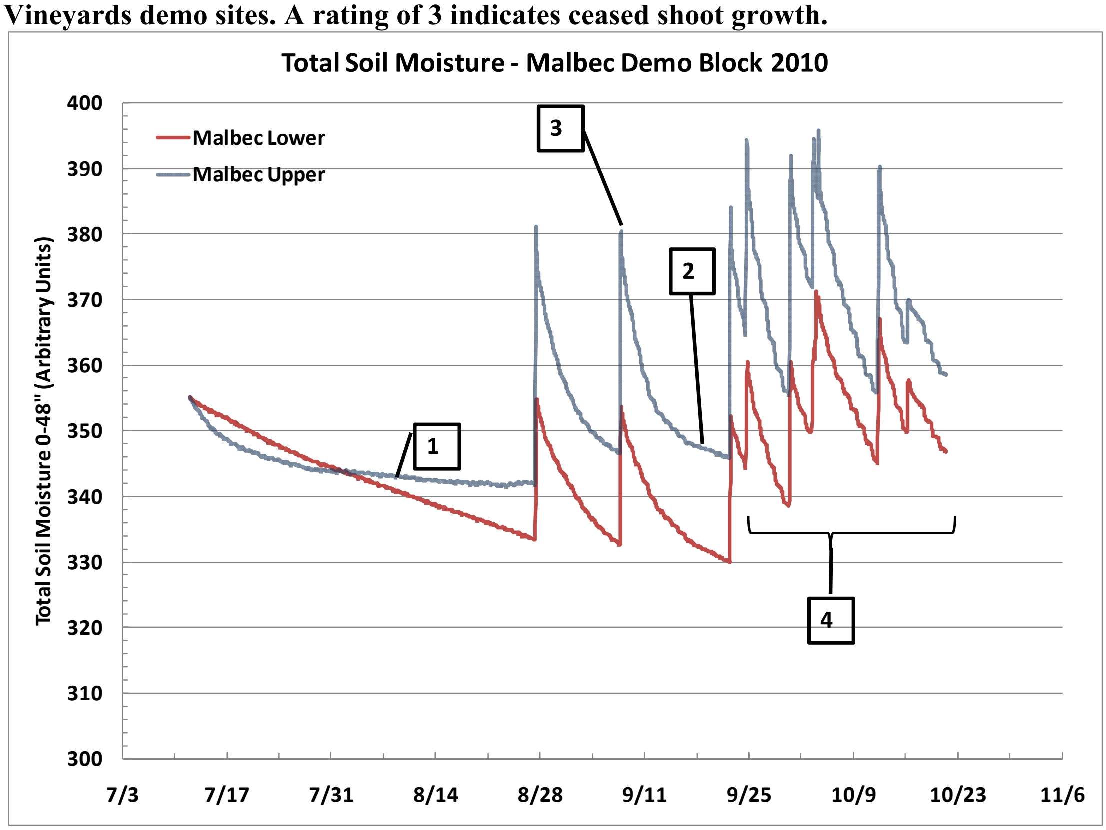


Figure 20a: Total soil moisture (relative units) beneath the emitter for the Malbec demo sites. The numerical callouts are discussed in the text.

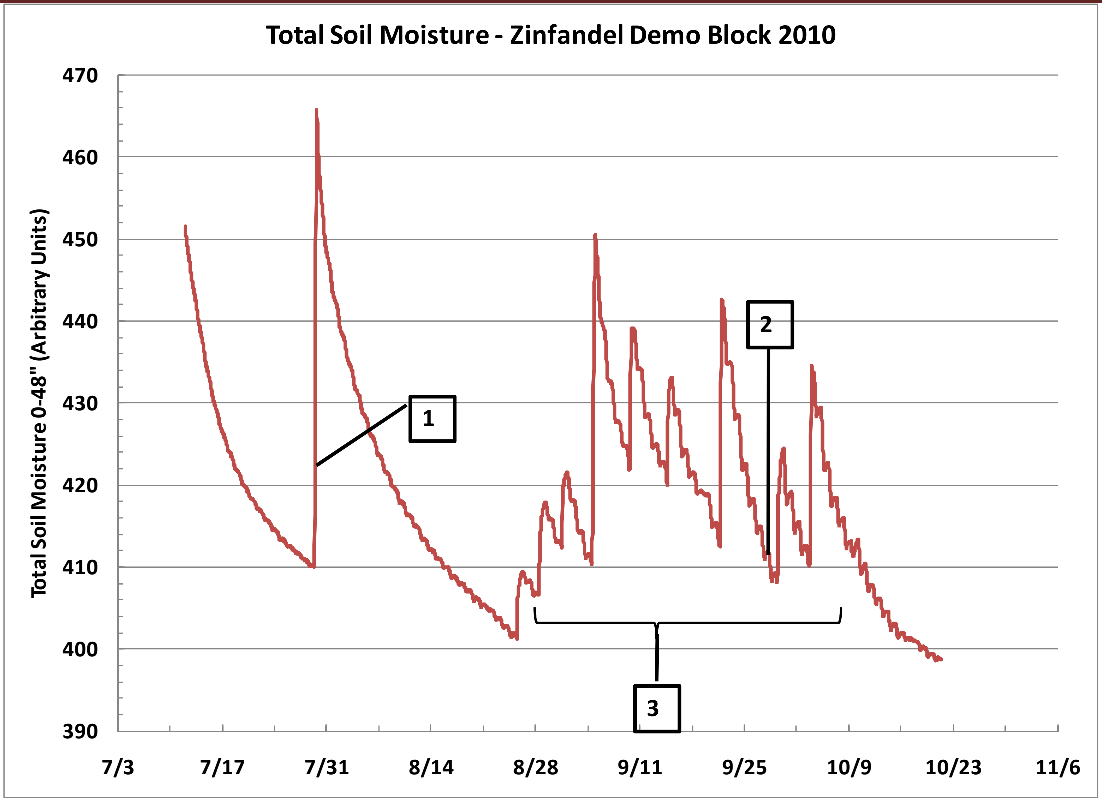


Figure 20b: Total soil moisture (relative units) beneath the emitter for the Zinfandel demo site. The numerical callouts are discussed in the text.

Several features are pointed out by the callouts as follows. (1) The lower (non-gravelly) site exhibits a declining soil moisture even before irrigation commenced. On the other hand, the upper (gravelly) site showed a flattening off of the soil moisture content curve, indicating that it was drying out before the non-gravelly site. The upper side would ideally be irrigated first, which could be accomplished by either valving off the line (depending upon where the riser feed is) or by installing a second irrigation lateral.

(2) The second irrigation interval show that the upper section flattens out more before the subsequent irrigation application, showing that the ideal irrigation interval is shorter than the other side (lower). However, it is not practical to irrigate both sides differently, so the irrigation must be tailored to the upper site to avoid excess stress. That said, it would have been generally better to allow the soil moisture to draw down to a slower rate of decline before the next irrigation so that wine quality could potentially be increased. Yet, the first two irrigations are more ideal than the irrigations that followed.

(3) The spikes in the soil moisture curves indicates drainage. Drainage is higher in the gravelly soil. The spikes are shorter in the non-gravelly soil. From the individual level charts, we will see that the drainage was within the root zone and not below it. (4) The short, irregular and frequent irrigations made during the latter portion of September and into October are not ideal for conservation, for wine quality or for ease of management. It is suggested that the vineyard adopt an approach more similar to that of the first two

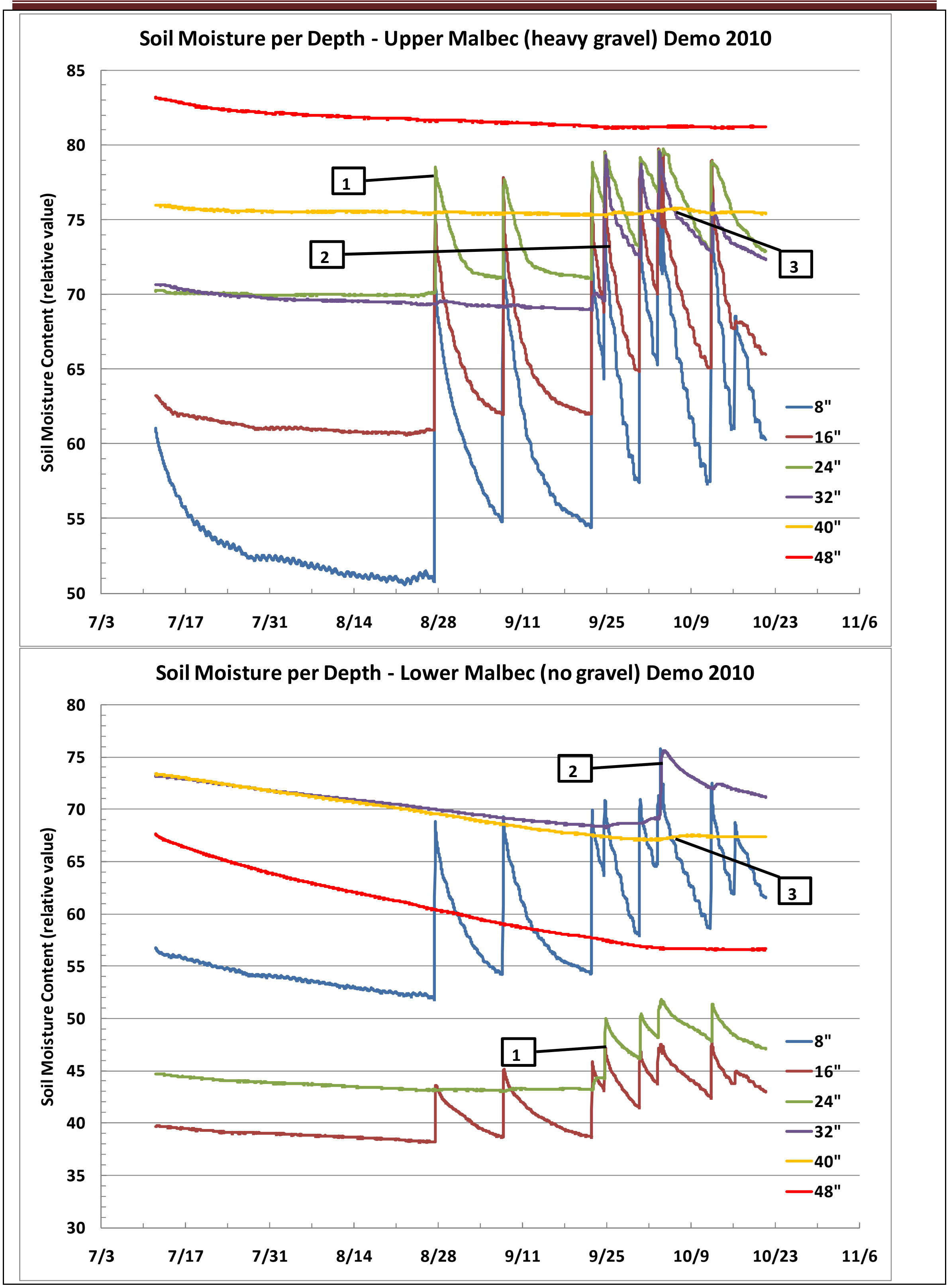


Figure 21: Soil moisture (relative values of water content) at several soil depths below the emitters for the two Malbec demonstration sites at Kunde/Wildwood.

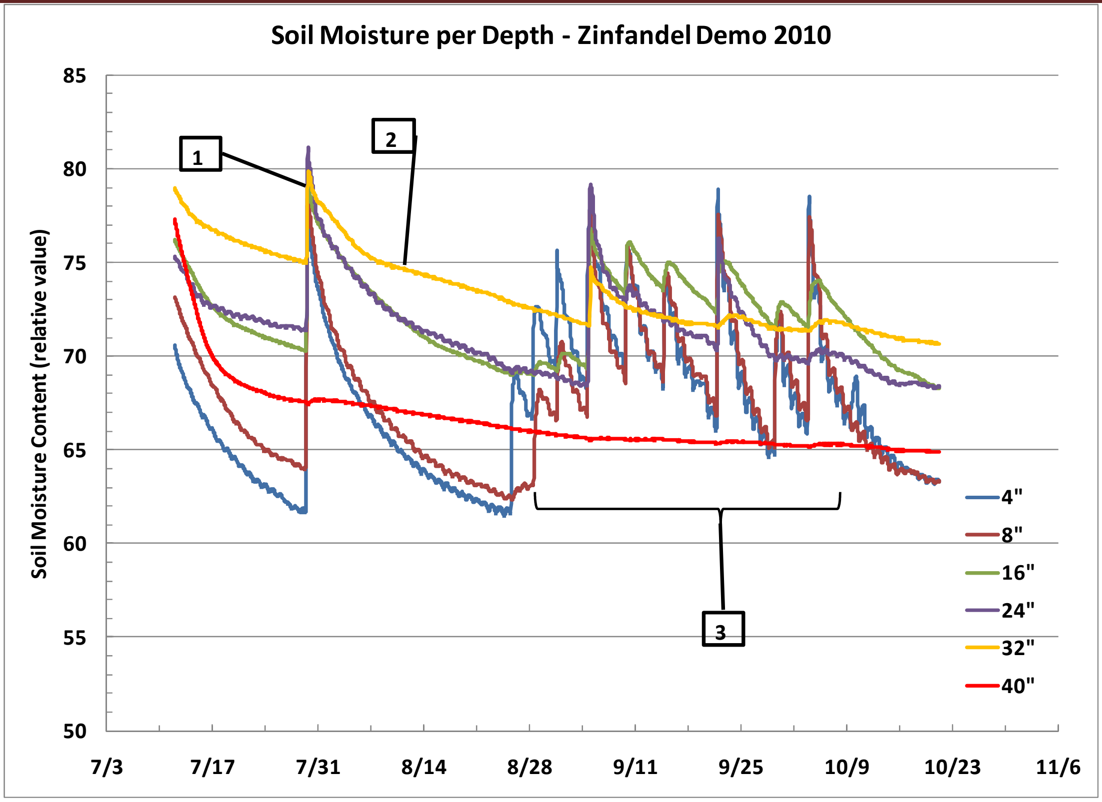


Figure 22: Soil moisture (relative values of water content) at several soil depths below the emitters for the Zinfandel demonstration site at Kunde/Wildwood.

irrigations, though with a higher volume so that the bottom of the root system (about 32-40 inches) may be irrigated during each irrigation event. The irrigation interval should be such that it begins to flatten out in the gravelly section of the block before each successive irrigation.

Total soil moisture for the Zinfandel site appears in **Figure 20b**. (1) The first irrigation event (actually applied for fertilization purposes) was actually the most ideal. The irrigation was enough to wet the entire root system (to be shown), and a long period of time was allowed to elapse before the next irrigation event. (2) Subsequent irrigation events were shorter and more frequent, leading to irregular changes in soil moisture over time. The short irrigation intervals were made before the slope of the depletion flattened out, and so the vines did not experience even a beneficial level of stress. (3) The majority of the irrigation season consisted of various application volumes and intervals. This is not the ideal way to irrigate a vineyard, as the rapid changes in soil moisture are less "natural" than full root-zone wetting and drying cycles. They are also less efficient in the long run. To the defense of the irrigation scheduler, this vineyard block is on a terrace, and long irrigation runs tend to cause water to run off of the berm and into the vine row. This may be alleviated by splitting the irrigation over two consecutive days, allowing the initial irrigation "pulse to redistribute within the profile before applying a second, probably lower-volume application to push water to deeper levels.

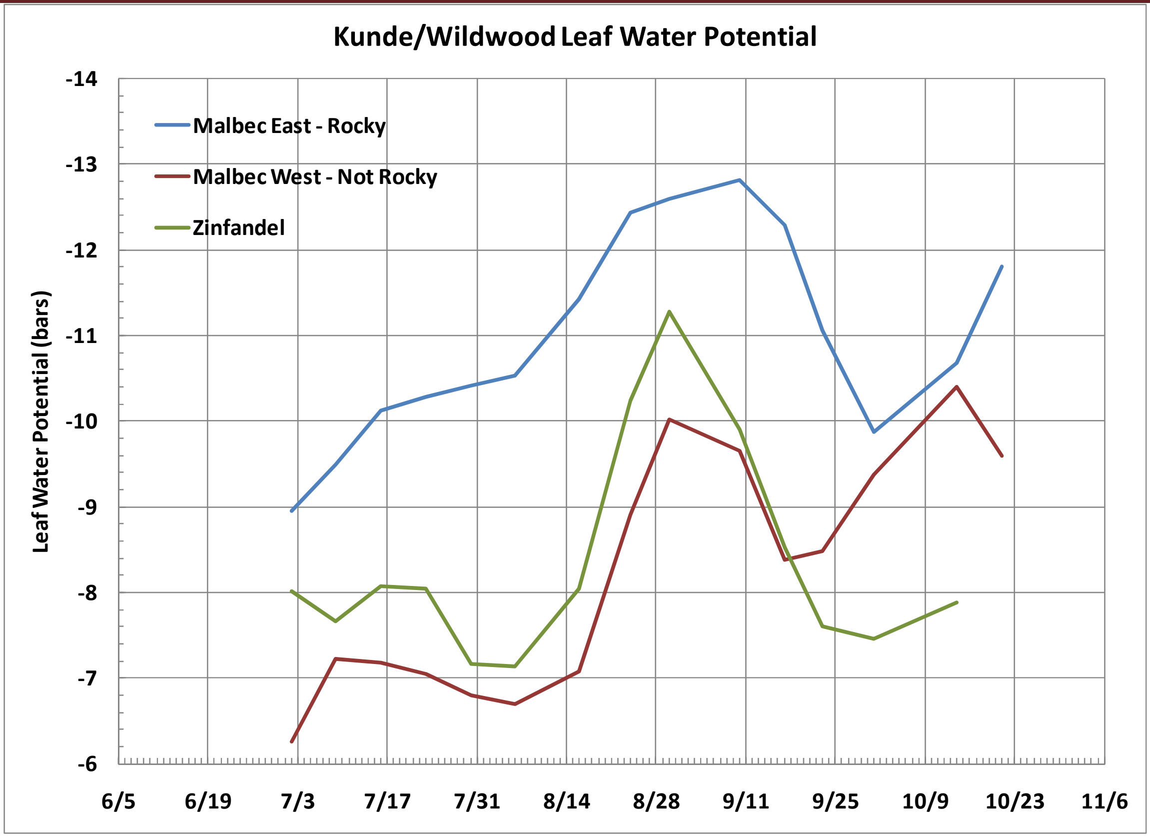


Figure 23: Midday leaf water potential measurements made at weekly intervals. Leaf water potential values above -10 bars indicates excessive water availability, between -10 and -12 bars indicates limited water resources, between -12 and -15 bars indicates moderate to mild water stress and below -15 bars indicates severe water stress. In order to improve clarity, values shown represent a 2-period moving average. Arrow bar at the bottom indicates irrigation time period.

The soil moisture by soil depth level are shown for the Malbec locations in **Figure 21**. For the Upper (gravelly) location compared to the Lower (non-gravelly) sites: (1) Initial irrigation applications reached to 24 inches at the upper location, but did not reach to that level in the lower location until the “double” irrigations that were applied towards the end of September. The gravel allowed water to infiltrate deeper, as it has less water-holding capacity per foot of soil. (2) Likewise, the soil moisture reached the 32 inch depth of the gravelly soil sooner than at the non-gravelly soil. Ideally, the volume should have been adjusted such that the 32 inch depth was reached for each irrigation and not by short intervals, which wetted primarily the shallower depths. This is the case because the root system at this site was relatively deep. (3) A very small increase in soil moisture at the 40” level was sensed towards the end of the season, but the change was minimal, indicating that the wetting front reached 32” and redistributed to 40”.

Soil moisture, by depth, for the Zinfandel location is shown in **Figure 22**. (1) The initial irrigation reached the 32” depth and was slightly sensed at the 40” depth. This suggests a good volume of irrigation for this site. Subsequent irrigations failed to regularly wet to the 32 inch depth and never reached the 40” depth. (2) Note the strong depletion of moisture at the 32” depth, indicating that that level was being used for uptake by the vine.

(3) The erratic irrigations late in the season caused wetting of the upper 16-24" only. Occasionally, the 32" depth was reached. A more regular irrigation regime would have been a better, more effective method of irrigation.

Midday leaf water potential for the three sites are shown in **Figure 23**. The upper, gravelly-soiled Malbec section had consistently lower (more negative) leaf water potential values than the non-gravelly section. The erratic, frequent irrigations toward the end of the season caused leaf water potentials to rise (become less negative), yet the vines were never in severe stress and should have been allowed to experience a greater level of water stress for sake of wine quality. It is suggested that a higher-volume, less frequent irrigation regime would have been more appropriate for this location, though it should have been irrigated with the gravelly site as a guide. Nevertheless, one would expect a wine quality difference between the two parts of the block, with the gravelly section providing a higher wine quality. Likewise, the stomatal conductance of the Malbec locations (**Figure 24**) indicates that the gravelly-soil location had consistently lower stomatal conductance, finally reaching the 150 mmol m^{-2} s^{-1} target level by harvest (at or shortly after veraison would have been ideal). The non-gravelly site remained quite high, suggesting that it was not sufficiently stressed so as to improve wine quality from this variety.

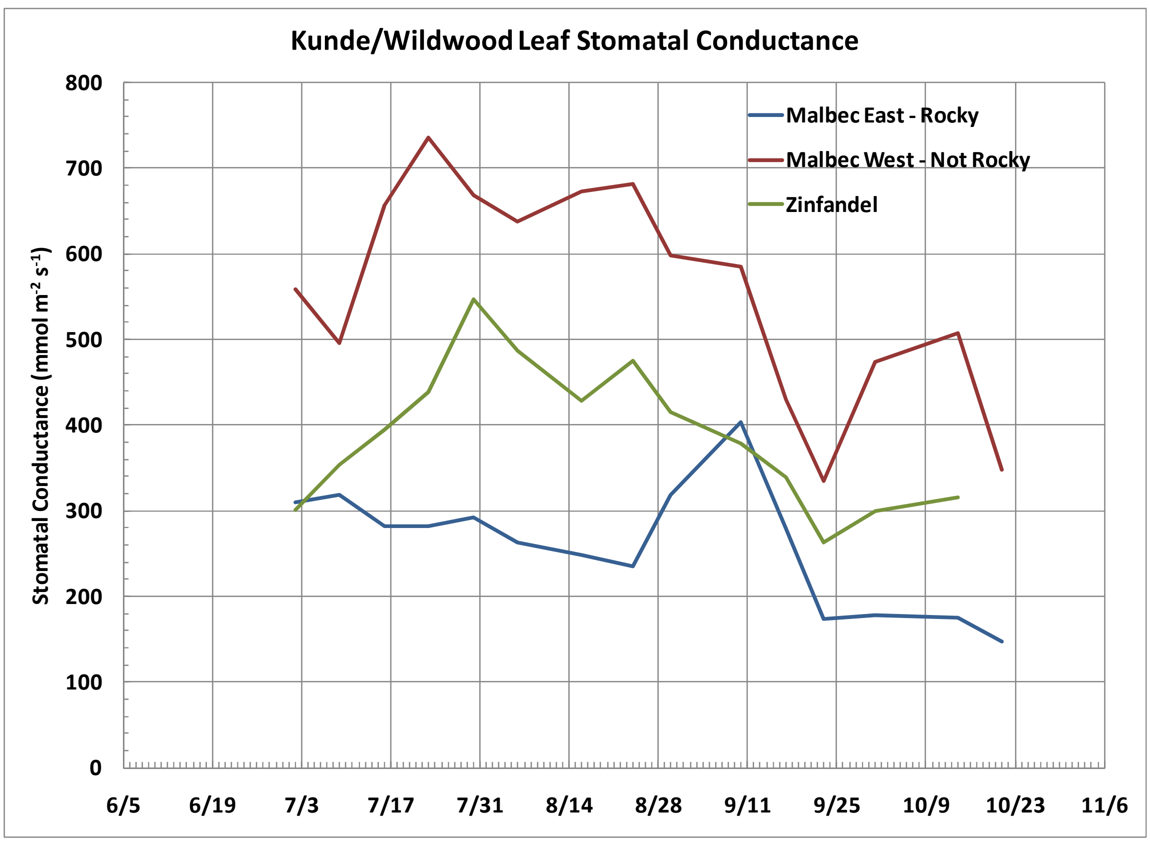


Figure 24: Midday stomatal conductance measurements made at weekly intervals. Values within 100 to 200 mmol m^{-2} s^{-1} indicate water-use-efficient conditions while those below 100 mmol m^{-2} s^{-1} indicate excessive water stress. In order to improve clarity, values shown represent a 2-period moving average. Arrow bar at the bottom indicates irrigation time period.

On the other hand, note that the stomatal conductance rose after the first two irrigation applications (gravelly site only), suggesting that the deeper irrigations may not be appropriate for this site. This contradiction can only be addressed by continued experimentation. It is suggested that an additional season be conducted in this manner to determine the ideal irrigation regime for this site.

The Zinfandel's leaf water potential fell to about -11.5 bars before the irrigations commenced during late August. The leaf water potentials rose to -7.5 bars later in the season, which is too high for a red variety such as Zinfandel. A moderate level of stress would have been more ideal. Likewise, stomatal conductance remained above 300 mmol m^{-2} s^{-1}, which is insufficient to stimulate the biochemical processes in the fruit that lead to higher wine quality. Additionally, vines that never experience water stress are less acclimated to stress and may be more negatively affected by abrupt changes in weather conditions.

Vineyard Cooling Demonstration

Project Description

The vineyard cooling demonstration portion of the project was intended to demonstrate two possible methods of vine and fruit cooling during high-heat events compared to that of an uncooled control treatment. This demonstration was conducted in a Merlot block trained to Scott-Henry trellis system and on O39-16 rootstock. Spacing was 8 feet between rows and 6 feet between vines. There were two cooled treatments, consisting of standard overhead impact sprinklers at 25 per acre (nominally 55 gallons per minute per acre) and a treatment that was pre-irrigated for 6-8 hours before an anticipated heat wave (replacing the micro-sprinkler treatment of 2009). The sprinkler system was activated when air temperatures (outside of the treatment areas) reached 102°F and was deactivated when temperatures fell below that level (or before evening, whichever came first). System activation was automated using the Ranch Systems network. Unlike 2009, where the sprinkler was run continuously, an automation program was written (which required some troubleshooting during the trial) where the system was run for ½ hour, then shut off for ½ hour, etc. The idea was that the canopy and soil were wetted from the ½ hour of application and the intervening period allowed for the water to evaporate, continuing to cool the canopy and cluster zone environment. Essentially, this saved 50% relative to continuous activation of the system during a heat event.

A one-acre buffer was left between the sprinkler plot and the one acre pre-irrigation plot. To the west of that plot was the larger control plot, which received no cooling.

For each treatment, air temperature was measured in the canopy using sheltered temperature sensors. Cluster temperatures were measured using temperature sensors that were embedded within the clusters during veraison and secured using twist ties. The sensors were situated such that they did not receive contact by direct sunlight. A total of 13 sensors were placed in clusters within each treatment. We are reporting averages herein.

Project Results

The 2010 season was abnormally cool during most of the growing season. A notable heat event occurred on August 24th where temperatures rose to well above 105°F in the vineyard. This abrupt heat event, following an abnormally cool spring and early summer, led to extensive fruit damage in the region. Very unfortunately, the system was found to have problems with leaks, valves that did not actuate properly, and the program used for the actuation, during that time period. The system was repaired shortly afterward and we were able to capture additional heat events that occurred during September.

Cluster temperature of the three treatments during 6 heat events in September are shown in **Figure 25**. The gray bars indicate when the sprinklers were activated. Without activation, cluster temperatures tended to be about 2°F cooler in the cooled trial relative to the control. This was due to natural temperature gradients that exist in that site. Subtracting off the baseline difference, we saw that the overhead sprinklers cooled the

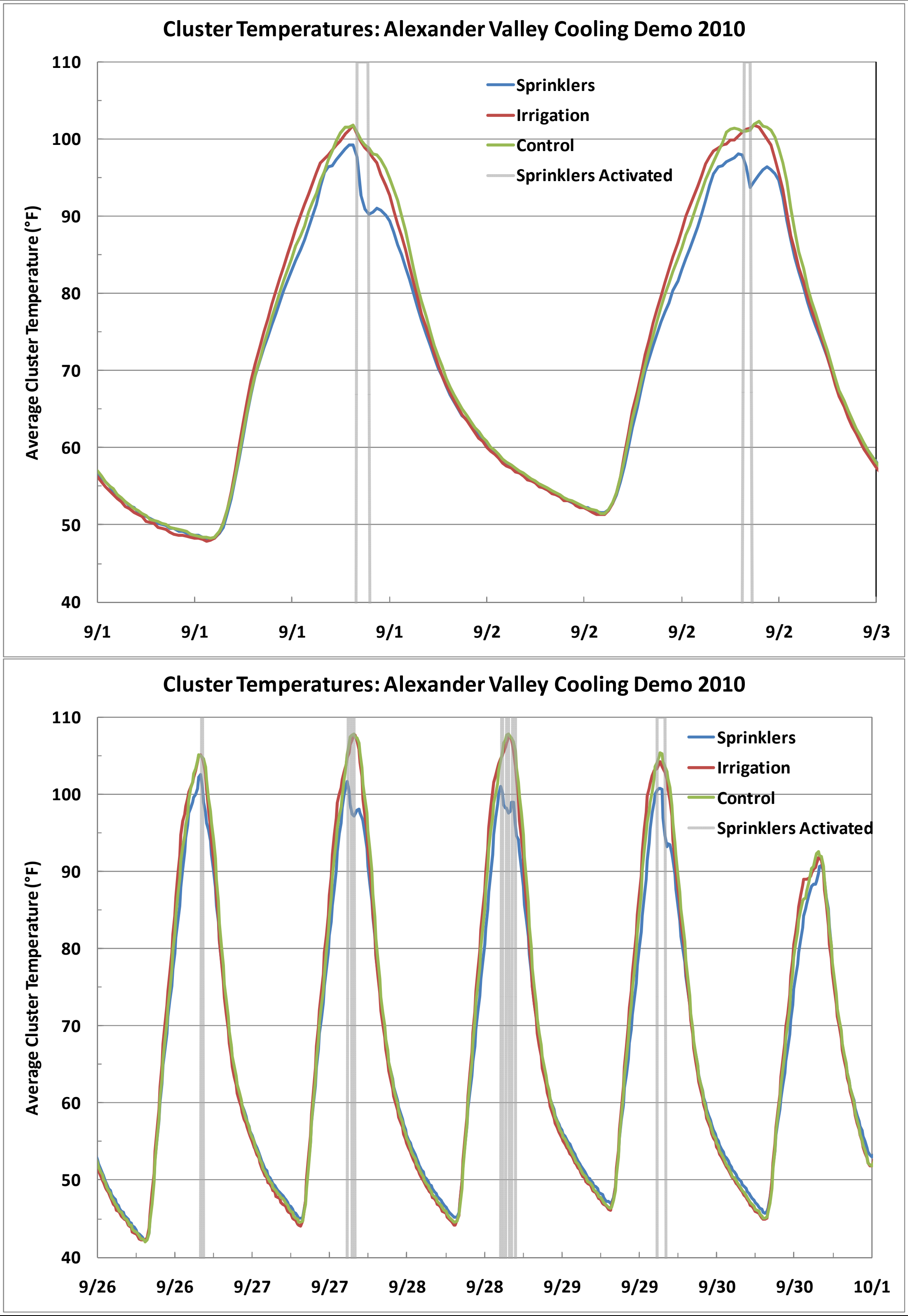


Figure 25: Cluster temperatures (average) measured during sprinkler cooling events in early September (above) and late September (below).

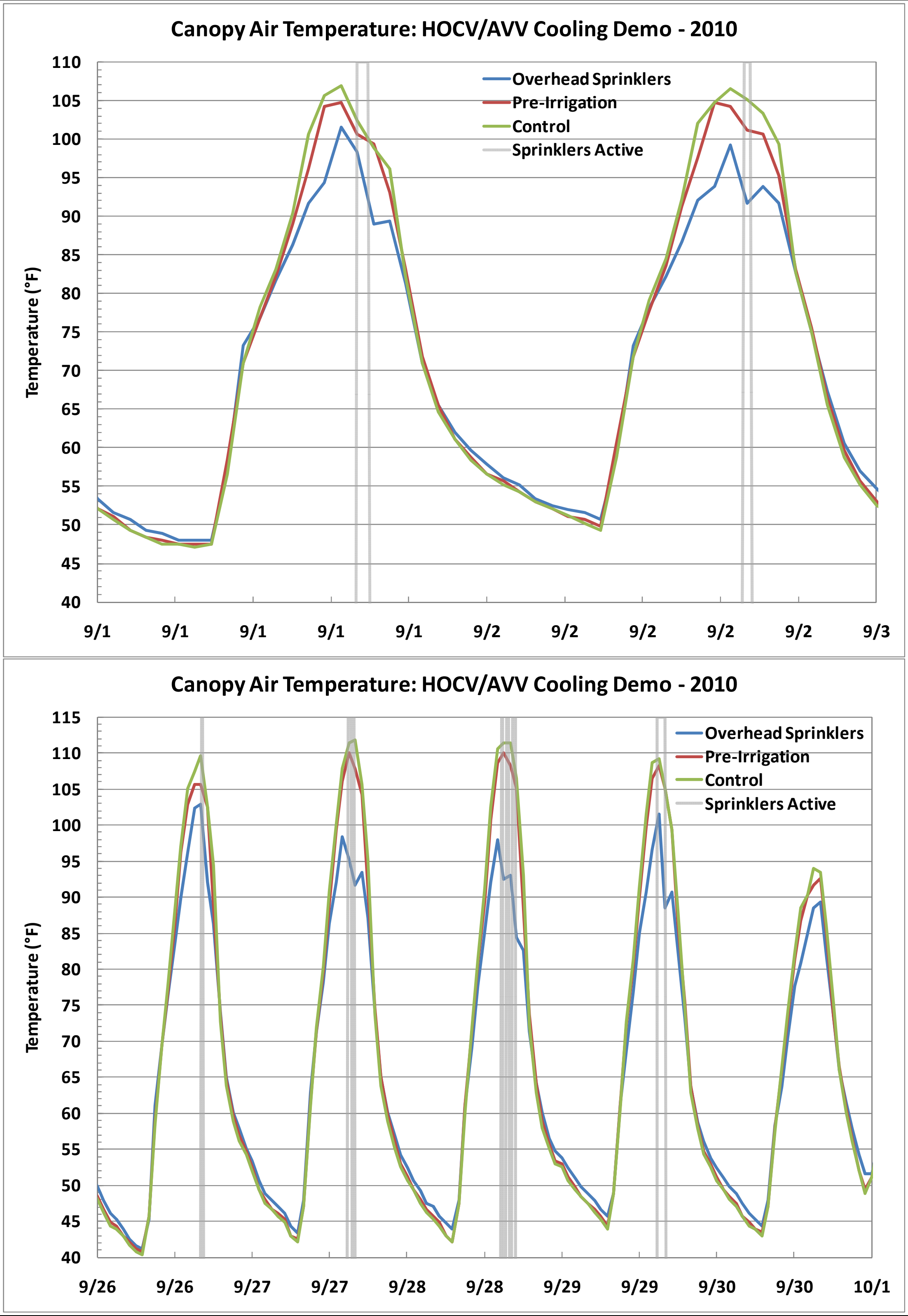


Figure 26: Canopy air temperatures (average) measured during sprinkler cooling events in early September (above) and late September (below).

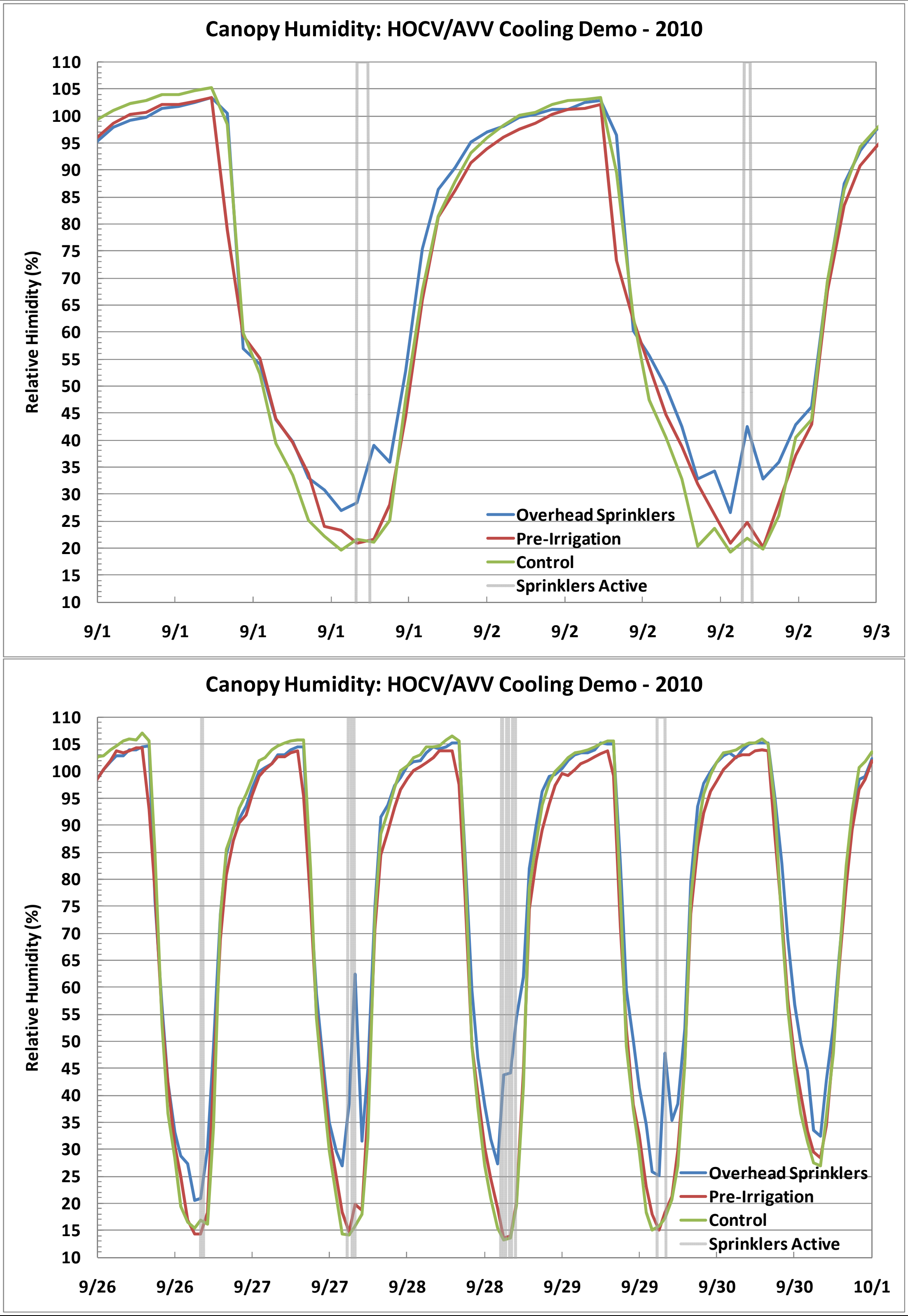


Figure 27: Canopy relative humidity (average) measured during sprinkler cooling events in early September (above) and late September (below).

clusters by about 3°F, on average. The rapid change in cluster temperatures can be seen in the charts.

Likewise, canopy air temperatures dropped when the system was activated (**Figure 26**). On average, and when corrected for the natural temperature gradient, air temperatures were reduced by an average of 6°F when the overhead sprinklers were run. Correcting for the natural gradient, the pre-irrigation treatment did not, on average, have a substantial effect on fruit or canopy temperature, showing less than a 1°F temperature drop during the heat waves relative to the control. Relative humidity increased substantially when the overhead sprinkler system was active (**Figure 27**). This could represent a challenge in using overhead sprinklers for cooling of varieties that are susceptible to Botrytis bunch rot. Nevertheless, the pulsing method combined with early shut down of the system prevented the elevated humidity from being carried over into the following day.

The minimal, if any, effect of providing the vines with a large irrigation prior to a heat event points out the fallacy of irrigating in anticipation of a heat event. Clearly, water stressed vines could likely be damaged during a heat event, as they are not able to cool themselves with transpiration as readily as vines in less water stress. But fruit, having no functional stomata, are not able to regulate their cooling. Thus, irrigation does not directly cool fruit and irrigation should be used primarily to reduce water stress, if it exists, in vines before a heat event occurs.

Despite the effectiveness of overhead sprinklers for cooling of vines and fruit during heat events, and despite conservation measures using an on/off/on type of regime, the best

Figure 28: Photos of clusters with temperature sensors in place (2009).

answer to protecting fruit from sun damage during heat events lies with the microclimate of the fruit zone. Avoiding excessive leaf removal (or any leaf removal in some cases) for vines trained to a VSP should be common practice for any region that occasionally experiences temperatures above 105°F or regularly experiences temperatures above 100°F. Row direction is also important. For Sonoma County, a row orientation roughly NE-SW will provide shade over the fruit during the hottest part of the afternoon (typically 3:00-4:00, PDST). Also, trellis modification away from a straight VSP using cross-arms will provide more shade over the clusters and for a longer period of time. These practices should eliminate the need for overhead sprinkler cooling.

Fruit & Wine Composition

Fruit was sampled a few days before commercial harvest on September 30th and send to a lab for fruit composition analysis. There was a clear gradient for Brix (**Figure 29**), where the sprinkler treatment had a much lower Brix than the control (by about 3 degrees) and a slightly lower (less than 1 degree) Brix than the pre-irrigation treatment. It is possible that these differences were due to the temperature gradient at the site. Likewise, juice pH (**Figure 30**) was highest in the sprinklers and lowest in the control. TA, on the other hand, was very similar amongst the treatments (**Figure 31**), though the chart exaggerates the differences.

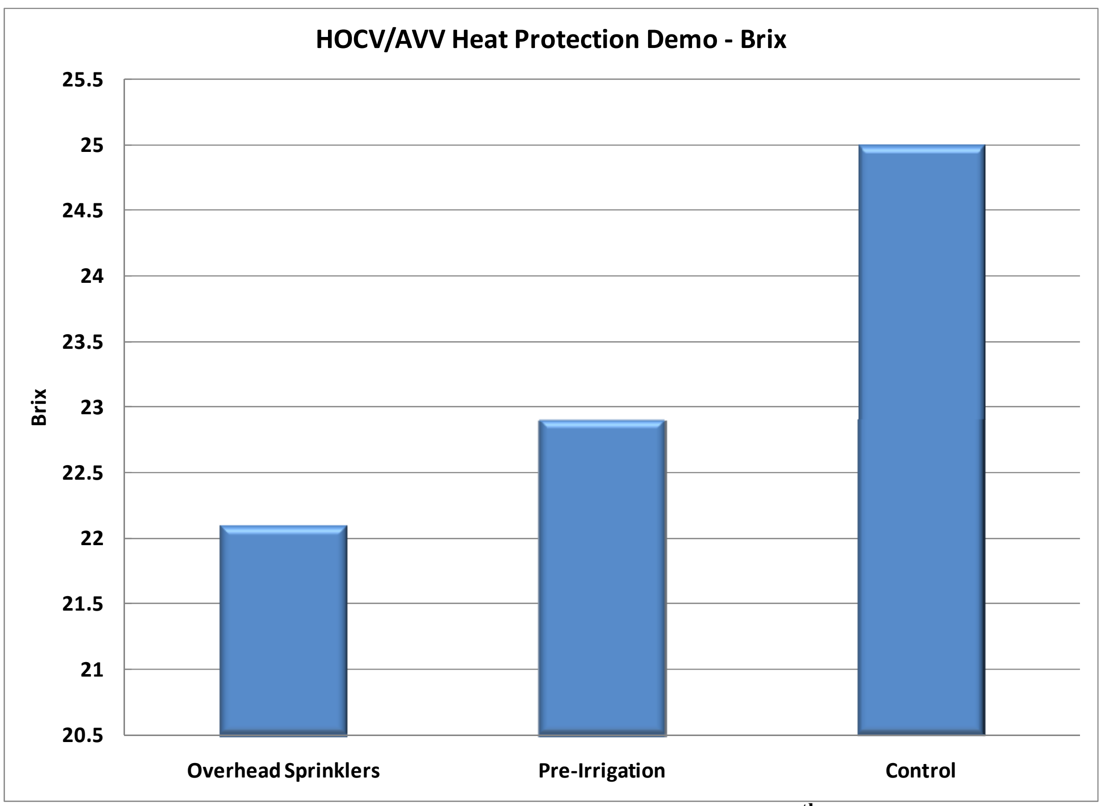


Figure 29: Brix (% soluble solids) of fruit on September 30th, just before harvest, of the Merlot in the cooling demo at HOCV/AVV.

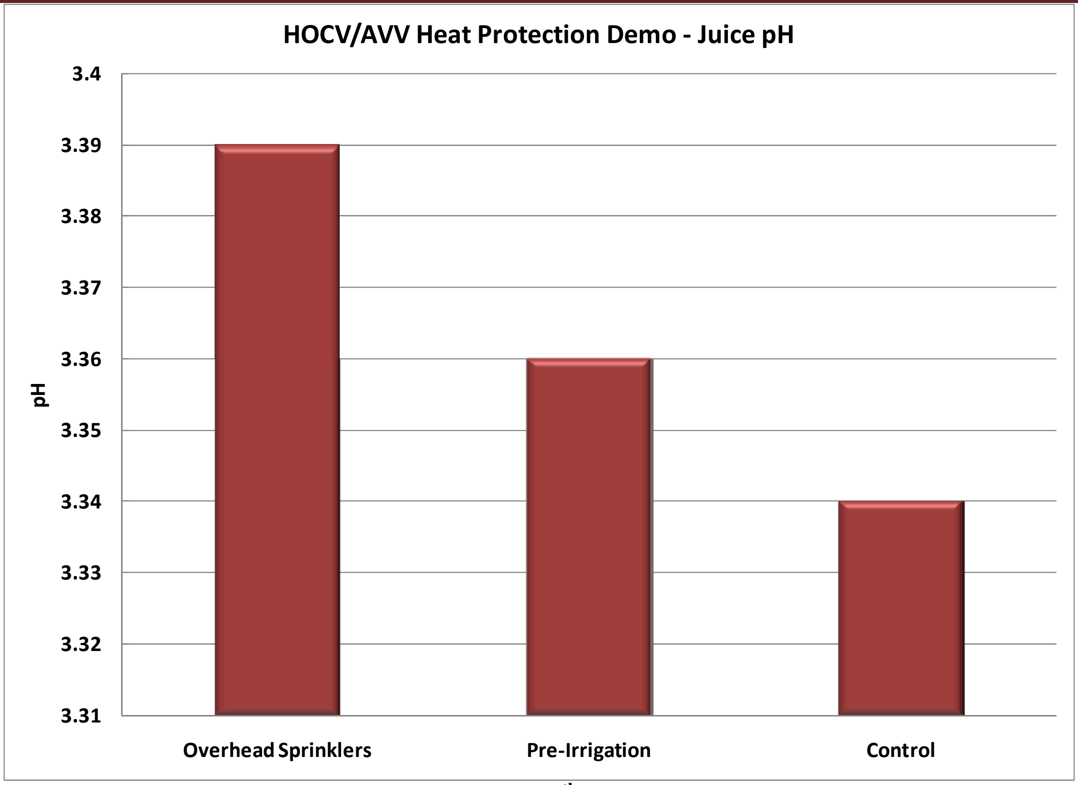


Figure 30: Juice pH of fruit on September 30th, just before harvest, of the Merlot in the cooling demo at HOCV/AVV.

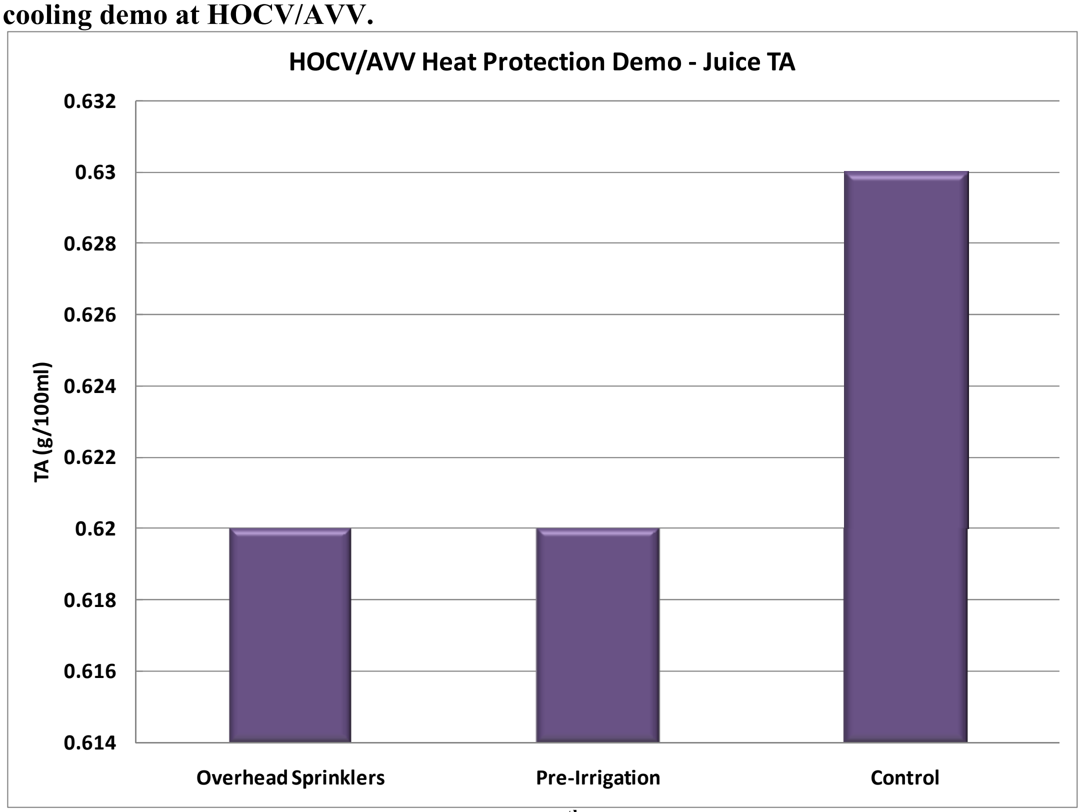


Figure 31: Juice TA of fruit on September 30th, just before harvest, of the Merlot in the cooling demo at HOCV/AVV.

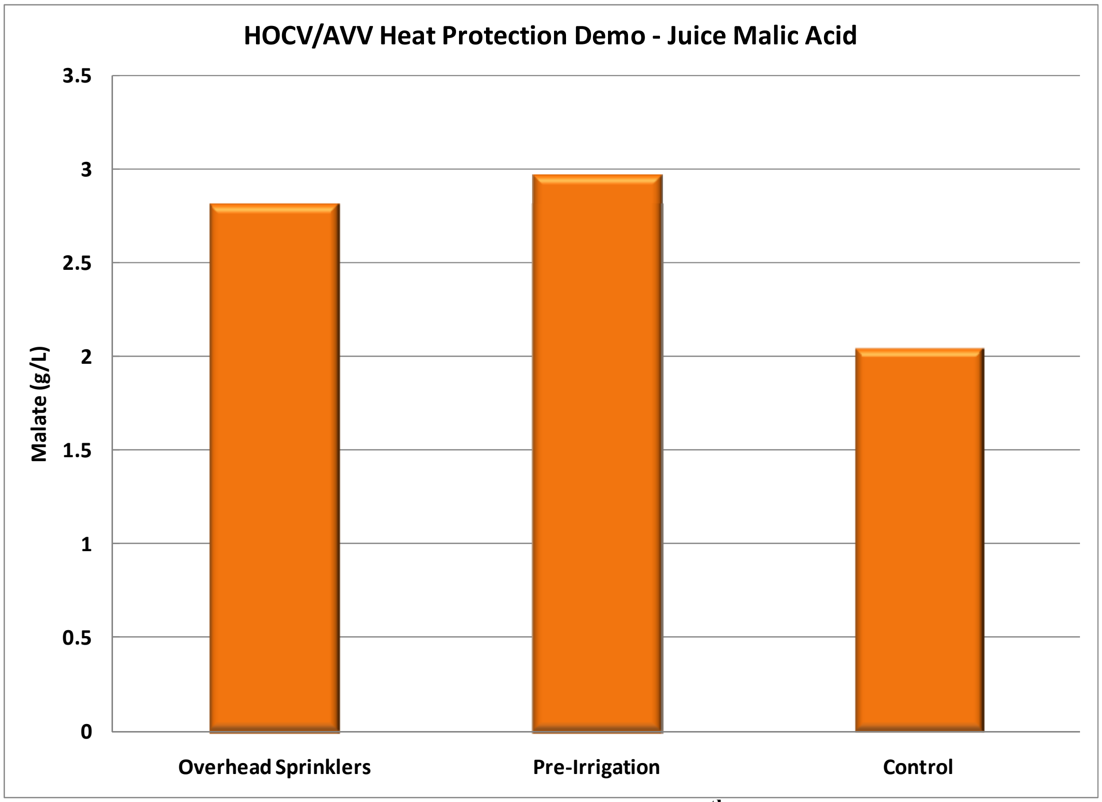


Figure 32: Juice malic acid of fruit on September 30th, just before harvest, of the Merlot in the cooling demo at HOCV/AVV.

Juice phenolics of fruit on September 30th, just before harvest:

Treatment	Total Anthocyanin	Catechin	Polymeric Anthocyanin	Tannin	Catechin/ Tannin Ratio
Control	1177	13	10	443	0.03
Overhead Sprinklers	862	15	11	597	0.03
Pre-Irrigation	887	27	10	575	0.05

Juice malic acid was lower in the control than in the other two treatments, which were similar to one another (**Figure 32**). Juice phenolics showed higher total anthocyanins in the control relative to the other treatments, though total tannin was lower in the control than in the other two treatments.

Small-lot wines were made from the treatments, and are not yet available for sensory evaluation at the time of this writing. However, the results of the evaluation will be appended to this report once it has been completed. In wines, total tannin was highest in the uncooled control and lowest in the overhead sprinkler treatment, suggesting that the cooling may have reduced potential wine quality.. On the other hand, malic acid levels were lowest in the control and highest in the overhead sprinkler treatment. Also, pH levels were highest in the control treatment. Again, these differences could have been due to a thermal microclimate gradient at the site.

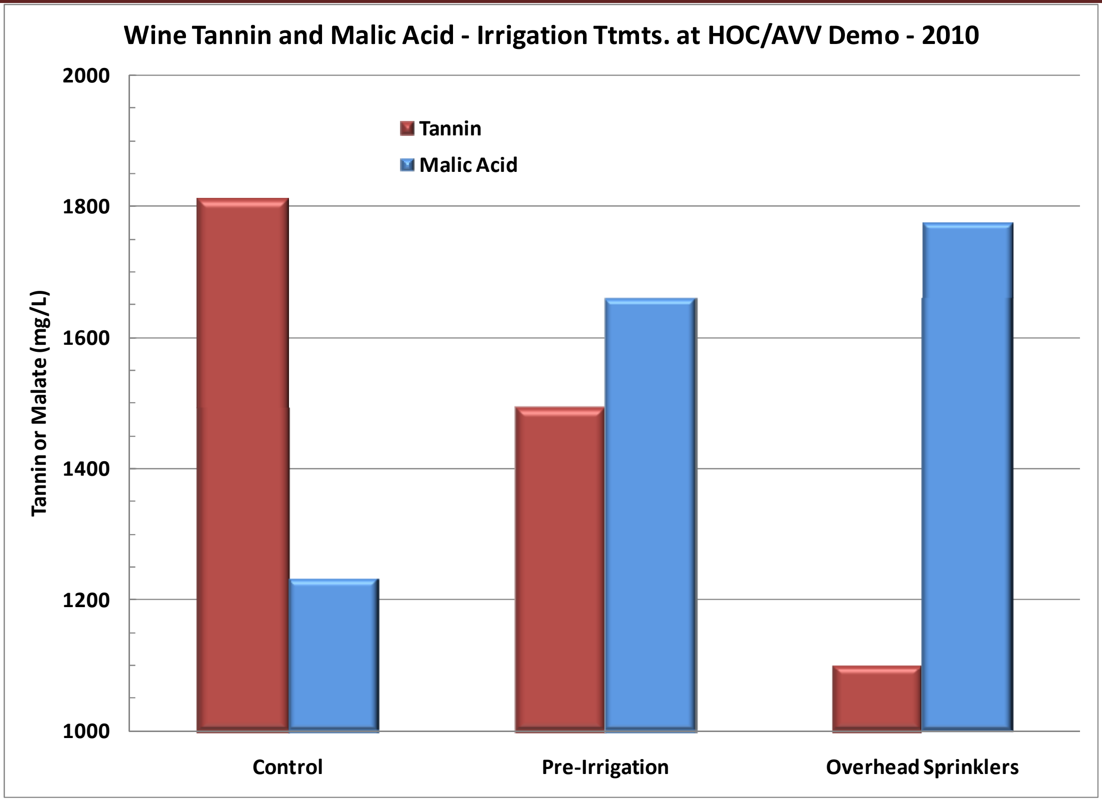


Figure 33: Total tannin and Malic Acid of small lot wines made from the three treatments in the cooling demonstration of 2010 at HOCV/AVV.

Composition of must and wines from the experimental wines

Treatment	Stage	Alcohol %	Malic Acid (mg/L)	Ammonia (mg/L)	NOPA-N (mg/L)	pH	Brix	TA (g/100ml)	Tannin (mg/L)
Control	Must			78	69	3.32	22.6	0.56	308
Pre-Irrigation	Must			94	100	3.42	21	0.59	277
Overhead Sprinklers	Must			51	66	3.43	21.3	0.54	351
Control	Wine	14.02	1231			3.83		0.53	1811
Pre-Irrigation	Wine	14.02	1659			3.74		0.54	1493
Overhead Sprinklers	Wine	13.83	1775			3.66		0.53	1100

Frost Protection Alternatives Demonstrations

The 2010 frost season was a relatively mild one, thus a demonstration of alternative frost protection methods was rather limited. We investigated three alternatives to using overhead sprinklers for frost: 1) cold air drains, 2) traditional wind machines and 3) frost blankets. We also installed some low-volume sprinklers in a block (pulsator and Netafim Stripnet), yet the frost events that occurred at that block occurred before budbreak in that block. Thus, evaluation was not possible in that block.

Cold Air Drains

A cold air drain from Shur Farms was installed in three locations at Kunde/Wildwood Vineyards. The sites selected were such that a "bowl" type of topography existed, with cold air flowing down into a low point that could be "drained" using the Shur Farms technology. Cold air drains operate from a different theory than do wind machines, in that they serve as an inverted "drain" for cold air that sinks to the low point of a topographic feature. The cold air is blasted high in the air and mixes with the surrounding air, thus removing the "pool" of cold air from the site. Warmer air aloft fills in the void and the temperature is elevated as a result.

Temperature was measured near the air drain, at canopy height (3') and higher (10'). Turn-on times are approximate and there were few opportunities to test out the system. Three events are shown in **Figures 34 and 34b**. Note that when the system was activated, there was an increase in temperature at both the 3' and 10' levels. After that occurred, temperatures began to fall again, yet in all cases, temperatures remained above the freezing point and well above the critical temperature for frost damage in vineyards (around 30-31°F). It is not possible to say whether those vineyards would have experienced frost damage had the cold air drain not been installed. However, the effect of the drain is indicated. On extremely cold nights, which were not experienced during this demonstration, it is quite possible that temperatures could have fallen to levels where damage could have occurred.

Wind Machines

We set up temperature profile masts at two locations: one in the Sonoma Valley near Kenwood and another in the southern Sonoma Valley/Sonoma Carneros region. The latter vineyard did not experience potential frost events more than once during the demonstration period. At each of the sites, temperatures were measured at 3', 10' and 16' of elevation. Also, a wind speed sensor was installed to measure wind speed. This was used as an indicator of whether or not the fans were actuated, as the fans would have upset the calm conditions during radiation frost events. Wind machines operate on the principle that, during a radiation frost, an inversion is set up where warmer air overlies cooler air nearer to the ground. The wind machines stir the air, mixing the warmer air aloft with the cooler air towards the ground, thus warming the air at ground level. The wind machine, unlike the cold air drain, works best for level topography.

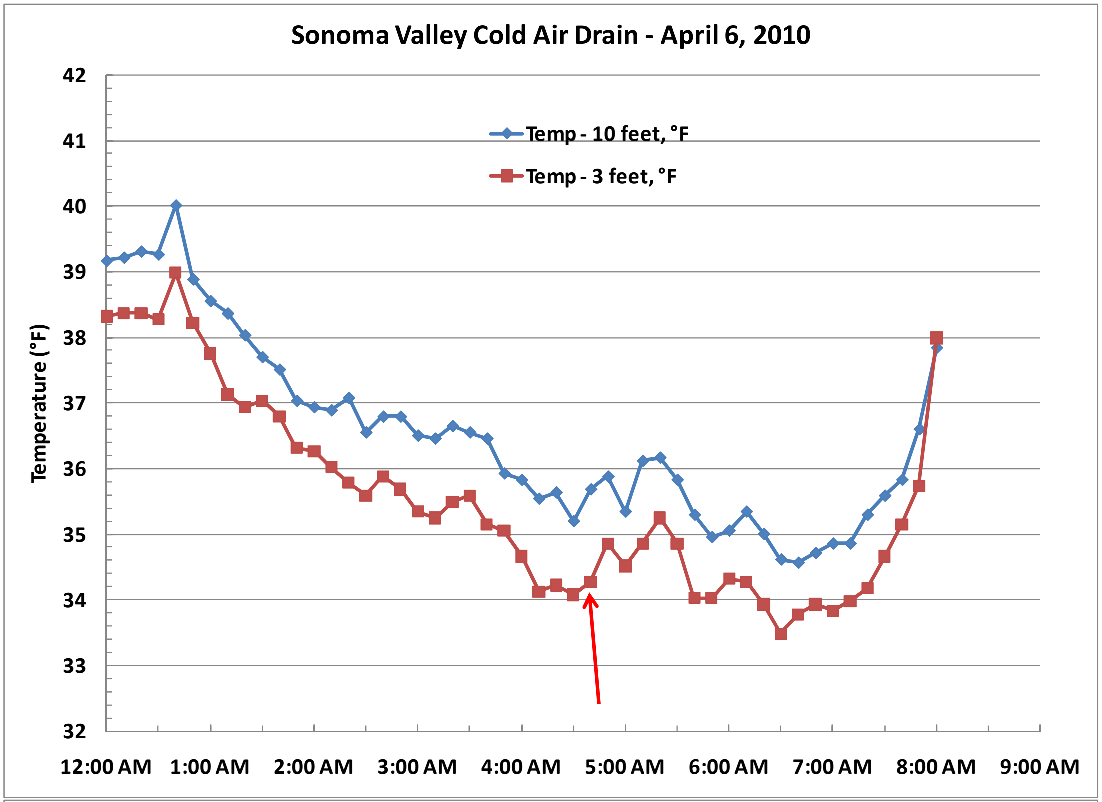
Like the cold air drain, the wind machine tended to increase temperatures temporarily, where after temperatures continued to fall. In all cases, temperatures remained above critical temperature for tissue damage, so the systems appeared to have worked.
The temperature inversions can be seen in the charts, where the temperature at 3' was as much as 3°F colder than the temperature only 13' above it.

Frost Blanket

We installed two rows of frost blankets in a vineyard off of Laguna Road in the Russian River AVA. The vineyard was a Pinot Noir on a VSP trellis. The vineyard typically experiences frost damage, as it is in a small pocket, where cold air flows through during cold nights. The frost blanket is a nonwoven polyester cloth. It is used in other crops for this purpose, but those crops are field crops and not vineyards. The purpose of the blanket is to intercept radiated energy from the ground and trap it underneath to keep temperatures elevated. We tried two weights. The frost blankets were draped over the canopy and tied together below the cordon. Temperature was measured inside of the blanket using sensors affixed to the canes. Likewise, sensors were affixed to canes outside of the blankets for comparison. Two temperature measurements were made inside and two outside of each treatment. No replicates were done for the treatments.

We found the blankets to be a failure. From a practical standpoint, the blankets blew off and shredded after a week in the vineyard. The blankets that remained caused temperatures to become elevated inside of the blankets during the daytime, but offered no benefit during the cold nights. Also, the rubbing of the blankets on the new growth caused some of the new growth to become damaged. The light-weight blanket (**Figure 37a**) did not show any benefit and actually showed a lower temperature internal to the blanket than outside of the blanket. This could have been an anomaly. The heavier-weighted blanket (**Figure 37b**) offered no protection.

It is likely that for these to be effective, they need to be place in a horizontal orientation, which is not practical for vineyards.



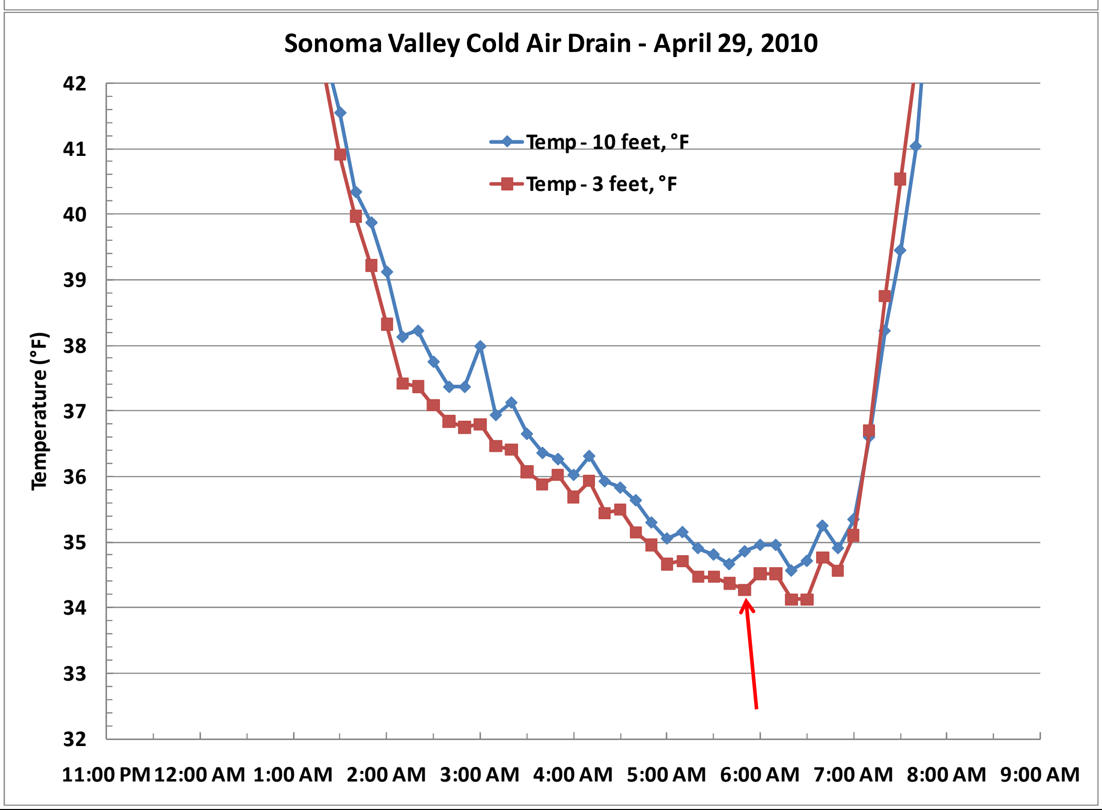


Figure 34: Air temperatures at two heights near the cold air drain unit for two nights when air drain was activated. Red arrow indicates time of activation.

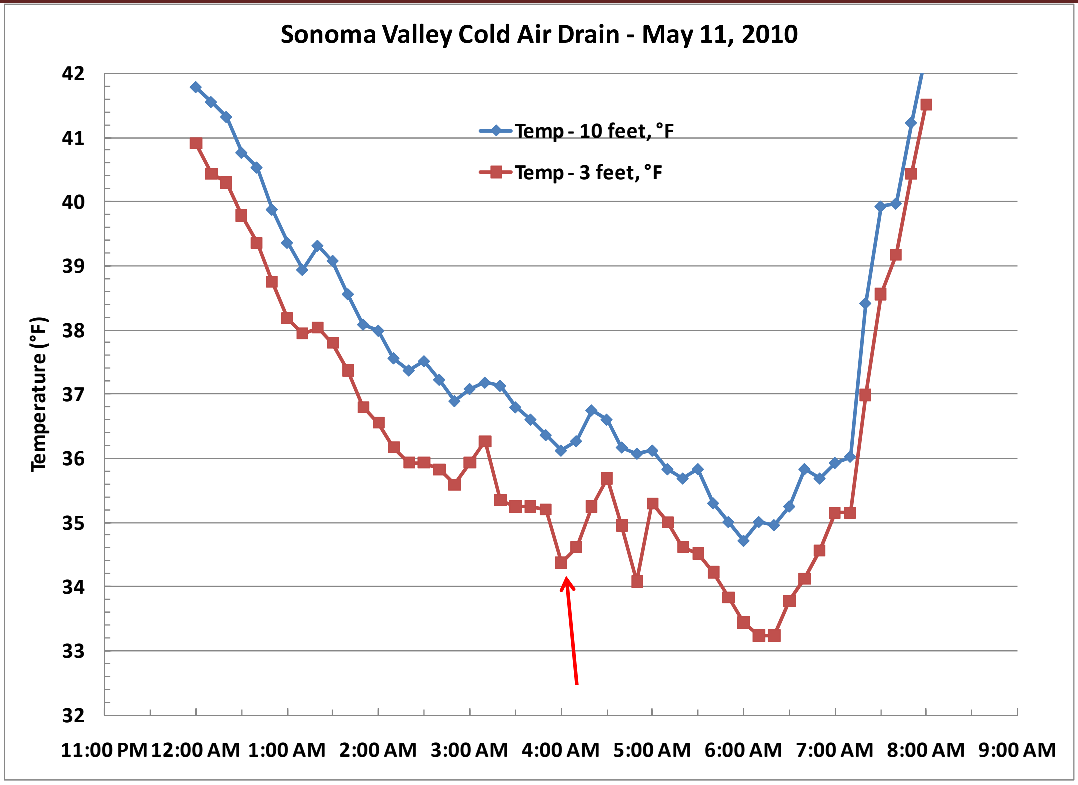


Figure 34b: Air temperatures at two heights near the cold air drain unit for another night when air drain was activated. Red arrow indicates time of activation.

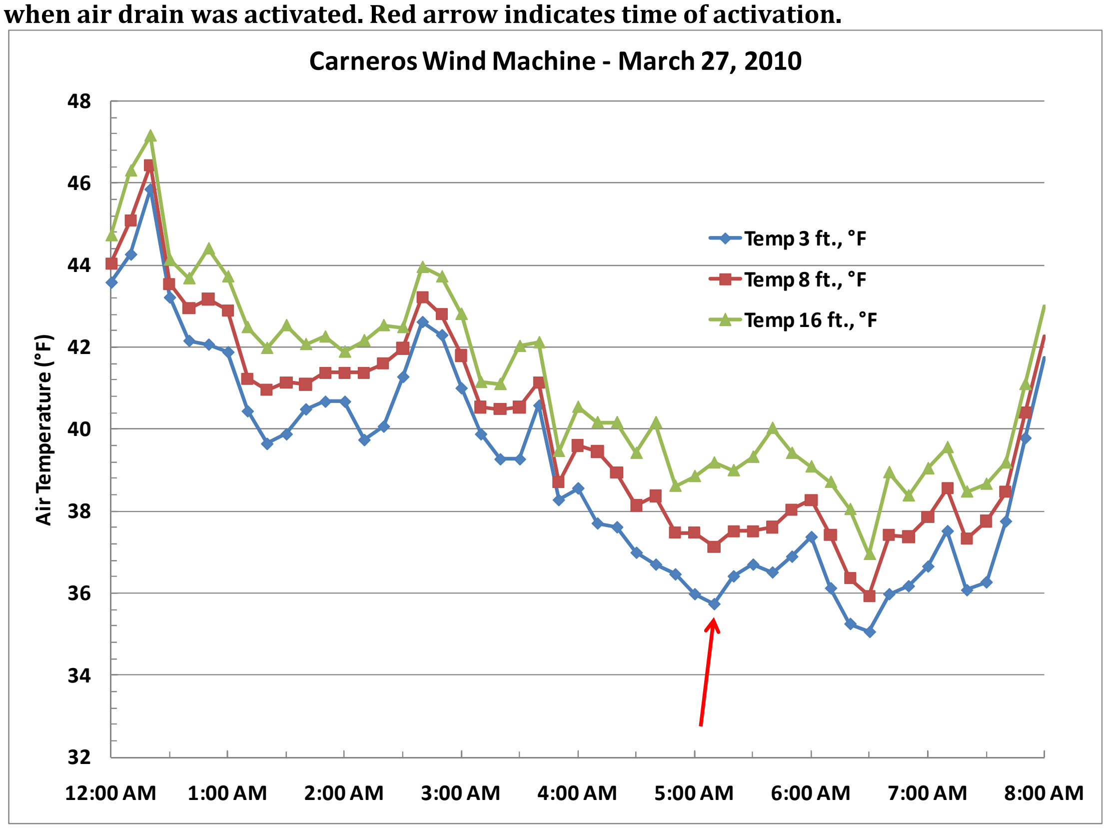


Figure 35: Air temperatures at three heights in the vineyard for a night when wind machines were activated. Red arrow indicates time of activation. Sonoma Carneros location.

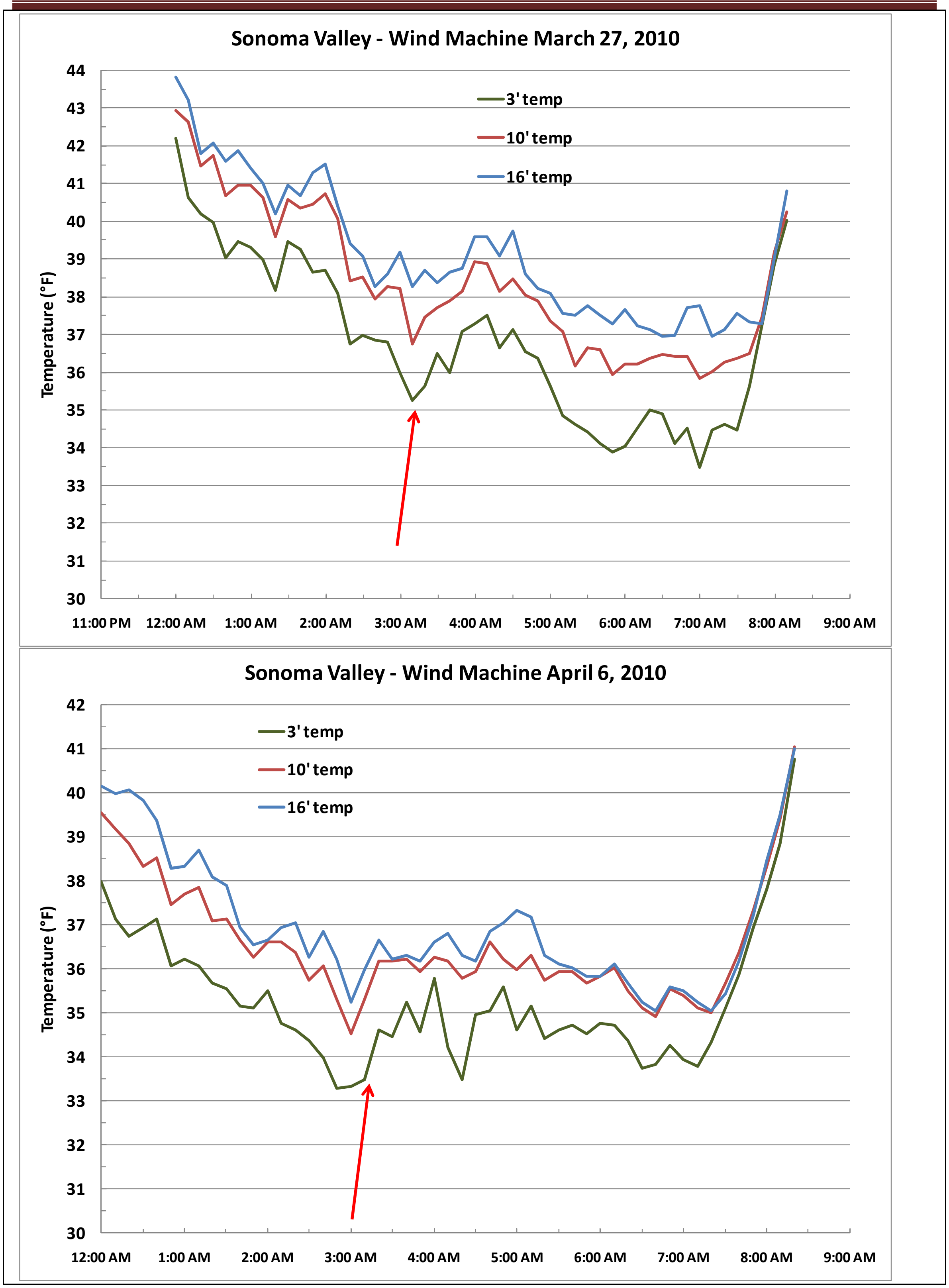
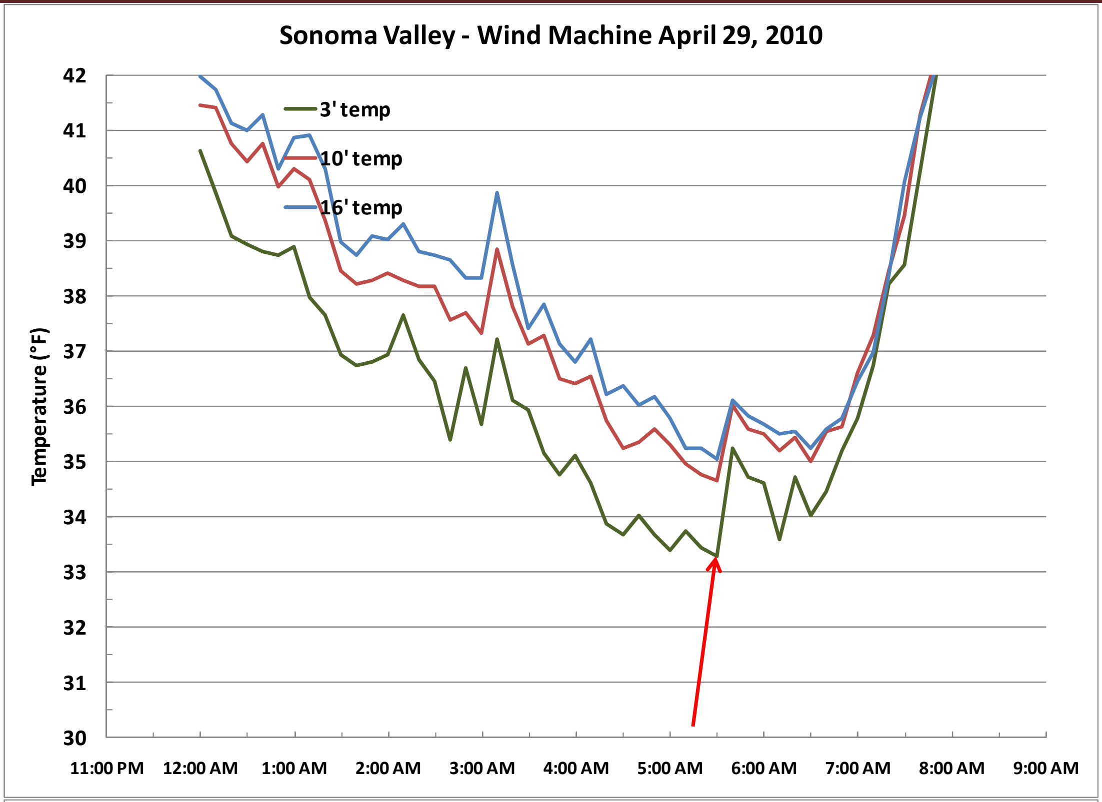


Figure 36a: Air temperatures at three heights in the vineyard for two nights when wind machines were activated. Red arrow indicates time of activation. Sonoma Valley location.



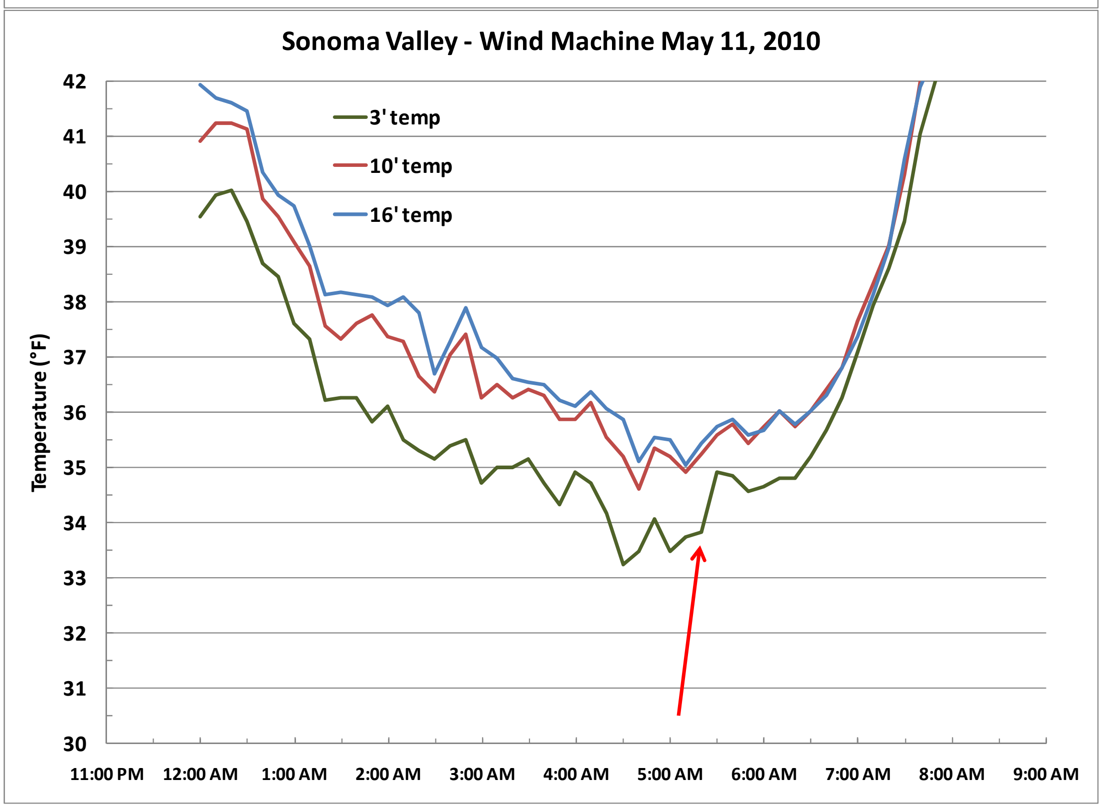


Figure 36b: Air temperatures at three heights in the vineyard for two nights when wind machines were activated. Red arrow indicates time of activation. Sonoma Valley location.

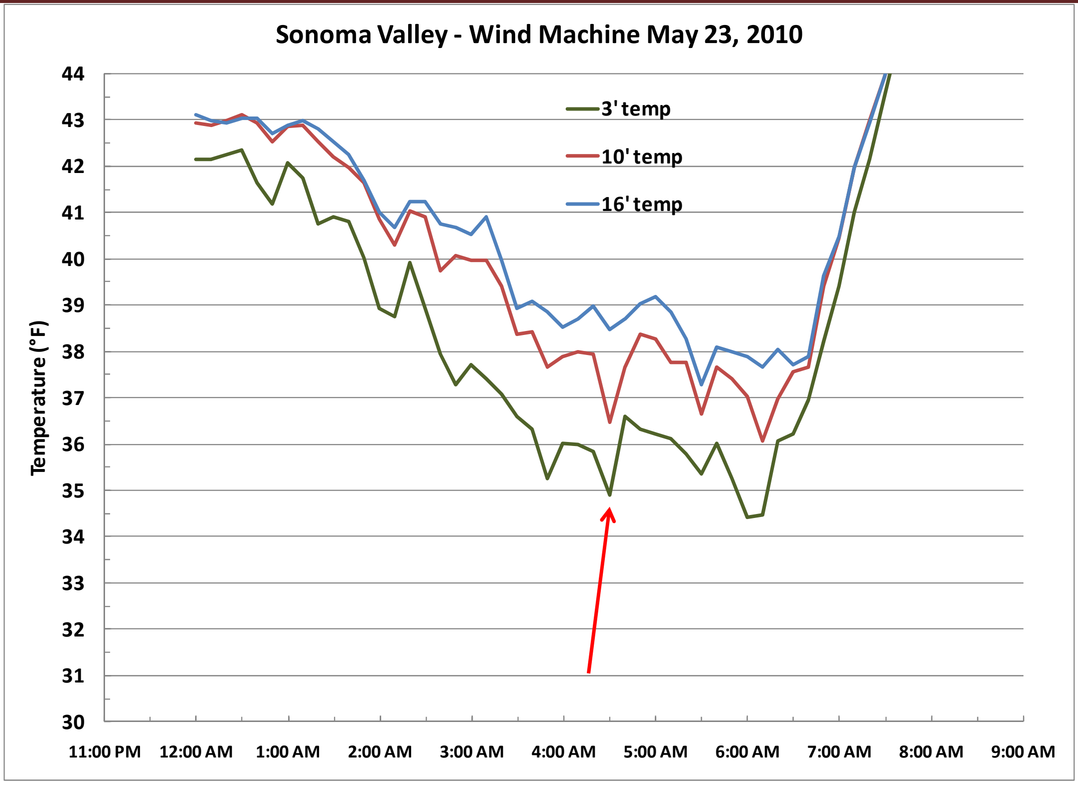


Figure 36c: Air temperatures at three heights in the vineyard for another night when wind machines were activated. Red arrow indicates time of activation. Sonoma Valley location.

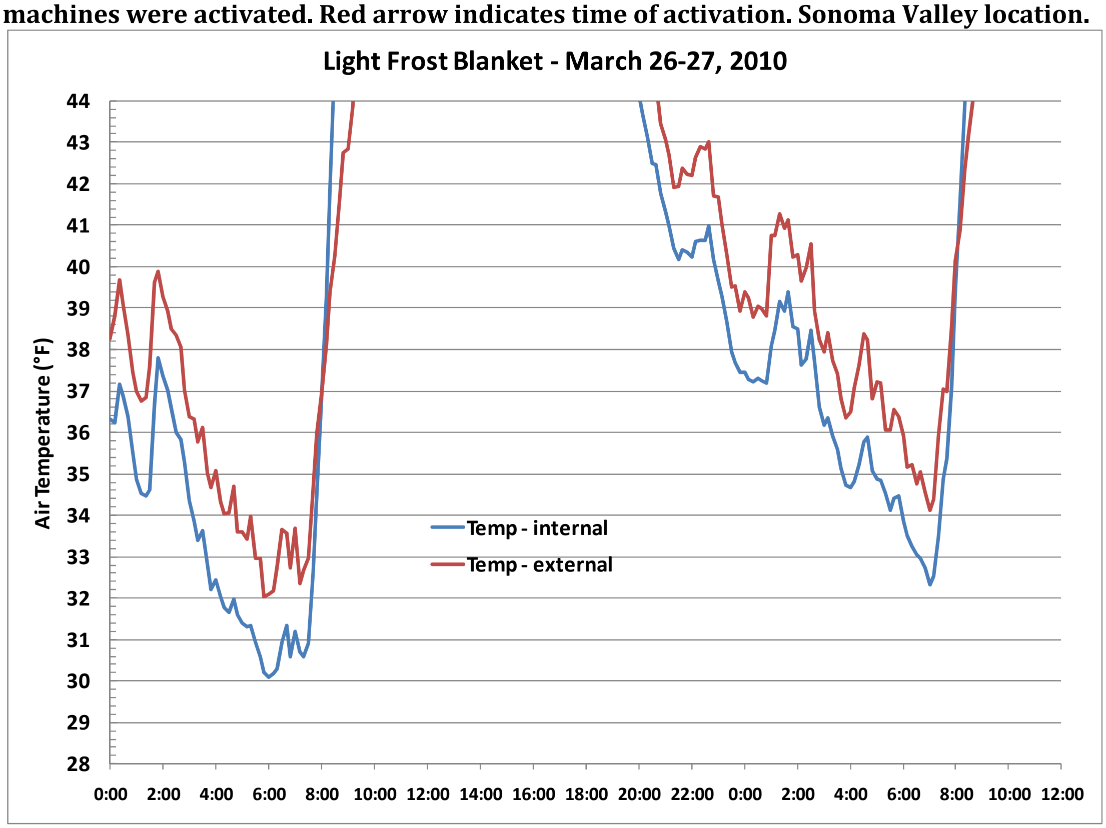


Figure 37a: Temperatures internal and external to a light frost blanket on a vineyard in Russian River AVA.

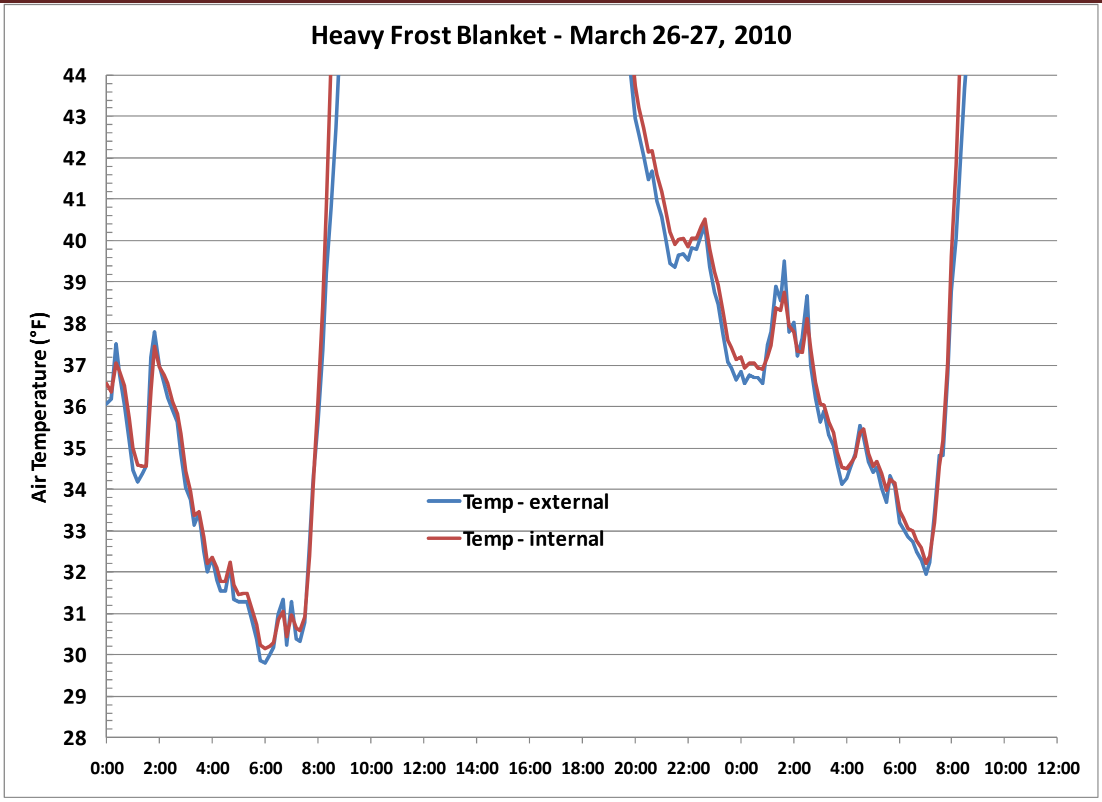
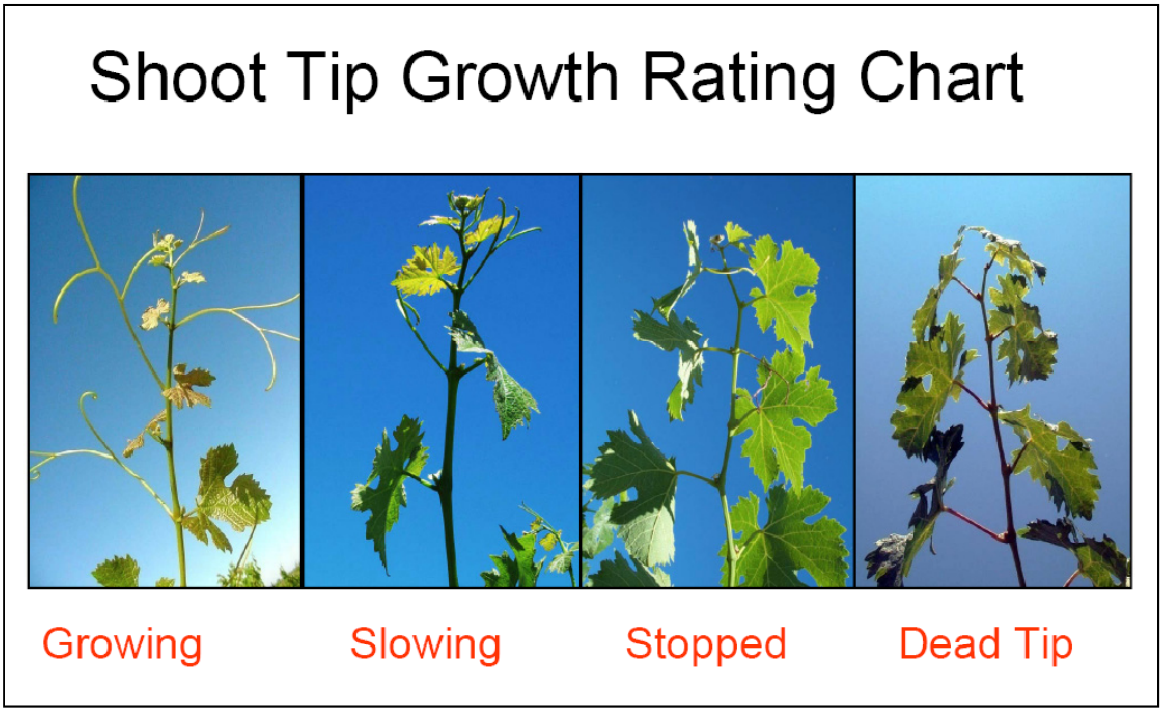


Figure 37b: Temperatures internal and external to a heavier frost blanket on a vineyard in Russian River AVA.

APPENDIX:

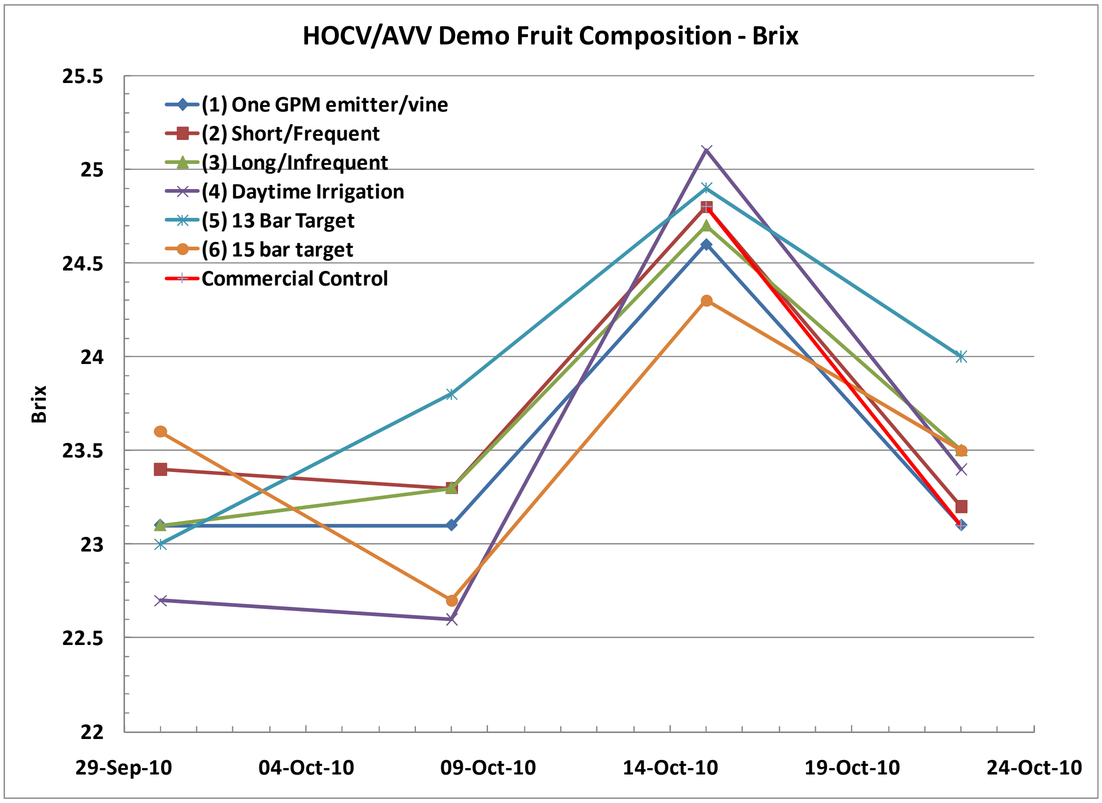
Shoot Tip Rating Chart

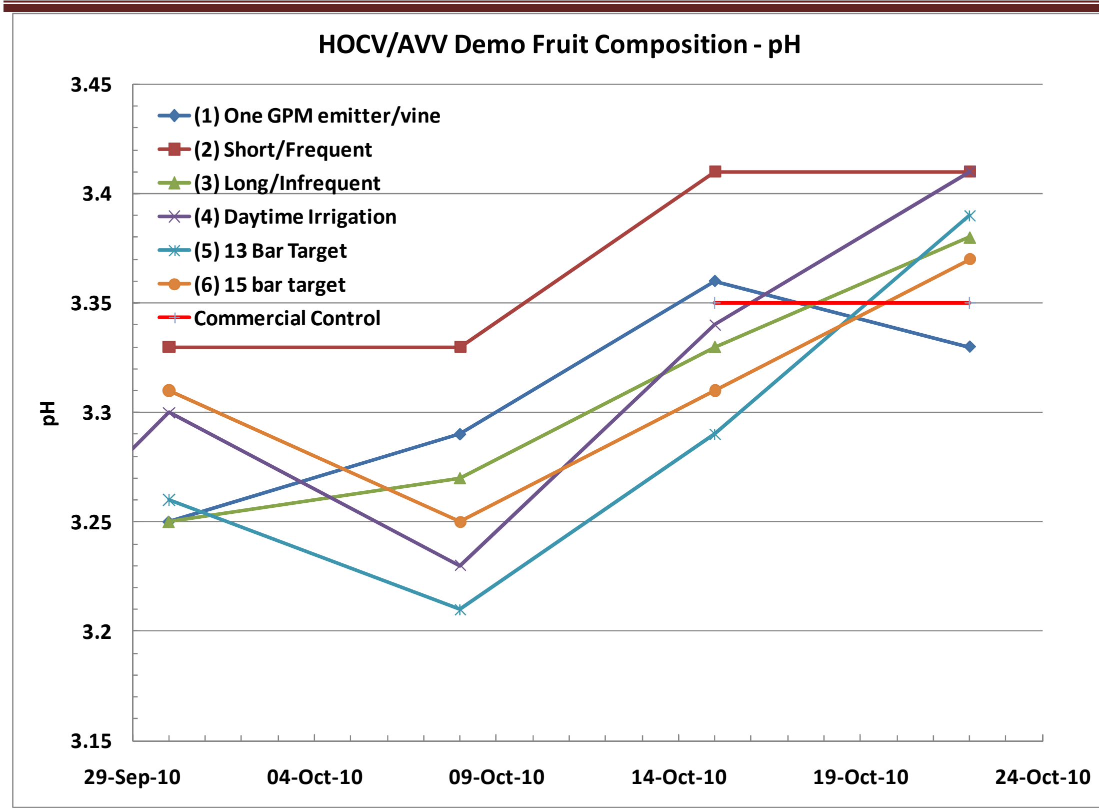


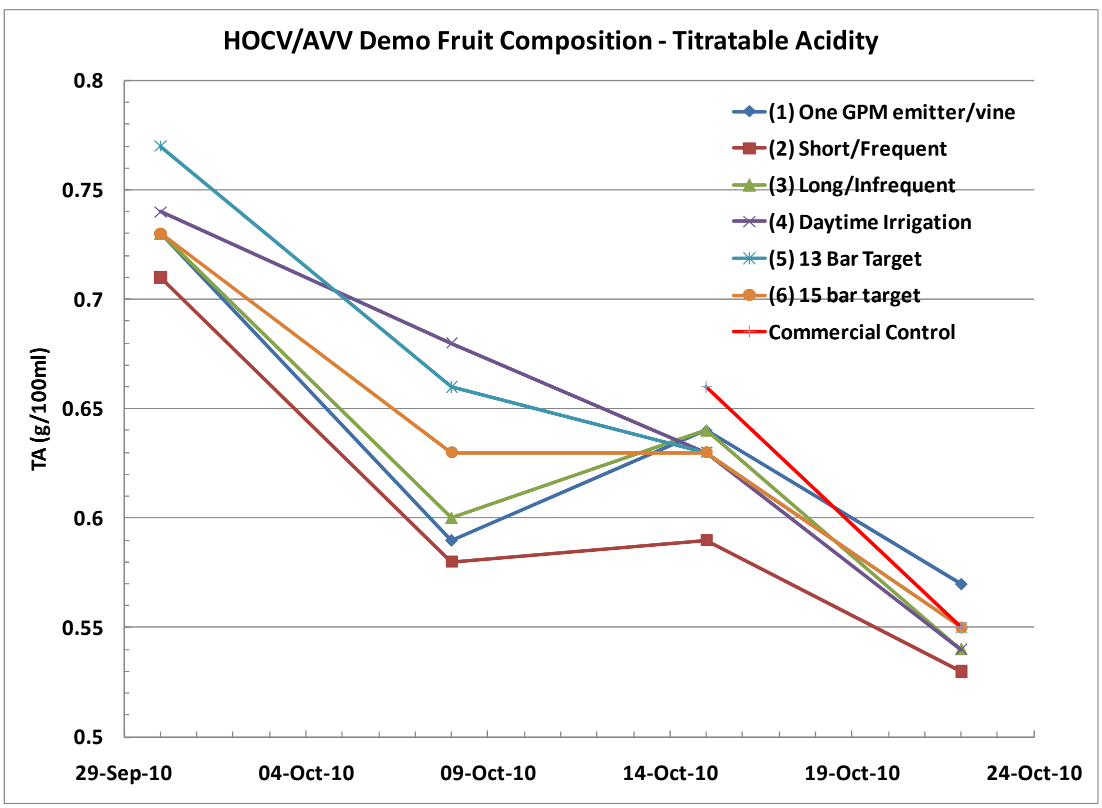
Shoot tip growth identification guide that was made available to the grower public at events and via Advanced Viticulture's website. Growers were advised to avoid commencing the irrigation cycle until shoot tips were either slowing or stopped.

Fruit Chemistry Plots from Irrigation Demonstration

These plots are included here for reference, though there were no apparent lessons learned from these measurements.




HOCV/AVV Demo Fruit Composition - pH
pH
3.45
3.4
3.35
3.3
3.25
3.2
3.15
29-Sep-10
04-Oct-10
09-Oct-10
14-Oct-10
19-Oct-10
24-Oct-10
(1) One GPM emitter/vine
(2) Short/Frequent
(3) Long/Infrequent
(4) Daytime Irrigation
(5) 13 Bar Target
(6) 15 bar target
Commercial Control


HOCV/AVV Demo Fruit Composition - Titratable Acidity
TA (g/100ml)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
29-Sep-10
04-Oct-10
09-Oct-10
14-Oct-10
19-Oct-10
24-Oct-10
(1) One GPM emitter/vine
(2) Short/Frequent
(3) Long/Infrequent
(4) Daytime Irrigation
(5) 13 Bar Target
(6) 15 bar target
Commercial Control

North Coast Vineyard Water Management: Best Management Practices

- **Reduce irrigation water usage**
  - **Irrigation avoidance:**
    - Don't start to irrigate too early in the season (wait until shoots stop growing before irrigating – assuming that shoots reach proper length before stopping)
    - Manage cover crop to minimize its competition (closely mowing is best option); disk in if absolutely necessary to maximize water conservation
    - **Limit use of overhead sprinklers for cooling:**
      - Leave some leaves and laterals to protect fruit from direct sunlight.
      - Leave one side of VSP loose to shade fruit.
      - North or northeast row orientations are less sensitive to heat stress than east-west oriented rows.
      - Limit or eliminate late-season sulfur and horticultural oil applications – these materials promote leaf and fruit burn during hot weather.
      - Increase trigger temperature for start-up of system.
      - Apply overhead sprinklers in pulses. Allow for evaporation between cycles. Less than 50% duty cycle should be effective.
      - Reduce system pressure for this purpose. Use just enough pressure to get sprinklers to turn.
      - Install a system of low-volume "misting-type" spray heads, instead of impact sprinklers.
  - **Irrigation reduction:**
    - Smaller vines use less water – leaf area transpires water. Begin irrigation later in the season and hedge vines to constrain canopy.
    - Restrain the use of nitrogen fertilizers that induce vegetative growth of vines
    - Irrigation scheduling should be based on the soil conditions: short and frequent for shallow and/or light-texture or rocky soils; long and less frequent for deep and/or heavy-textured soils.
    - Install additional drip tubes to selectively irrigate weaker zones in the vineyard earlier in the season without irrigating the entire vineyard block.
    - As above, install a second drip tube to irrigate soil zones with lower total available water holding capacity on a more frequent basis than zones with higher total available water holding capacity.
    - Use soil moisture devices in weakest soils of each block to discover how long irrigation may be applied before water is wasted (i.e. moving past root zone). Soil moisture devices can also help to determine length of intervals between applications, by observing the drying pattern.

- Employ a moderate deficit irrigation program while monitoring soil and/or vine water status. Vine water status monitoring (using a pressure chamber or Porometer) is highly desirable, since soil moisture instruments are not easily calibrated.
- **Reduce post-harvest irrigation:**
  - Refrain from using overhead sprinklers for irrigation of vines.
  - Use drip irrigation for post-harvest fertigation and irrigation of the vines.
  - Vine irrigation is not necessary if vines are in senescence. Irrigate only if leaves are green following harvest. Some fertilizers (e.g. potassium and micronutrients) may be applied if vines are not active, but do not apply nitrogen if vines are senescing.
  - Use overhead irrigation only for shallow irrigation of cover crop seeds. Consult local farm advisor for best practices for cover crops.
  - Use permanent (self re-seeding or perennial) cover crop to avoid re-seeding every fall.

- **Improve system and irrigation efficiency:**
  - Perform frequent (at least once per week) and repetitive inspections of drip laterals and emitters, valves, filters, etc. Look for leaks in the system. Repair any leaks immediately.
  - Perform system uniformity evaluations at least once per season using timed collection of water output in catch cans. Less than 65% uniformity triggers system flush.
  - Reduce height of drip emitters where possible to reduce evaporative losses from splashing.
  - Apply mulch under the vines (or under drip emitters) to reduce surface evaporation – use caution with mulch cover, however, if voles are a potential pest problem
  - Nighttime irrigation is more efficient than daytime irrigation.
  - Apply short and frequent irrigation applications (as mentioned above).
  - Monitoring vine water status will allow for decisions regarding whether improved efficiency will allow for an overall reduction in irrigation volume.

- **Perform rotational (nighttime) pumping:**
  - Pump during the night, when water demand on the river is at its lowest.
  - Recharge ponds at nighttime or irrigate at night, if direct feed.
  - Rotate with neighbor growers or within your own vineyard blocks.
  - Electric pumps: Install time-of-use meter to significantly save PG&E costs.

Photos from the Demonstration Field Days:

HOCV/AVV Demonstration site

Mark Greenspan


Pressure Compensating Emitter
Pressure (psi)

Brooke Cole, NRCS

Mark Houser, HOCV/AVV

Mark Greenspan

Pete Opatz

Nick Frey, SCWGC

Valerie Minton, Sotoyome RCD

Kunde/Wildwood Vineyards Demonstration Site

Steve Thomas, Wildwood Vineyards

Arturo Carvahal, NRCS

Leandra Swent, Southern Sonoma RCD

Marcus Trotta, Sonoma County Water Agency

Brooke Cole, NRCS

Cold Air Drain – Wildwood Vineyards

Frost Blankets

Temperature profile weather station in Sonoma Valley. Wind machine is in the back.

Acknowledgements and Contributors

The success of this project was made possible through significant efforts from the following people and organizations.

Mark Houser, Vineyard Manager for **Alexander Valley Vineyards / Hoot Owl Creek Vineyards**: The vineyard was one of the sites for the demonstration (irrigation and cooling). Mark, his staff, and the winery staff were outstanding partners for the project.

Steve Thomas, Vineyard Manager for **Kunde's Wildwood Vineyards**. The vineyard was another of the sites for the demonstration (irrigation and frost). Steve and his staff were also outstanding partners for the project.

Sonoma County Winegrape Commission, with Executive Director, Nick Frey, and his staff, were instrumental in promoting knowledge about the project to the grower community and in coordinating the invitations and RSVP's for the two field days. Nick also served as master of ceremonies for the Field Days and continues to support the project in many different ways.

Wilbur-Ellis prepared the BBQ lunch for the Wildwood demonstration day.

While much of the equipment was rented or purchased, the following companies donated equipment and/or time to the project:

AquaSpy: Donated six soil moisture sensor probes to the irrigation project. (aquaspy.com)
Ranch Systems: Loaned some of the components of their system as well as providing field time. (ranchsystems.com)
Viticision: Donated time and expertise, and loaned temperature sensors to the fruit cooling project. Their analysis is included in this report. (viticision.com)
Netafim: Donated Stripnet sprinklers for the frost demonstration. (netafim.com)
Wyatt Irrigation: Tim Goetz coordinated donation of Stripnet sprinklers. Donated automated inline valves to project and was essential in the efforts to get system up and running.