Monitoring vine water status

Part 2: A detailed example using the pressure chamber

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In a nutshell

- The pressure chamber is the tool most commonly used to measure the vine water status
- Leaf water potential (LWP) has allowed us to establish reliable thresholds of vine water status
- Stem water potential remains the simplest way to assess vine water status and to give recommendations on irrigation (when, how much and for how long)

Plant water status can be measured directly by several different methods using the pressure chamber. Assessments are required on each particular block and at several locations within the block if the soil is heterogeneous. Typically there is significant variation in vine water status across a block. While we cannot remove this heterogeneity, we can deal with in a practical manner. In the first instance, it is suggested to map out the heterogeneity across the block using methods such as NDVI and/or soil electrical conductivity surveys. If more precise data are required, it could be recommended to follow this up with detailed vine stem water potentials to map out the wet and dry areas of the block. Depending on the size and the number of vineyards, several pressure chambers (or soil probes) may be required if the block is large since leaf and stem water potential vary significantly during the day. Using these comprehensive maps, choose extreme and average sections which can then be used as indicators of how to manage the rest of the block and to save on time and labour.

Leaf water potentials (LWP)

Measurements are carried out using a pressure chamber (Figure 1) according to the technique described by Scholander (1965). Leaf water potentials are reference measures of vine water status and have enabled solid reference thresholds of vine water status to be established, mainly with the predawn leaf water potential (PLWP) (Carbonneau,1998; Carbonneau *et al*., 2004) and with the stem water potential (SWP) (Choné *et al*., 2001). PLWP is mainly used for research purposes and practically speaking SWP is recommended. In addition these methods have demonstrated the importance of water constraint and deficit on vine functioning according to (i) developmental stage; (ii) duration of water constraint or deficit and (iii) its intensity/level (Myburgh, 2007; Deloire *et al*., 2005, 2004; Ojeda *et al*., 2002; 2001; Van Leeuwen *et al*., 2004; Naor *et al*., 1997; Myburgh *et al*., 1996; Van Leeuwen and Seguin, 1994).

This reliable, validated tool is conducive to appropriate sampling at the plot level.

Figure 1. *Example of a pressure chamber used to measure leaf water potential.*

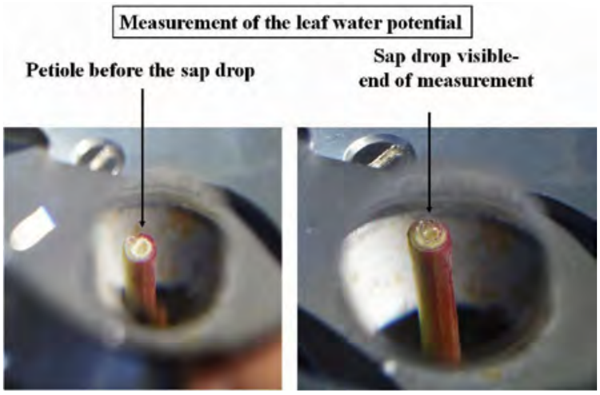

Figure 2. *The leaf water potential is obtained by pressurising a leaf with a neutral gas (such as nitrogen or air). When the sap drop is visible it is the end of measurement and the pressure is read on the pressure gauge. The duration of the measurement is less than a minute.*

Three cardinal measures of water potential

Pre-dawn leaf water potential (PLWP)

This data is obtained by measuring the leaf water potential by means of a pressure chamber (Scholander *et al*., 1965). It estimates the capacity of the cells to retain water by pressurising a leaf with a neutral gas. The less free water there is in the plant, the greater the pressure required to cause it to exude. The result is expressed in bar or MPa, always as a negative value. The measurement of predawn leaf water potential (PLWP; ψ_{plwp}), is performed before sunrise, when the stomata of the plant are closed and when the grapevine has been able to equilibrate its water potential with wettest layer of the soil. PLWP is mainly used for research purposes only. Threshold values for $PLWP_{plwp}$ have been proposed by

Carbonneau (1998), which makes it possible to evaluate the degree of water deficit experienced by the plant (Tables 1 and 2). The approximate values are the result of 20 or more years of observations in many vineyards of different cultivars. The PLWP is the reference for most cultivars in interaction with the terroir unit. Table 3 gives some indication on possible reasoning of PLWP, vine physiology and berry ripening.

Table 1. *Predawn leaf water potential and grapevine water status (according to Carbonneau, 1998). The physiological and biochemical vine requirements to these thresholds will depend on the cultivar, the phenological stage and the duration of the water deficit. (1 bar = 0.1 MPa = 100 KPa). This is mainly used for research purposes and is unlikely to be used in practical situations.*

Classes	Predawn leaf water potential (Ψplwp, MPa)	Level of water constraint or stress
0	0 MPa ≥ ψ_{plwp} ≥ –0.2 MPa	No water deficit
1	–0.2 MPa > ψ_{plwp} ≥ –0.4 MPa	Mild to moderate water deficit
2	–0.4 MPa > ψ_{plwp} ≥ –0.6 MPa	Moderate to severe water deficit
3	–0.6 MPa > ψ_{plwp} ≥ –0.8 MPa	Severe to high water deficit (= stress)
4	< –0.8 MPa	High water deficit (=stress)

Table 2. *The following table proposes simplified thresholds of pre-dawn leaf water potentials. The physiological and biochemical vine requirements to these thresholds will depend on the cultivar, the phenological stage and the duration of the water deficit (1 bar = 0.1 MPa = 100 KPa) (From Deloire and Heyns, 2011).*

Predawn leaf water potential (Ψ_{plwp}, MPa)	Level of water constraint or stress
0 to –0.3	Little or no water deficit (for most cultivars)
–0.3 to –0.6	Moderate to severe water deficit (depending on the cultivar)
< –0.6	Water stress (for most cultivars; irreversible cell damage)

Table 3. *Threshold values of pre-dawn leaf water potentials (Y_{plwp}, MPa) and possible consequences for vine functioning. It should be noted that the threshold values can vary amongst different grape cultivars (Ojeda et al., 2002; Williams and Araujo, 2002; Deloire et al., 2005).*

Y_{plwp} (MPa)	Vegetative growth	Berry growth	Photosynthesis	Grape ripening
0–0.3	normal	normal	normal	normal
–0.3 to –0.5	reduced	normal to reduced	normal to reduced	normal or stimulated
–0.6 to –0.9	reduced to inhibited	reduced to inhibited	reduced to inhibited	reduced to inhibited
< –0.9	inhibited	Inhibited	total inhibition	partial or total inhibition

Midday leaf water potential (MLWP)

The midday leaf water potential (MLWP) allows the measurement of plant water status during the day. It is a method which enables the measurement of a short term hydric response (for example on an hourly basis) of the vine in reaction to a change in the root water absorption and the leaf transpiration (interaction soil water content x climate x leaf transpiration x cultivar). The leaf water potential is not really recommended due to high variability between measurements.

Stem water potential (SWP)

The stem water potential (SWP) is measured on leaves which are bagged with both a plastic sheet and an aluminium foil at least 30 minutes before measurement (Myburgh, 2010). The bagging of the leaves prevents transpiration and their water potential reaches equilibrium with water potential in the stems. Stem water potential values are highly correlated with transpiration (Choné *et al*., 2001). They are particularly accurate for revealing small water deficits, or water deficits on soils with heterogeneous soil water potential (in interaction with the vine rooting). Stem water potential is generally measured between 11h00 and 15h00. The stem water potential is stable and sensitive, which means that 4 to 6 bagged leaves are enough to get correct information on a vine water status for a specific homogeneous situation. The relationships between the SWP and the PLWP plateaus beyond –0.6 to –0.8 MPa of PLWP (Sibille *et al*., 2007; Williams and Araujo, 2002), which means that the SWP is difficult to use beyond a certain level of water deficit (YSWP < –1.4 MPa). Nonetheless, Table 4 gives some useful reference values for most cultivars. For excellent information on SWP thresholds see Choné *et al*. and Lovisolo *et al*. 2010.

Table 4. *Stem water potential (measured between 11.00 and 15.00h), and possible relationship to the level of vine water deficit. The table proposes thresholds for most cultivars. Recommended vine water status* according to phenological stages: budburst – flowering: classes 0 to 1; pea size – véraison: classes 1 to 2; véraison – harvest: classes 1 to 4 according to the desired yield and style of wine. Class 5 has to be avoided (From Deloire and Heyns, 2011).*

Classes	SWP (Ψ_{SWP}, MPa)	Level of vine water deficit
0	≥ –0.6	Zero water deficit
1	–0.7 to –0.9	Mild to moderate water deficit
2	–1.0 to –1.2	Moderate water deficit
3	–1.2 to –1.4	Moderate to important water deficit (according to cultivar)
4	–1.4 to –1.6	Strong to severe water deficit (according to cultivar: possible plant and cell damage)
5	< –1.6	Severe water deficit (stress: plant and cell damage).

* The recommendations have to be considered in the context of soil type, depth and water content, cultural practices, climate and cultivars.

For practical use in vineyards using data from water potentials measured by the pressure chamber, several factors must be taken into account, i.e. (a) the diversity and heterogeneity of plots (which involves sampling); (b) the time taken to carry out the measurements (1–2 min per leaf and 4–6 leaves used for an average measurement; the number of measurements per plot is variable according to the heterogeneity of the situation); (c) labour costs; (d) the size of the vineyard (the time taken to move among plots); (e) the pre-dawn leaf water potentials are carried out just before daybreak which limits the sampling period to about two to four hours; and (f) extreme temperatures just before or during the day of measurement could influence leaf water potential results for specific cultivars (example of heat wave). As a very general indication, an irrigation of 12 mm could increase the stem water potential measured during the middle of the day (Ψ_{SWP}) by –0.4 MPa, 12 to 24 hours after the irrigation event. The irrigation programme has to be calibrated according to commercial targets of the yield and the desired style of wine. The amount of water, which will be applied will depend on the soil type and water content, the potential evapotranspiration and the cultivar (drought sensitive versus drought tolerant variety; Schultz, 2003). The duration of the irrigation will depend on the irrigation system (water flow rate of the drippers) and the number of drippers per m^2 or hectare. The irrigation programme has to be calibrated and established according to the recommendations provided in this article (one season could be enough for the calibration). A pressure chamber is therefore needed to begin the calibration. If the 'site by cultivar' combination is 'stable', the irrigation programme could be reproduced from one year to another. However the programme will have to take into account unpredictable climatic variables such as heat waves. Changes in soil water content can also be monitored with soil probes and morphological observations could be used in parallel with the pressure chamber.

Table 5. *Stem water potential as indicators of vine water status.*

Vigour	Safe window	Moderate to high water constraints	Water stress (Avoid)
0 to –0.6 to –0.9 MPa	–0.6 to –1.1 MPa	–1.1 to –1.4 MPa	Values more extreme than –1.4 MPa

* Values closer to 0 indicate that the vine is more hydrated.

In a nutshell

- It is recommended to avoid water constraint from budburst to the end of flowering
- From berry set to veraison (early berry softening), if a water constraint is applied, it is recommended to avoid high constraint and stress to preserve the fruit metabolism and composition (quality)
- From veraison to harvest, the irrigation program will depend on the desired yield and concentration of sugars and other fruit components (severe water stress has to be avoided)
- Irrigation is required before a heat wave

Examples of irrigation strategies

Vineyards and vine irrigation should be managed according to the production goals and the phenological stages:

- Bud break to flowering
- Flowering to the very beginning of veraison (berry softening)
- Veraison (very beginning of berry softening) to harvest

Table 6 provides some examples of possible irrigation strategies using the information on vine water status.

Other morphological indicators (growth and necrosis of the apex, leaf shrivelling, and tendril angle) and/or physiological indicator (berry sugar accumulation) could be used in parallel of measuring vine water status.

Table 6. *Examples of irrigation options at the various developmental stages of the vine. Other options could be chosen according to yield, fruit quality/composition and potential wine style goals.*

Developmental stage	Stem water potential (MPa)*	Predawn leaf water potential (MPa)*	Purpose
Budburst to fruit set	0 to –0.6	0 to –0.3	Avoid water deficits as flowers and fine roots are developing during this stage. Fruit set is very sensitive to any water stress
Fruit set to early veraison (start of berry softening)	0 to to –0.6	0 to –0.3	To prevent inhibition of canopy and fruit growth and metabolism avoid water constraints
	–0.7 to –0.9 or –1.0 to –1.2	Regulated deficit irrigation (RDI) at –0.3 to –0.5	To achieve a reduction in vigor and fruit size trying to avoid perturbation of fruit metabolism (more extreme values than shown here will result in the inhibition of important compounds: tannin, aromatic precursors, organic and amino acids)
Veraison to harvest	0 to –0.6	0 to –0.3	Avoid any water constraints to prevent the inhibition of fruit growth
	–0.7 to –0.9 or –1.0 to –1.2	–0.3 to –0.5	To manage fruit volume (more extreme values than shown here will affect leaf functioning and result in slowed sugar and anthocyanins)
Post-harvest	0 to –0.9	0 to –0.5	To replenish vine carbohydrate reserves, water stress has to be prohibited to avoid inhibition of photosynthesis

* Values closer to 0 indicate that the vine is more hydrated.

Summary in a nutshell

- There are various ways to practically assess soil moisture and vine water status including soil probes, the pressure chamber and morphological indicators.
- The decision on which tool/method to use and how to manage irrigation belongs to the growers and the winery but training to use decision making tools is often required/recommended.
- Cost, labor, practicality and efficiency should be considered prior to choosing a method or a tool.
- Irrigation management needs to consider practical goals such as yield, fruit quality/composition and desired/potential wine style
- While new tools or technologies are under development, the above considerations will still apply when they become available.

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