A small sensor called an iButton is situated in clusters located on the interior and exterior to log temperatures every 10 minutes.

MARKUS KELLER, WSU

Deficit Irrigation

How low can you go?

By Melissa Hansen

It's often thought that if some is good, more must be better. But that axiom does not apply to regulated deficit irrigation, according to research conducted by Washington State University (WSU) scientists. Regulated deficit irrigation is a management strategy used by grapegrowers to fine-tune canopy development and improve fruit-quality attributes.[1]

"Though some water stress can often help improve wine grape quality, there is such a thing as not providing enough water for the vine," says Dr. Markus Keller, lead investigator of regulated deficit irrigation research supported by the Washington State Wine Commission, a state agency representing all wine grape growers and wineries. Keller, a horticulturist at WSU's Irrigated Agriculture Research & Extension Center in Prosser, specializes in vine physiology, irrigation and cold hardiness and is author of *The Science of Grapevines: Anatomy and Physiology*.

The research by Keller et al. could help wine grape growers save up to 30% of the water used to irrigate grapevines and save energy costs to pump the water without sacrificing grape yields and quality. Throughout the world, water availability is a growing problem due to a changing climate. During the 2015 drought in Washington state, water was rationed in prime irrigated acreage in the Yakima Valley, where high-value crops such as apples, grapes and hops are grown.[2]

The WSU study showed that regulated deficit irrigation (hereafter referred to as deficit irrigation), while generally beneficial, can be taken to extremes and go too low. Vines receiving only 25% of crop evapotranspiration (ETc) in the study were economically unsustainable due to reduced yields and vine decline compared to other treatments in the trial.

Earlier research has suggested that relatively severe deficit irrigation can achieve significant water savings compared to moderate deficit irrigation and can have additional effects on vine performance.[3,4] But that research raised two questions: 1) How severe is too severe? 2) Can water be saved and grape quality improved without sacrificing long-term vine productivity?

The impact of increased water supply during ripening and its relationship to alleviating drought-induced berry shrinkage was examined because little research in this area has been conducted in the field. Recommendations in the "Guidelines for Integrated Production of Grapes" from the International Organization for Biological and Integrated Control declare that irrigation of vines for wine production must not be applied after *véraison* (or is highly restricted) to guarantee "good wine."[5]

But withholding water after *véraison* is at odds with recommendations to avoid inappropriate water stress during ripening.[6] Some studies have suggested that late-season irrigation may help alleviate drought-induced berry shrinkage and does not increase berry size.[7]

This text was condensed from a report in the *American Journal of Enology & Viticulture.*

SUMMARY OF WEATHER CONDITIONS

		Seasonal temperatures (d)[b]				Precipitation (in)	
Year	GDD (°F)[a]	>86°F PV/RP	>95°F PV/RP	<59°F S/F	<50°F S/F	Annual	Seasonal[c]
2011	2,959	32/16	2/2	20/9	1/1	3.6	2.1
2012	3,305	50/4	15/0	7/9	1/4	4.0	1.8
2013	3,528	55/19	16/1	10/6	0/0	1.9	1.5
1995-2013	3,245	53	13	10/9	0/2	4.7	2.2

Data were collected by an on-site weather station located less than 400 meters from the experimental vineyard block in southeastern Washington.
[a] Cumulative growing degree-days (>50°F) from April 1 to Oct. 31.
[b] Number of days from April 1 to Oct. 31 with maximum temperatures above or below four threshold temperatures. (PV: pre-*véraison*/RP: ripening; S: spring/F: fall).
[c] Cumulative rainfall from April 1 to Oct. 31.

SHOOT VIGOR AND VINE SIZE

	Shoot length[a] (inches)	Lateral leaves (per shoot)	Pruning weight (ounces/foot)	Weak canes[c] (%)
ET_{25}	27 b[b]	10 b	2.2 c	33 a
$ET_{25/100}$	35 a	16 b	3.9 b	25 b
ET_{70}	36 a	23 a	4.6 ab	27 ab
ET_{100}	39 a	22 a	5.6 a	22 b
2011	41 a	23 a	3.6 b	n.d.
2012	31 b	15 b	3.8 b	30 a
2013	32 b	15 b	4.9 a	23 b

Cabernet Sauvignon grapevines irrigated at various fractions of crop evapotranspiration (denoted by subscripts of ETc) from fruit set to harvest over three years; $ET_{25/100}$ refers to 25% ETc before *véraison* and 100% ETc thereafter.
[a] Length of primary shoots at harvest.
[b] Means followed by different letters differ significantly at $p < 0.05$ by Duncan's new multiple range test.
[c] Proportion of canes with less than five nodes (not determined in 2011).

YIELD AND YIELD COMPONENTS

	Yield (tons/acre)	Berries/ cluster	Berry weight (g)	Yield: pruning weight (pounds)
ET_{25}	2.1 b[a]	69 c	0.84 c	7.3 a
$ET_{25/100}$	3.8 a	89 a	0.95 b	8.2 a
ET_{70}	3.9 a	76 bc	1.08 a	7.1 a
ET_{100}	4.4 a	80 ab	1.06 a	6.9 a
2011	2.5 b	70 c	1.18 a	6.6 a
2012	3.8 a	79 b	0.84 c	8.6 a
2013	4.3 a	88 a	0.93 b	7.0 a

Cabernet Sauvignon grapevines irrigated at various fractions of crop evapotranspiration (denoted by subscripts of ETc) from fruit set to harvest over three years; $ET_{25/100}$ refers to 25% ETc before *véraison* and 100% ETc thereafter.
[a] Means followed by different letters differ significantly at $p < 0.05$ by Duncan's new multiple range test.

Deficit irrigation regimes

A deficit-irrigation study was conducted at Cold Creek Vineyard, a property owned by Ste. Michelle Wine Estates that was planted in 1981 in the Columbia Valley appellation in southeastern Washington state. The trial was conducted in 2011, 2012 and 2013 on own-rooted Cabernet Sauvignon grapevines (clone FPS 08).

Cold Creek Vineyard was irrigated using drip irrigation with pressure-compensating, 1-gallon-per-hour emitters spaced 3.5 feet apart. Vine spacing was 6.8 feet between vines with 9.8-foot-wide tractor rows. Vines were trained to bilateral cordons at 3.5 feet aboveground and spur-pruned in winter to 67 nodes. Shoots were loosely positioned between two foliage wires, and the trial received standard applications of fertilizers, herbicides and other pest- and soil-management practices as other blocks in the vineyard. Because the vineyard did not receive enough precipitation in winter months to replenish the soil-moisture profile, the root zone was irrigated to near field capacity prior to bud break.

Weather data collected daily from an on-site weather station owned by Ste. Michelle Wine Estates is summarized in the table "Summary of Weather Conditions." Cumulative growing degree-days were calculated from daily maximum and minimum temperatures, with a base temperature of 50° F from April 1 to Oct. 31. Four temperature thresholds were counted separately to identify the number of hot and very hot days (temperatures above 86° F and greater than 95° F) during pre-*véraison* and ripening, and two temperature thresholds were used to identify the number of cool and cold days (less than 59° F and less than 50° F) in the spring and fall.

Four irrigation regimens were applied in four replicated blocks to replace a range of crop evapotranspiration (ETc) fractions from fruit set to harvest. Evapotranspiration (ET) is the sum of evaporation of water from the soil and plant transpiration and uses a reference crop surface such as grass, without any water stress, multiplied by a grapevine-specific and seasonally variable crop coefficient to calculate the crop's water use.[8]

The trial was designed to vary the timing and extent of water deficit from no water stress to relatively severe stress. The same vineyard was part of previous deficit-irrigation research conducted in the three years leading up to the present trial.[9]

The overall goal of this study was to investigate the impact on fruit and wine composition from more widely contrasted irrigation regimes than were previously studied.[10] The study measured vine growth and yield components, plant water status and gas exchange and canopy microclimate. Although experimental wines were made by co-investigator Dr. Jim Harbertson's team, the effects on fruit and wine composition are not covered here but will be contained in other reports.

Irrigation regimes were implemented when shoot growth stopped, which typically occurred soon after fruit set. The four irrigation treatments were:

- 100% ETc (ET_{100})
- 70% ETc (ET^{70})
- 25% ETc (ET_{25})
- 25% ETc before *véraison*, 100% ETc thereafter ($ET^{25/100}$)

All treatments were fully irrigated after harvest in preparation for winter. Although there was yearly variation in the three growing season temperatures, the effects from irrigation treatments were consistent between years.

Deficit irrigation treatments did not enhance water-use efficiency: Lower seasonal irrigation water supply was also associated with lower yield, but deficit irrigation did reduce water use. The average amounts of irrigation water supplied over three years varied from 16.0 inches (1.3 acre-feet) in the ET_{100} treatment; 12.6 inches (1.05 acre-feet) in the ET_{70} vines; 11.4 inches (0.95 acre-feet) in the $ET^{25/100}$, and 6.8 inches (0.5 acre-feet) in the ET_{25}. On average, deficit irrigation reduced the amount of water supplied by 22% in the ET_{70}, 31% in the $ET^{25/100}$, and 56% in ET_{25}.

Vine vigor

Vines in this trial exhibited most of their shoot growth before fruit set. Though primary shoots in all treatments stopped growing before *véraison*, lateral shoots in the ET_{100} and ET_{70} vines continued to grow through harvest. Effects on vine vigor, size and density of canopy from irrigation were consistent across the three years.

Vine vigor was measured through multiple parameters (see table "Shoot Vigor and Vine Size") and included shoot length (measured at harvest), number of lateral leaves per shoot and pruning weights. A new way to capture vine vigor (called percentage of weak canes) was developed by determining the proportion of canes with less than five nodes.

Vine vigor between the ET_{100} and ET_{70} regimens was not statistically different. However, the ET_{25} treatment resulted in very weak vines and had the lowest pruning weights, shortest shoots with few laterals and the greatest percentage of weak canes of all four treatments. These vines also showed leaf yellowing and some leaf abscission.

Treatment carryover effects on shoot vigor in the following year were observed in the ET_{25} vines, which had shorter internodes and fewer main and lateral leaf numbers at fruit set, even though all the deficit irrigation treatments received the same amount of water before fruit set and abundant amounts after harvest. The decreased berry number per cluster in the second and third years of the ET_{25} treatment suggests that the severe deficit limited flower cluster formation in the buds. Similar carryover effects in reduced vine capacity and yield were observed in a long-term trial in Argentina with Malbec.[11]

Canopy microclimate

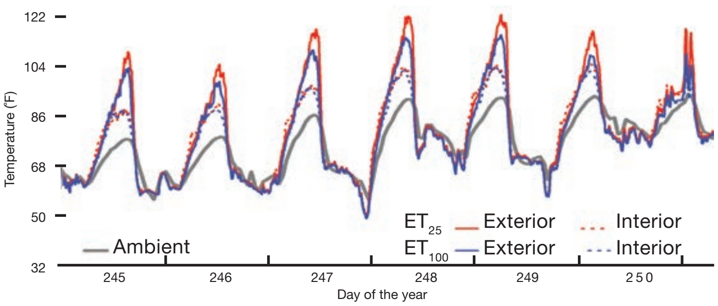
To understand treatment differences in canopy microclimate, small sensors called iButtons were used to log temperatures at 10-minute intervals. The iButtons were placed on the exterior and interior faces of grape clusters (see photo of iButton in grape cluster on page 49). Daytime temperatures of sun-exposed clusters were often around 20° F warmer than ambient air temperatures; however, at night these same clusters were only a few degrees below the ambient air temperature (see "Exterior and Interior Cluster Temperatures," below).

While temperatures of the few shaded clusters did not differ between irrigation amounts, the sun-exposed clusters of the ET_{25} vines (the warmest of the four treatments) were almost 10º F warmer during midday than those of the ET_{100} vines. The smaller and more open canopy and small number of lateral leaves in the ET_{25} vines allowed more light and resulted in higher temperatures in the fruit zone compared to other treatments. The ET_{25} clusters experienced almost twice the number of hours above 95° F and fewer hours below 68° F compared to clusters in the ET_{100} treatment.

Berry dilution?

The ET_{25} treatment resulted in the lowest yield, smallest berries and smallest number of berries per cluster (see table "Yield and Yield Components"). Although berry weight was smaller in the $ET^{25}/_{100}$ treatment than fruit in the ET_{70} and ET_{100} treatments,

INTERIOR AND EXTERIOR CLUSTER TEMPERATURES



Ambient temperature and simulated cluster temperatures are depicted one week after *véraison* of Cabernet Sauvignon vines irrigated at various fractions of crop evapotranspiration (denoted by subscripts of ETc) in 2011. Each line represents the average of eight iButtons placed on both the exterior and interior faces of different clusters and logging temperature at 10-minute intervals. The ambient temperature was logged hourly by an on-site weather station.

yields were similar and small berries were achieved without the penalties that accompanied the severe deficit treatment.

Although both the ET_{25} and $ET^{25/100}$ vines received the same amount of water early in the season, the ET_{25} treatment had smaller berries than the $ET^{25/100}$ vines. One explanation for this is that the 100% ETc supplied at *véraison* may have alleviated pre-harvest berry dehydration.[12]

Additionally, because the increase in water occurred when berries ranged from blue to green, research from Keller's group suggests that photosynthetic recovery following the increased water supply may increase sugar supply via phloem flow to the berries.[13] Indeed, total soluble solids (berry sugars) were intermediate in the $ET^{25/100}$ vines (242 mg) compared to 213 mg for ET_{25} and 282 mg for ET_{70} or ET_{100}.

Deficit irrigation without yield penalties

Though moderate water deficit in red wine grapes is generally associated with positive attributes such as fruitier and less vegetal aromas, more anthocyanin pigments and sometimes lower astringency when compared to vineyards where abundant water is applied,[13] the research showed there can be too much of a good thing when it comes to water stress and wine grapes.

Supplying only 25% ETc between fruit set and harvest was too low, economically unsustainable and led to a decline in vine capacity and yield, according to the report. The 25% ETc vines had the most open canopy and consequently the highest cluster temperatures of the four irritation treatments, the greatest light intensity in the fruit zone and the smallest yield (almost half of the other regimens in two of the three years).

"By contrast, limiting water to 25% ETc early during the berry-development period and then increasing it to 100% ETc at *véraison* proved to be an interesting irrigation-management option for Cabernet Sauvignon," the report states. This treatment limited vigor and berry size while keeping yields moderate—and without the penalties as in the severe deficit treatment. Moreover, the $ET^{25/100}$ treatment conserved irrigation water.

An indirect benefit of using less water than ET_{100} was weed control.

Although this study did not quantify weed growth, visual observations found more abundant weeds in the fully watered vines of ET_{100} compared to other treatments. With its meager application of water from after fruit set to *véraison*, the $ET^{25/100}$ treatment may be a way to reduce weed growth and the need for herbicides or cultivation.

How low can you go?

While earlier field trials by the same researchers had found that 35% ETc is viable,[4,10] the present work established that 25% ETc is not economically sustainable in the arid climate of eastern Washington, where the study was conducted.

The results of this study help to better understand the role that deficit irrigation plays in fruit quality. Small berry size is often cited as the primary reason for fruit composition improvements made by water deficit. But this study suggests that potential changes in fruit composition due to water deficit may be indirectly related to altered canopy size and microclimate, in addition to decreased berry size.

Melissa Hansen, research program manager for the Washington State Wine Commission, grew up in California's Central Valley and worked in California's grape and tree fruit industries before moving to Washington. She covered grapes and tree fruit for the Yakima, Wash.-based *Good Fruit Grower* magazine for 20 years before her current position.

The references for this article are available online at winesandvines.com