Understanding Grapevine Water Management: An Evolutionary Process

Looking back on irrigation management – Hey, can’t a guy change his mind?

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As a so-called (by others) and self-proclaimed “expert” in grapevine water relations and water management, one might think that I have all of the answers. No one knows better than I that I learn something new every day (except sometimes on weekends), and that changing my mind is a regular and repeating occurrence. In my professional practice as a viticulture consultant, I certainly continue to learn about all aspects of viticulture, even water management.

During my master’s work at UC Davis, we published two papers on berry water relations and how the xylem apparently ceases to function from veraison onward, with the phloem taking over to hydrate the berry during ripening. Our measurements provided evidence that agreed with previously-published scientific papers that offered evidence to a dysfunctional xylem. More recently, some papers have found evidence to the contrary, that the xylem function remains intact after veraison yet flow ceases or slows because the xylem is not needed. This is an excellent example of how science builds on itself, continuing to ask new questions and test old ideas in different ways.

Likewise, in practical viticulture, methods change as ideas are tested, some are proven effective and others tossed aside as better ways supplant less effective ways. I was recently re-reading a two-part article that I wrote in 2005 on irrigation management and quickly realized that I would have written some of it differently were I to write it again today. There are portions that I still agree with and others that I feel quite differently about in 2011.

Still the Same in My Mind: Value in Plant Water Status Measurement

One thing is clear: I still believe highly in plant water status measurement. Since my days doing basic research in grapevine water relations, I have employed plant water status measurement as a fundamental means to study both plant biophysics as well as for practical irrigation management of vineyards. The pressure chamber, which measures stem or leaf water potential, was and continues to be one of the most well-worn and comfortable tools in my toolbox. Its portability lends to its practicality, and the measurements are well understood by scientists, viticulturists, growers and even many winemakers.

I have heard some frustration with the pressure chamber (a.k.a. pressure bomb) that I completely understand: 1) It can only be used midday, during a brief period of time (though a few people do pre-dawn measurements) and only during sunny weather. 2) Measurements can sometimes be misleading, for instance when measuring after an irrigation application or on an unusually hot day. 3) It tells us what the water status (actually sap tension, or energy state) of the plant is but not how the plant is dealing with that condition.

It is for those reasons and others that I rarely, almost never, make pressure chamber readings without other measurements and observations. The other measurement I make is stomatal conductance. As I believed in 2005, if I only had one plant measurement to make, it would be stomatal conductance, not leaf water potential. The reason relates to No. 3 above. Stomatal conductance, measured by an instrument called a porometer, is a measurement of the relative openness of the collection of stomata (leaf pores). Stomata open to allow CO₂ influx as well as water vapor efflux. Water vapor efflux allows the leaves to continue the transpiration process, by which liquid water within the extracellular matrix inside of the leaf evaporates into the sub-stomatal cavity and out through the stomata into the surrounding air. In so doing, thermal energy is used, thus cooling the leaf, much like our perspiration cools our skin. Stomata close during the night, but they also close
Understanding Grapevine Water Management during the daytime under adverse conditions, such as low humidity, very high or very low temperature, or water stress in the vine. Abscisic acid (ABA), a plant hormone, is partially responsible for activating the stomatal closure (not so for the humidity response). The important thing is: that same ABA also stimulates many of the ripening processes in the fruit. Ah! Stress on vines is good for fruit ripening, yes, but not too much stress.

That is the beauty of the stomatal conductance measurement. Its measurement is also an assessment of the overall physiological stress level of the vine — not just a biophysical measurement like water potential. In red grapes grown for quality wines, we want to stress the vines (mildly) during portions of the growing season. Thus, the stomatal conductance measurement provides quantifiable feedback about how the vines are doing so that we can adjust our irrigation practices (if we are irrigating at the time) accordingly. A recently-published work indicates a “sweet spot” for stomatal conductance, based on both water-use efficiency and fruit phenolic development. The sweet spot was approximately 110 to 150 mmol m\(^{-2}\) s\(^{-1}\). I was delighted to read that because, from practice, I have been suggesting a range of 100 to 150 m\(^{-2}\) s\(^{-1}\) for a target level of stomatal conductance at or shortly before veraison.

This kind of vindication elevates my ego a notch or two, yet I always fall back to earth when evaluating this data in practice. The porometer is a difficult instrument to work with and some have become frustrated with it. Variability in the measurements is high, as the instrument that I use measures only 31 mm\(^2\) of leaf area at a time. Still, there are about 200 stomata per mm\(^2\), so we are sampling more than 6,000 stomata every time we measure. Nevertheless, we do find considerable variability from leaf to leaf and find that we must make about five measurements every place we measure (usually only three measurements are needed for the pressure chamber). Even then, the measurements take only 30 seconds, so we find that an adequate sample can be measured in just a few minutes. On the other hand, stomatal conductance is highly sensitive to the environment, and measurements can vary from day-to-day or week-to-week. This seems to be particularly true when the vines have a surplus of water available, such as late spring and early summer. By the time they get close to the sweet spot, the variability seems to decline. I’m not sure why that is, but perhaps when vines experience moderate stress, the stomatal closure is less affected by the environment than it is by the water stress itself.

As I have always said, neither the pressure chamber nor the porometer gives any indication at all about how much irrigation needs to be applied and when. This is true for visual assessments (about which my mind has not changed all along). These are tools used for monitoring the effects of our water management practices on the grapevines. And it is in the determination of irrigation scheduling where I diverge from my earlier thinking.

What has Changed in My Mind:
Irrigation Scheduling Tools
In my 2005 article, I espoused the use of evapotranspiration (ET) models and shunned the use of soil moisture monitoring. In my reasoning against the use of soil moisture for irrigation scheduling, I contended that soil is highly heterogeneous, the drip irrigation wetted zone is not easily represented by the measurement, soil moisture devices are not easily calibrated and that the units are fixed in place and are not portable (actually, I didn’t cite that last reason, but it was in my thought process). All of those reasons are true, but I have found that soil moisture monitoring is a tremendous tool for irrigation scheduling. Why has my thinking changed?

First, let me qualify this by saying that soil moisture monitoring is a valuable tool only if it is: 1) measured at multiple depths and at least as deep as the bottom of the root zone, 2) is measured continuously, not in weekly snapshots, 3) is installed to capture as nearly as possible the center of the wetted “bulb” of soil and 4) is placed in an area of the vineyard where soil has some of the lowest water holding capacity.

Soil moisture needs to be measured at multiple depths. The bare minimum number of depths is 2, but ideally measurement depths of at least 1-foot intervals are monitored. The purpose of this is to gauge how deeply the irrigation applications are infiltrating. The goal is, in general, wet to the bottom of the root zone and
no deeper. Measuring soil moisture at several depths, and identifying patterns of wetting following an irrigation, gives good feedback and allows us to "calibrate" our irrigation volumes to match our desired depth of wetting.

My feeling now is that the volume (or hours of irrigation) chosen should be recorded for each block and that volume used for successive irrigations, while the interval between irrigations is manipulated to achieve the desired level of water status in the vines. There may be situations where the entire root zone is not targeted for wetting, such as in heavy soils where water status remains too high between irrigations, so the entire root zone is not irrigated. However, in lighter-textured (i.e., sandy or silty) soils, it is usually advisable to wet down to the bottom of the known root zone. This provides greater soil volume from which to draw upon, having the benefit of a larger pool of nutrients as well. The lighter soils will become depleted more quickly than the heavier ones and the vines will reach their desired water status target more rapidly than in heavier soils.

Continuous measurement is essential. By continuous, I mean hourly, or every 30 minutes, approximately. Subtle and not-so-subtle patterns in soil moisture levels during and after an irrigation can provide a tremendous amount of information regarding the irrigation wetting front, moisture redistribution after irrigation, root activity by soil level, and even level of stress. Weekly, similar periodic soil moisture measurements cannot show these features. With the help of other soil moisture specialists, I have trained myself to identify key patterns and to refine the irrigation practices accordingly. That means that the sensors must be connected to an electronic data logging device, to be off-loaded periodically or delivered automatically via radio telemetry. The good news is that technology keeps improving and also gets more affordable as time goes by. There are numerous soil moisture solutions out there, and a discussion about them here would be lengthy. Also, I will avoid recom-
Soil Moisture per Depth Interval

Monitoring irrigation at several depth levels allows irrigation volume to be adjusted such that it reaches the desired depth of rooting or some fraction thereof. Shapes of the continuously-monitored curves indicate where active root uptake exist as well as other information.

mending any particular sensor or manufacturer here since my business engages in distributing, installing and operating some of the manufacturers’ devices in vineyards. In fact, I hesitate to enter any new vineyard consultation without setting up some soil moisture monitoring. I feel confident that it improves my ability to improve the irrigation practices of any vineyard I work with.

Regarding calibration, the only readily-calibrated instruments are those that measure soil matric potential, such as gypsum blocks or other granular matrix sensors. Devices that measure water content (such as volumetric water content) are not easy to calibrate. While possible to calibrate the water content sensors, I find that one does not need to calibrate them to fully exploit their benefits. Looking at soil moisture patterns over time is more important than identifying actual percentage of water in the soil. Indicators of full points and refill points are easily determined on a site-by-site basis, eliminating the need for specific calibration. For drip irrigation, irrigation volume is not determined using volumetric water content, as it may be used for flood or sprinkler irrigation. We have the method described above to accomplish the volume requirements.

As these devices are installed in the ground permanently, determination of their optimal location is critical. First, the question is rightfully asked: “Where do I install the sensor relative to the drip emitter?” The answer I give is: “As close to the emitter drop as possible without the emitter dripping on the above-ground portion of the sensor probe.” We used to place sensors about 8 inches away from the emitters, yet we’ve found that the wetted bulb extends only 9 to 12 inches away from the emitter in heavy soil—even less of a radius in lighter soils. So, installation of the sensor array too far from the emitter will give the false sense that irrigations are not penetrating deeply enough and that the soil dries out earlier than it actually does. The consequence of this blunder is excessive irrigation. I typically install the sensors about 3 to 4 inches away from the emitter drop location.

Where in the vineyard block to install them? I generally want to target some of the weaker (less water holding capacity) soils in the block. I aim for a location that is not unusually weak, but is representative of the weakest quarter of the block or irrigation set, using a soil map or aerial imagery. The reason for this is that the irriga-
Total Soil Moisture in Profile

Slopes are indicative of water consumption rates and relative vine moisture stress levels.

Total soil moisture plots can provide indications of relative stress levels as well as to determine irrigation intervals without the need for ET models.

- The block's condition cannot be controlled on a site-specific basis, so one must irrigate according to the soils having the lowest storage capacity. That means that the heavier soils will be irrigated less than they can handle, but that is less important than ensuring that water remains available to the weaker areas between each irrigation event.

- Looking at total soil moisture in the profile makes it easy to schedule irrigation events without the need for ET models. Since we know what the soil moisture level was right before our last irrigation, we wait until the moisture returns to that point again before irrigating. This takes the guesswork out of scheduling. The ET model is chock full of estimation, and I’ve found that I generally irrigate much less than crop ET would dictate—often less than 20 percent of full ETc (crop ET). The ET model does not account for stomatal closure; and since we are timing our irrigations such that some stress is developed in the vines (in most cases), the vines operate at a higher water-use efficiency than the ETc model accommodates.

- Continuous soil moisture monitoring and new tools to facilitate data transfer and evaluation have made irrigation scheduling easier than ever. Using these tools allows us to reduce our irrigation applications such that the site’s terroir is not “diluted” by over-irrigating.

Footnotes


