The Leaf Water Potentials: Principles, Method and Thresholds

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by Alain Deloire & Drikus Heyns

Among the tools available to measure plant water status, there are the different leaf water potential methods.

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). In addition, they have demonstrated the importance of water constraint and deficit for vine functioning according to (i) phenological stages; (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.

The three leaf water potentials

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 reference method used today is the measurement of predawn leaf water potential (PLWP; ψ_{plwp}), which 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 the most humid layer of the soil. 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 & 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.

Leaf water potential (LWP)

The leaf water potential (LWP) allows measuring the 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 measurement is a way of obtaining whole vine water status during the day. 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 humidity (in interaction with the vine rooting). Stem water potential is generally measured between 11h00 and

FIGURE 1. Example of a pressure chamber used to measure leaf water potential. (Photo from L'Ormarins vineyard)

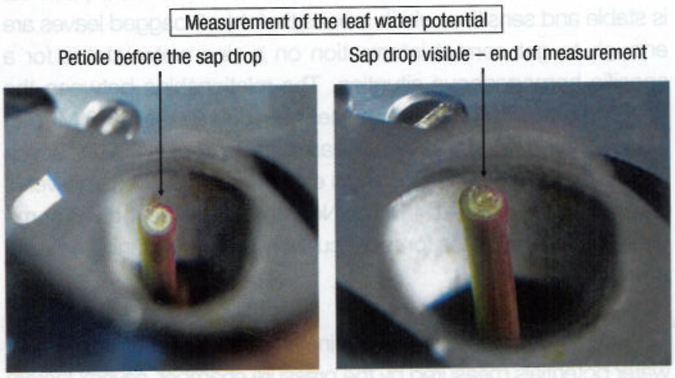

FIGURE 2. The leaf water potential estimates the capacity of the cells to retain water by pressurising a leaf with a neutral gas. When the sap drop is visible it is the end of measurement and the pressure is read on the pressure gauge. The duration of the measurement is a few seconds.

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).

Classes	Predawn leaf water potential (Ψ_{plwp}, 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).

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 (Ψ_{plwp}, MPa) and possible consequences for vine functioning. It should be noted that the threshold values can vary among different grape cultivars (Ojeda *et al.*, 2002; Williams and Araujo, 2002; Deloire *et al.*, 2005).

Ψ_{plwp} (MPa)	Vegetative growth	Berry growth	Photosynthesis	Grape ripening
0 to -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

TABLE 4. Stem water potential (measured between 11.00 and 15.00 h. in universal time), and possible relationship to the level of vine water deficit. The table proposes thresholds for most cultivars and terroir units in South Africa. Recommended vine water status* according to phonological 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.

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 damages)
5	< -1.6	Severe water deficit (stress: plant and cell damages).

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

15h00, when values reach a minimum. 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 are most linear 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 exploit beyond a certain level of water deficit (ψ_{SWP} < −1.4 MPa). Nonetheless, table 4 gives some useful reference values for most cultivars and terroir units in South Africa.

For operational management of vineyards using data from the leaf 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 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). The need is to get homogeneous plots as reference. As a very general indication, an irrigation of 12 mm could increase the stem water potential (Ψ_{SWP}) by -0.4 MPa., 12 to 24 hours after irrigation. The irrigation programme has to be calibrated according to commercial targets as 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 (pET) and the cultivar (drought sensitive versus drought tolerant variety; Schultz, 2003). The duration of the irrigation will depend on the irrigation system (drip 2.3 VS 4 litre per hour) and the number of drippers per m2 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 "terroir unit x cultivar" combination is "stable", the irrigation programme could be reproduced from one year to another (the climatic variable will therefore be the heat waves which are not predictable). Otherwise, the evolution of the soil water content with soil probes and morphological observations could be used in parallel with the pressure chamber [see articles of Dr P Myburgh (ARC-Infruitec, Nietvoorbij), in 2010 and 2011 WynLand magazine].

The leaf water potential could be used (and is used in many viticultural countries) to manage vineyard irrigation and to adapt irrigation to cultivar. It is a useful method for precision irrigation which could help to save water. It is also a useful method to understand vine physiology and berry composition. Water (in relation with soil type, depth and water content) (Van Zyl, 1988), temperature (including the heat waves) and wind (including sea breezes) are the most important abiotic (climatic) factors in South Africa which affect vine water content and thus vine functioning, berry composition and style of wine. Regarding climatic changes/evolution, precision irrigation and therefore water saving is an important consideration for the future of the SA wine industry.

Authors

Prof Alain Deloire, Department of Viticulture and Oenology, Stellenbosch University. Drikus Heyns, Distell, Stellenbosch.

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