

## Measuring water use by juice and wine grapes in eastern Washington

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Washington's water resources are finite and are demanded by a range of users: agriculture, industry, electric power, wildlife conservation, and population centers. Dry years can accentuate tension among competing users of water; in a drought, there are clear winners and losers among irrigators. The enforcement of strict regulations on water quality has meant that little if any runoff will be tolerated from farms into streams or canals. Issues of both water quantity and water quality will continue to impinge upon irrigation management.

Over the past decade or so, irrigation management has approached the forefront of grape production in both the juice and wine grape industries albeit at different rates and under different rationales. Juice grapes like 'Concord' and 'Niagara' are well adapted to the relatively cool, humid climate of the northeastern U.S. In the warm, sunny, high desert of central Washington, vines can suffer both water and light stress. The goal of healthy canopies and reasonable crop loads challenges growers to keep the vines well-watered but not over-watered. Too little irrigation induces stress like that manifested in 'Blackleaf' disorder. Too much irrigation can delay ripening, and if the water is applied by surface means, can produce runoff that exceeds standards for water quality. In wine grapes, WSU researchers demonstrated the value of 'regulated deficit irrigation' (RDI) in improving fruit and wine quality. The key to successful RDI is 'regulated': careful application of water stress to control the growth of the canopy, to reduce the size of berries, and to expose the fruit to sunlight. Too little RDI leads to excessive water stress, which may delay ripening this season and contribute to poor cluster initiation for next season's crop. Too much irrigation promotes lush, shady canopies that also can delay ripening, delay vine hardening for winter, and reduce overall fruit quality.

Too much or too little? How does a grape grower manage the scheduling and application of irrigation water? Several tools are available, not one of which gives the definitive answer, but in combination with other methods and with the grower's knowledge of the vineyard, provide reasonable, objective guidelines. One approach uses weekly measurements of soil water in the rooting zone, which can be several feet in a deep soil. As the vines transpire, soil water is depleted. The grower's goal is to irrigate long enough to replenish soil water to its former level, renewing the reservoir from which the vines draw. One difficulty of this technique is that it does not provide an indication of the vine's water status. It is possible for vines to be water-stressed in a seemingly wet soil, for example, if the roots have been damaged, or in a situation where the evaporative demand from the leaves surpasses the roots' capacity to draw water from the soil. It is also possible to over-irrigate and not detect excessive water in the soil if the water has percolated below the depth where measurements are taken. Some growers have found

the equipment to be expensive, but over time the development of new devices along with competition among manufacturers will make it more affordable and more efficient to measure soil water. Decision aids like WSU's *WISE* system, a web-based tool, are available to augment soil water data to produce a better estimate of when and how much to irrigate.

Another approach is to irrigate according to the physiological status of the vine. This method has found a following among wine grape growers who practice RDI. The vine's water status typically is assessed by measuring leaf or xylem water potential, an indicator of how well (or poorly) hydrated the vine is. *Vitis vinifera* grapes can withstand a certain degree of dehydration, or water stress, which corresponds to suggested values of xylem water potential. Thus, a grower irrigates when the vines approach the desired limit of water stress. One difficulty with this method is that leaves must be treated under a very specific protocol which effectively limits the number of measurements that can be recorded per day. Also, there is some anecdotal evidence that *vinifera* vines in Washington may tolerate more stress than vines in California, where the relationships between water potential and vine stress were developed. However, when combined with measurements of soil water, a grower gleans information on two pieces of the water management puzzle: supply (soil water) and demand (indirectly via water stress). This approach may have less utility for juice grapes where a non-stressed vine is desired. Xylem water potentials that indicate a well-watered vine won't suggest that it is time to irrigate, whereas by the time that water potentials drop measurably, irrigation may be applied too late to prevent stress.

The most widespread approach that combines soil, vine, and environmental factors is the use of evapotranspiration (ET) estimates from weather stations. The term ET represents the sum of water lost from the soil surface through evaporation (E) and from the vine through transpiration (T; a special term for evaporation from plant canopies). Generally, ET is not measured directly but is estimated from a series of equations that include local measurements of radiation, temperature, and humidity. Some assumptions are made about the ease with which water evaporates from a soil surface and from the vine canopy. High quality ET data are available to subscribers of WSU's PAWS network of weather stations. Calculations usually are programmed into the software of commercially-available weather stations. Within the past few months, a stand-alone ET meter has been put on the market. Values are available for "reference ET," a theoretical maximum ET defined as ET from a well-watered, non-stressed reference crop, usually short grass or alfalfa. Other crops have lower ET than this theoretical maximum; ET for any other crop is determined by multiplying reference ET by a crop coefficient (the fraction of reference ET used by your real crop). Crop coefficients vary by crop, obviously, but also by the size and age of that crop, and by growing region. The benefit of using ET is that it suggests how much water to apply. However, estimates of ET do not indicate when to irrigate. The grower must decide whether to time irrigation based on a threshold cumulative value of ET (in other words, cumulative water loss), or whether to irrigate on a calendar basis using cumulative ET to determine the length of the set.

Crop coefficients are critical to the effective use of ET data for irrigation management. Three difficulties face growers who use the existing published values for grapes in eastern Washington: 1) no coefficients were calculated specifically for *V. labrusca* (e.g., 'Concord'); 2) coefficients were developed for grapes under drip

irrigation, where E is less than under sprinkler or rill irrigation; and 3) coefficients for *V. vinifera* were determined before the widespread adoption of RDI, so are meant for large, well-watered canopies. It would be valuable to have an accurate, revised set of crop coefficients that account for current management practices in both juice and wine grapes.

A first step in deriving new crop coefficients is to separate E from T so that we can account for irrigation method. Measurements of T independent of E provide data on consumptive use by the vines and give us an impression of the water status of the plant. One research tool that measures T is the 'sap flow gauge.' This instrument measures the water (xylem sap) that flows through a vine trunk in the same way that engineers might measure the flow of water through a pipe. A flexible heater is wrapped around the trunk and a known amount of heat is applied (Figures 1 and 2). Sap flow gauges must be well insulated so that the only heat entering the trunk is that from the flexible heater, not an unknown amount from the sun or hot air (Figure 3). Miniature temperature sensors are placed around the heater, and on the surface of the trunk above and below the heater. From the temperature measurements, we can calculate how much heat moved up and down the trunk, away from the trunk, and into the xylem where it was carried up the trunk in the transpiration stream. Because we know the thermal properties of woody tissue and of water, we can convert the amount of heat that was carried off by the transpiration stream into an equivalent amount of water. That amount of water is T and it can be expressed as ounces or gallons per square foot of leaf area per day (because transpired water evaporates from the leaves), gallons per vine per day (or week), or acre-inches per day (or week), depending on the end use of the data and the units that are familiar.

Sap flow data based on square feet of leaf area (meaning the surface area available for transpiration) are useful for developing new crop coefficients because the size of the canopy is accounted for. The other side of the ET coin could be provided by soil scientists who determine E for various combinations of irrigation delivery systems and soil types in vineyards. This application of the sap flow technique has less direct relevance for growers because leaf area is tedious to measure even for researchers and is very difficult to estimate accurately. Its best use right now is in research. Sap flow data expressed as water use per vine could be useful directly in irrigation management for the specific vineyard block where sap flow was measured. These are the actual values of water transpired by vines in that vineyard. It would be important to measure sap flow on as many vines as is practical, to accommodate variability among vines and gain a representative sample. Continuous measurements will show rapid increases and decreases in water use during sunny or cloudy days (Figure 4); over periods like a week or two, maximum rates of sap flow decline as the vines deplete soil water, then increase after an irrigation. Season-long measurements of sap flow (Figure 5) show the gradual increase in daily water use as the canopy grows, the days lengthen, and the evaporative demand increases. Toward harvest, days are shorter, evaporative demand is lower, and some leaves senesce, resulting in lower rates of water use per vine. From the data, one can calculate easily total water use by the vineyard per day, week, or season. The information can be combined with estimates of soil water and vine stress for a more comprehensive toolkit for irrigation management.

The sap flow technique (direct measurements of vine water use) has great potential for assisting growers with the timing and duration of irrigation. At the moment,

one disappointing drawback is that the gauges are not robust enough for general field use in commercial vineyards. The current offering of commercially-manufactured gauges grossly underestimates water use at high rates of sap flow (above about 1 pint per hour per vine, or 0.125 gallons per hour; see Figure 4). In Washington, mature 'Cabernet Sauvignon' vines under the stress of deficit irrigation use about this amount of water at mid-day in the middle of summer; mature, well-watered 'Concord' vines transpire up to 6 times as much at the same time. These are gross values that do not account for the size of the canopy. We designed our research system specifically for the high rates of sap flow that occur in mature vines; but maintenance of a multiple-gauge system as it is currently configured requires meticulous attention and a fair amount of troubleshooting. It would be tremendously valuable if an engineering or sensor technology firm became interested in refining the gauges for robustness and simpler installation. Smarter algorithms to control the heaters, radio-based data transmission, and graphical user interfaces for examining the data would open up the technique to vineyard consultants and growers. By combining sap flow measurements (direct measurements of consumptive use) with other tools that were mentioned above, vineyard managers would have the information necessary to improve irrigation management by applying the right amount of water at the right time. Until sap flow systems are made more robust and automatic, we will continue to use them in research to provide information on the seasonal dynamics of water use by juice and wine grapes in eastern Washington.

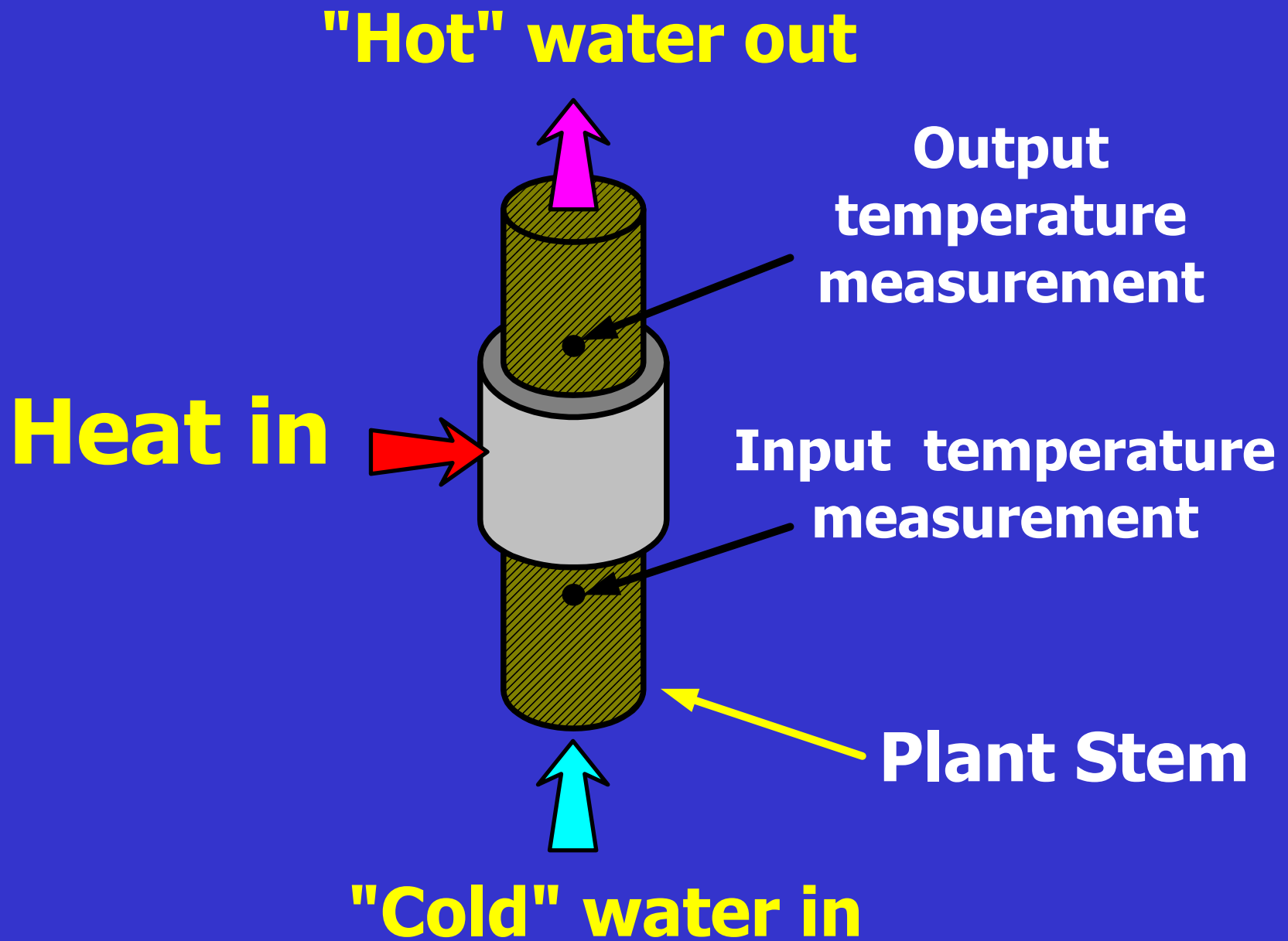


Figure 1

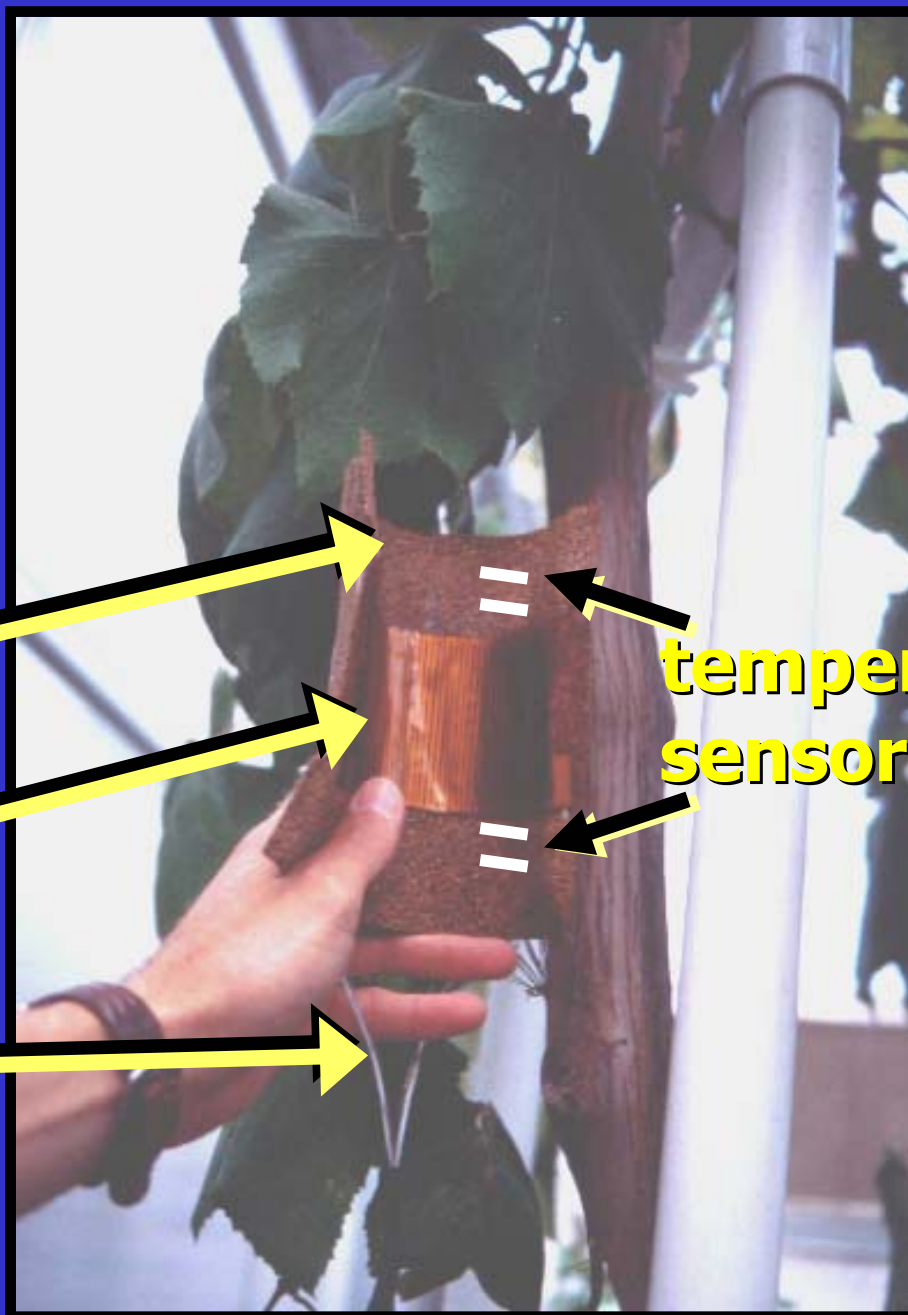
**"heat balance"  
sap flow gauge  
to measure  
vine water use**

**cork backing**

**heater**

**heater &  
signal wires**

**temperature  
sensors**



**Figure 2**



**insulating sap gauge  
from environmental heating**



**sun shield**

**Figure 3**

# Example: daily water use by mature 'Concord' vines

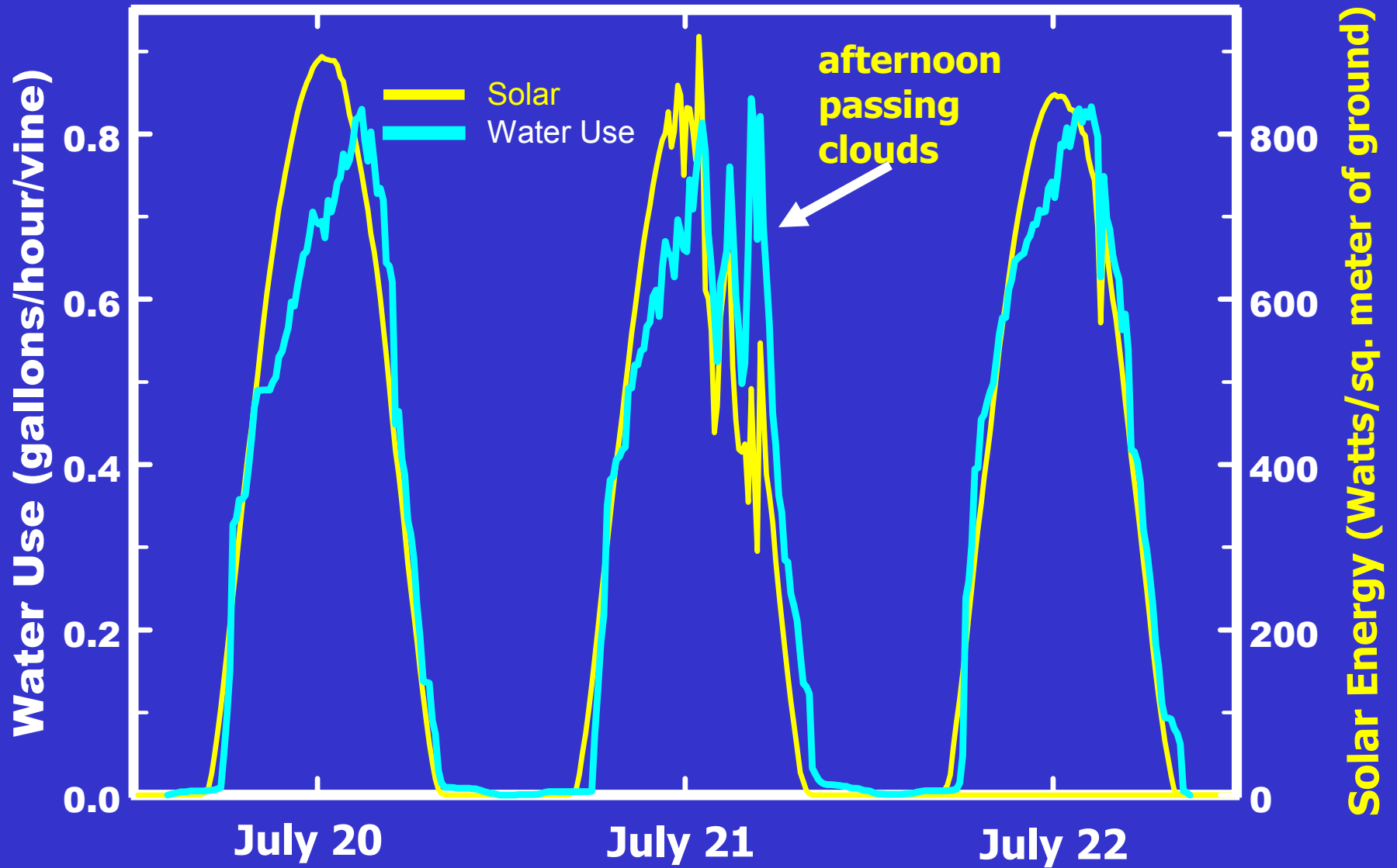


Figure 4

# Season of water use: mature 'Concord' vines

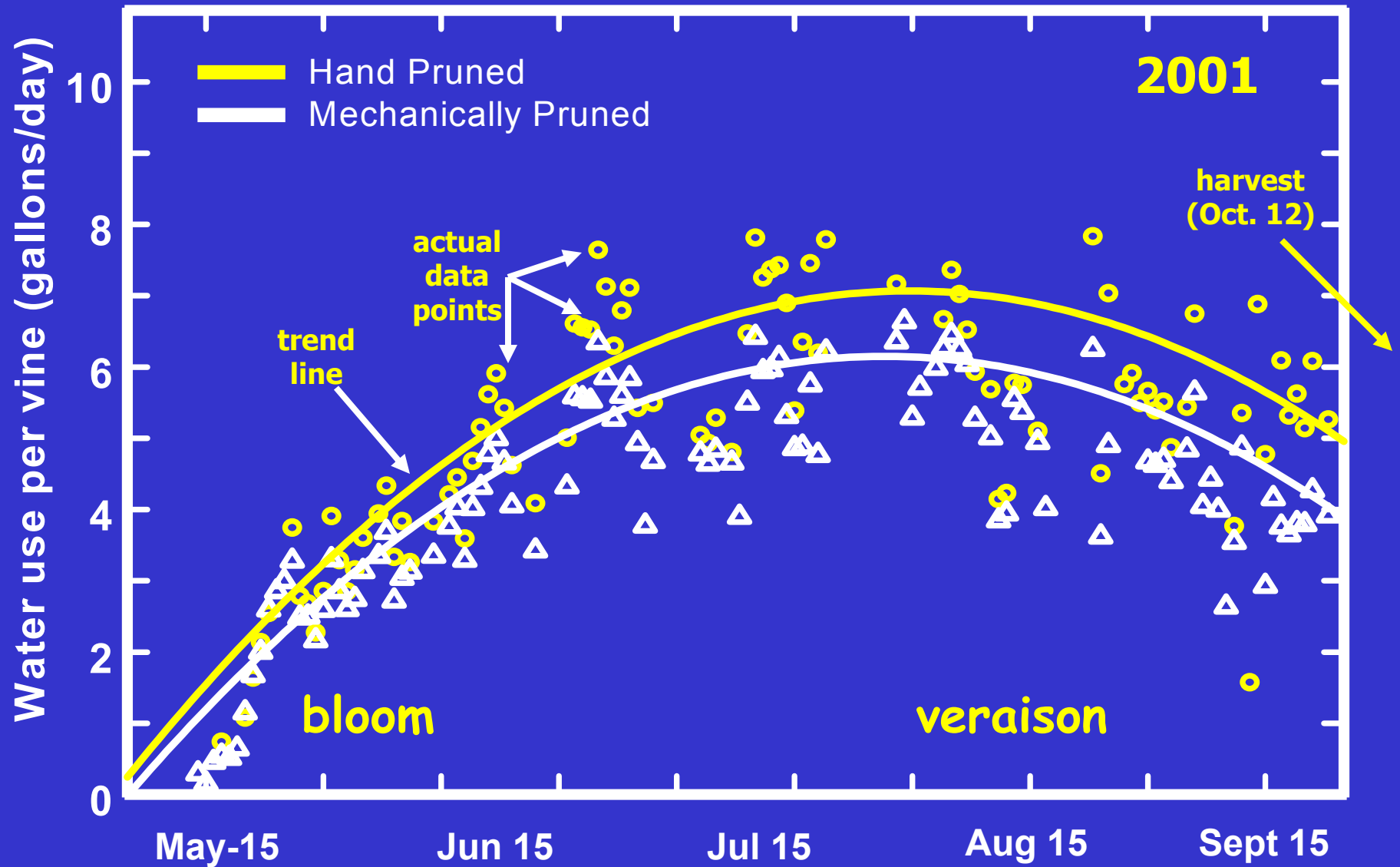


Figure 5