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COMPARISON

Three most common methods – measuring vine water status

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Regulated deficit irrigation (RDI), has become widely accepted as a method to improve winegrape quality in the last ten years. By imposing a pre-determined, measurable level of water stress at a particular stage of vine growth, winegrowers have found that they can enhance the intrinsic value of their grapes while they save money on labor and energy bills and help preserve a very valuable natural resource.

Dr. Greenspan prepares a leaf for measurement of stem water potential. A black plastic bag is wrapped tightly around the leaf, then the bag is covered with aluminum foil to avoid overheating the leaf. The bag and foil will be left on the leaf for 90 to 120 minutes.

A critical aspect of any successful RDI program is monitoring the vine's water status or its response to the elements that make up its unique microclimate. However, which method of measurement will work best for an individual vineyard manager in a particular area is still a question that often arises. This is a report on plant-based measures of vine water status, but they are certainly not the only answer.

Plant-based monitoring is considered to be a reliable, practical approach because it queries the vine itself, rather than the elements of its environment, to determine its internal stress level.

Because plant water status is a key metabolic indicator, its actual measurement provides a valuable gauge of vine growth and winegrape development. This measurement can be accomplished in many different ways, but plant-based and soil-based measures are the most common.

Grapevine vegetative and reproductive growth processes relate directly to the vine's water status and only indirectly to the surrounding soil moisture and atmospheric conditions. Therefore, this report will concentrate on the three most common plant-based methods of measurement that utilize a pressure chamber to determine the vine's water status.

The pressure chamber (also called a pressure bomb), has become an invaluable tool for measuring vine water status in vineyards. It is available at a reasonable cost, it's portable and the measurements are done in real time in the vineyard, so irrigation management decisions can be made as data is collected.

However, there has been some procedural confusion about the use of a pressure chamber because there are basically three ways it can be used to measure vine water status. These include: predawn leaf water potential (PDLWP), mid-day leaf water potential (LWP), or mid-day stem water potential (SWP). The three methodologies vary mainly in the timing of the measurement and preparation of the leaf to be sampled. The confusion seems to focus on which method is most reliable and meaningful for a specific situation or environment.

In 2002, L.E. Williams and F.J. Araujo reported the results of a study they conducted to compare the three methods of measuring grapevine water potential and also correlate data from those trials to other measures of soil and plant water status (Williams, L.E. and F.J. Araujo, 2002, "Correlations among predawn leaf, mid-day leaf and mid-day stem water potential and their correlations with other measures of soil and plant water status in *Vitis vinifera,*" *J. Amer. Soc. Hort. Sci.* 127(3): 448–454). The following information is a restatement of the findings demonstrated in the Williams' publication.

The differences in the three plant-based water status methods, stated simply, are; measurements of mid-day water potential, either stem or leaf, should be taken in the one-hour period beginning 30 minutes prior to solar noon and ending 30 minutes after solar noon. It is during this time that maximal diurnal water use or canopy conductance has been measured on non water-stressed grapevines using a weighing lysimeter. Predawn leaf water potential measurements are taken beginning at 3:30 am and ending at sunrise.

This short time-limit has been the most common restraint to use of mid-day leaf water potential in vineyards, but it is necessary for technical reproducibility. In vineyards, however, the window is often extended by another hour. The data obtained may not be reproducible enough for technical research, but is accurate enough for irrigation scheduling.

Leaf Water Potential
A fully expanded leaf exposed to direct sunlight is chosen for measurement. To measure mid-day leaf water potential, the targeted leaf must first be covered entirely with a small plastic bag that is wrapped tightly around the leaf and secured. Securely bagging the leaf before cutting it from the shoot avoids any further transpiration, which alters the resultant pressure reading. If this critical bagging step is omitted, the data will be inaccurate.

As quickly as possible after bagging, the petiole of the bagged leaf is cut from the shoot with a sharp razor as close to the shoot as possible. The petiole is then quickly placed through the chamber lid and secured tightly, with the cut edge of the petiole facing outside and the bagged leaf blade inside the chamber.

The chamber is sealed and then slowly pressurized with nitrogen gas. When the positive pressure exerted on the leaf in the chamber equals the negative pressure inside the leaf, liquid in the leaf blade will begin to be forced out of the cut edge of the leaf.

During pressurization, the operator carefully watches the exposed edge of the petiole for the appearance of a drop of water (sap). As soon as the drop appears, the user reads the corresponding pressure from the chamber gauge. This pressure value is the leaf water potential, read in negative (–) bars.

In comparison, mid-day stem water potential tests are done during the same time period as mid-day leaf water potential but handling of the leaf is changed. Stem water potential has been considered to be less variable than mid-day LWP, improving the ability to detect small pressure differences among treatments. But until this study was completed, a comprehensive study comparing the two had not been tested in grapes.

Stem Water Potential
The stem is thought to be less susceptible to fluctuations in environmental pressures than the leaf and, therefore, more representative of the actual level of stress in the entire vine. In the mid-day SWP test, a leaf on the shaded side of the canopy is chosen to minimize any possible heating effects.

The leaf is wrapped in a black plastic bag that is covered with aluminum foil to prevent overheating by the sun. The bag is left on the leaf 90 to 120 minutes. This effectively stops the natural transpiration from the leaf, allowing the leaf water potential to come into equilibrium with the stem water potential. After 90 to 120 minutes has elapsed, the leaf is excised and tested in the pressure chamber as stated above.

Pre-dawn Leaf Water Potential
Pre-dawn leaf water potential is determined using the same basic methodology as LWP, but the readings are taken beginning at 3:30 am and ending before sunrise, using fully expanded leaves. It has been assumed that, before sunrise, the vine is in equilibrium with the soil's water potential, therefore making PDLWP a more sensitive indicator of soil

water availability. But the obvious difficulty with the method is timing: readings must be done prior to sunrise, making its practicality questionable.

Comparison of methods

For any measure of plant water status to be a sensitive indicator of water stress, it must be responsive to differences in soil moisture status and/or the resulting growth differences due to water application. The measure should also be closely related to short- and medium-term plant stress responses and less dependent on changes in environmental conditions.

For winegrapes, it would seem that LWP, SWP, and PDLWP each meet these criteria. The best indicator of which method is the most effective and yet most practical might be as simple as the ease of operation if the data from all three plant-based measures of vine water stress can be proven to be highly correlated.

Additionally, the value of that plant-based stress data would be even greater if it could also be shown to be highly correlated with other indicators of vine water status. In the Williams and Araujo study, other indicators of vine water status used for further correlation with vine water potential are net CO_2 assimilation rates (A) and stomatal conductance to water vapor (g_s), both measured at solar noon, and soil water content (SWC), measured with a neutron probe.

The three indicators of vine water potential in this study were measured on both Chardonnay and Cabernet Sauvignon vines grown in Napa Valley in the 1999 growing season. Because both vineyards were part of a study on the effects of deficit irrigation, all vines had been irrigated weekly at various fractions of estimated vineyard evapotranspiration from berry set until the dates of measurements.

Vine water status and leaf gas exchange were measured on two dates in the Chardonnay vineyard and one date in the Cabernet Sauvignon vineyard.

Individual leaf replicates numbered six for each scion-rootstock combination and irrigation treatment in the Chardonnay vineyard on the first date, August 24, 1999, and five for each treatment in the Chardonnay on September 21, 1999.

Individual leaf replicates for the Cabernet Sauvignon on the only date measured (August 24, 1999) was also five. This produced 86 total data points.

Use of irrigation treatments at both locations resulted in a wide range of vine water status. The lowest values of PDLWP, LWP, and SWP recorded for an individual leaf were –0.85, –1.85, and –1.65 Mpa, (–8.5, –18.5, and –16.5 bars) respectively. The highest values of PDLWP, LWP, and SWP were –0.02, –0.75, and –0.55 Mpa, (–0.2, –7.5, and –5.5 bars) respectively. In most cases, significant differences among irrigation treatments for one measure of vine water status were also similarly different for the other two.

Test results showed that all three methods of estimating vine water status were highly correlated with one another. The best correlation was between mid-day LWP and mid-day SWP ($r^2 = 0.92$).

All three methods were significantly ($r^2 = 0.69$) correlated with soil water status in the Chardonnay vineyard and also significantly correlated with net CO_2 assimilation (r^2 = 0.67, 0.50, 0.48) and stomatal conductance at mid-day (r^2 = 0.69. 0.58, 0.54) in both vineyards.

All three measures of vine leaf water potential were linearly correlated ($r^2 = 0.93$) with berry weight and vine yield when measured the first week of October 1999. These data would indicate that either measurement of mid-day leaf water potential would give a good estimate of the water status of grapevines.

Pre-dawn leaf water potential has been used in many studies as the standard to which other measures of vine water status are compared. It is assumed that this is the period when the vine is in equilibrium with soil water potential.

However, the authors cite references showing that PDLWP of some non-grape species come into equilibrium with the wettest portion of the soil in the plant's root zone. Therefore, the soil moisture a vine responds to at mid-day may differ from that at pre-dawn due to the flux of water that is occurring when a vine is actively transpiring. If this is correct, differences at pre-dawn may not necessarily reflect the water status of the vine later in the day, as was observed in the Williams and Araujo study.

It has also been demonstrated that season-long measurements of mid-day LWP have been shown to be highly correlated with the seasonal changes in soil water content of treatments irrigated with differing amounts of water. That data and the data from this study in Chardonnay indicated that mid-day LWP was reflective of the amount of water in the soil profile.

All three methods of estimating vine water status were similarly correlated with SWC, applied amounts of water, and with one another, and were also significantly correlated with leaf gas exchange. Therefore, under the conditions of the Williams' and Araujo study, the criterion that measurements of plant water status should reflect: 1) the availability of soil moisture and/or, 2) applied water amounts, or 3) short- and medium-term plant-stress responses, were tested and met for all three measures of leaf water potential.

For practical use, critical values of mid-day leaf water potential, stem water potential, and pre-dawn leaf water potential could be established and utilized to make decisions such as when to begin irrigating each season and the interval between irrigation events. This would allow a grower/ manager to maintain a specific degree of vine water stress to produce winegrapes that are appropriate for the wine style.

However, from a purely practical standpoint, measurement of mid-day leaf water potential would be most convenient. The main limitation is the time frame allowable to assure consistency. In this study, that time was one half hour before and after solar noon.

The short time limits the acreage or the number of vines that can be measured in one day. The time can be lengthened, however, in a practical field situation, to one hour before and one hour after solar noon. This allows two hours for data collection and is certainly acceptable as long as the other factors affecting consistency (using the same vines each time, well-trained users, bagged samples, replicates) are carefully observed.

There is one other critical factor in using a pressure chamber to ascertain vine water status. It has been demonstrated that the individual making measurements of plant water status is a significant source of variation. It is, therefore, imperative that technicians be well-trained in use of the pressure chamber, and the choice of leaves to sample, and data discrepancy recognition. Trainees should be monitored closely for awhile to ensure they are using the equipment properly and their technique is appropriate and consistent.

Conclusions

In the above study, it was shown that mid-day leaf water potential, mid-day stem water potential, and pre-dawn leaf water potential values from two vineyards on three dates were linearly correlated with each other and with measurements of net CO_2 assimilation and stomatal conductance.

In Chardonnay vines, the three plant-based water stress indicators were also highly correlated with measures of soil water availability. It can be assumed, then, that they all represent equally viable methods of assessing the water status of winegrape vines.

In a practical situation, it may be more favorable to choose the method that best fits each manager's strategy, then be sure that method is followed precisely throughout the season.

Although there is significant correlation between the methodologies, that does not suggest that it would be advisable or even admissible to interchange the methods in a vineyard in a given season.

Finally and importantly, be sure all technicians are well-trained in both methodology and theory to assure the consistency that is required in building a valuable database.