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A few words on grapevine leaf water potential

>>> The majority of vineyards are grown under limiting water supply, with consequences on grapevine physiology, berry growth and composition/quality versus wine styles. Assessing vine water status is crucial to understand vine function and to optimize drought mitigation strategies, such as irrigation. In this regard, the leaf water potential methods, notably predawn and stem water potentials, are relevant for quantifying vine water status and are generally used as references to calibrate others methods and/or for precision irrigation. <<<

■ Leaf water potential, a tool for vine water status assessment

Amongst the tools available to measure vine water status[1], the leaf water potential method, using a pressure chamber (Figure 1), has been the standard method in research and development. It has also been highly useful for the calibration of other technologies to assess soil or vine water status including soil moisture sensors, sap flow sensors, infrared tools, etc). Solid reference thresholds of vine water status have been established, mainly with pre-dawn leaf water potential (PLWP)[2] and with stem water potential (SWP)[3, 4]. The strong relationships between leaf water potential, soil water status and plant function explain why the measurement of plant water status (duration and intensity of water deficit) is so important across all the phenological stages[5, 6, 7]. However, this reliable, validated tool is dependent on appropriate sampling at the plot level.

■ The three leaf water potentials (PLWP, MLWP and SWP)

Pre-dawn leaf, midday leaf and stem water potentials (respectively, PLWP, MLWP and SWP) are measured on detached leaves using a pressure chamber according to the technique described by Scholander (1965)[8]. The method consists of pressuring the leaves with a neutral gas. The water potential is estimated from the pressure required to force out the xylem sap from the mesophyll cells. The greater the pressure required to exude the xylem sap from the petiole, the more negative is the leaf water potential (figure 2). Pre-dawn, leaf and stem water potentials are expressed in bars or MPa, always as negative values.

➔ Pre-dawn leaf water potential (PLWP)

The reference method used today for addressing grapevine water status is the measurement of predawn leaf water potential (PLWP; ψ_{plwp}), which is performed one to two hours before sunrise, when grapevine water status is at a maximum. Pre-dawn water potential measurements present the advantage of being stable, regardless of climatic conditions, and are closely linked to soil water status in the vicinity of roots. Threshold values for PLWP have been proposed by Carbonneau (1998)[2], which makes it possible to evaluate the degree of water deficit

Figure 1. Example of a pressure chamber used to measure leaf water potential (photo from A. Deloire, South Africa).

experienced by the plant (table 1). The values are the result of more than 20 years of observations in many vineyards and for different cultivars. The PLWP is the reference for most cultivars in interaction with the terroir unit. One must consider, however, that PLWP measurements can lead to an underestimation of the water deficit experienced in drip-irrigated vineyards with very low soil water holding capacity. Indeed, measurement of PLWP after a short irrigation event may suggest adequate soil moisture, although the majority of the rootzone faces dry conditions, thus resulting in an unexpected and quick vine water status decline. Table 2 provides guidelines on vine physiology and berry ripening responses to decreasing PLWP.

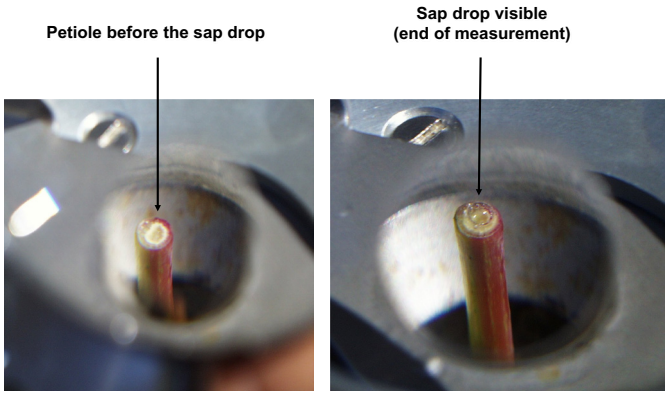

Figure 2. The leaf water potential is determined from the pressure required to force out the xylem sap from the mesophyll cells of a detached leaf, using a neutral gas. When the xylem sap drop is visible at the petiole surface, it is the end of measurement and the pressure is read on the pressure gauge. The duration of the measurement is a few seconds.

Table 1. Pre-dawn leaf water potential and grapevine water status[2]. The physiological and biochemical vine responses 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). pressure gauge. The duration of the measurement is a few seconds.

Classes	Predawn leaf water potential (Ψ_{plwp}, MPa)	Level of water constraint or stress
1	0 MPa ≥ ψ_{plwp} ≥ -0.3 MPa	No water deficit
2	-0.3 MPa > ψ_{plwp} ≥ -0.5 MPa	Mild to moderate water deficit
3	-0.5MPa > ψ_{plwp} ≥ -0.8 MPa	Moderate to severe water deficit
4	< -0.8 MPa	Severe to high water deficit (=stress)

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Table 2. 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 amongst different grape cultivars[7].

Ψ_{plwp} (MPa)	Vegetative growth	Photosynthesis	Berry growth	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
-0.5 to -0.8	reduced to inhibited	reduced to inhibited	reduced to inhibited	reduced to inhibited
< -0.8	inhibited	inhibited	Inhibited	reduced to inhibited

➔ Midday leaf water potential (MLWP)

Midday leaf water potential (MLWP) is a 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 climatic demand x leaf transpiration x cultivar/rootstock). The measurement of midday leaf water potential is not recommended as a decision support aid for irrigation scheduling because it is highly responsive to the fluctuations in the microclimate surrounding the leaves.

➔ Stem water potential (SWP)

Stem water potential (SWP) is measured on leaves that are bagged with both a plastic sheet and aluminium foil for at least 30 minutes before measurement. The bagging of the leaves prevents their transpiration and their water potential reaches equilibrium with the water potential in the stems. Stem water potential measurement is a way of obtaining a more integrative indicator compared with midday leaf water potential, and is less prone to leaf microclimate. However, stem water potential values are highly correlated with climatic demand and the overall plant transpiration flow[3]. Stem water potential is generally measured between 13h30 and 15h30, when plant water status is at a minimum. Stem water potential was shown to be more stable over time and across the shoot or canopy than midday leaf water potential. It is also more sensitive to mild water deficits or water deficits in soils with heterogeneous soil humidity (in interaction with the vine rooting) than the measurement of pre-dawn water potential[3]. The relationships between the SWP and the PLWP are most linear beyond -0.6 to -0.8 MPa of PLWP, but the SWP is difficult to interpret beyond a certain level of water deficit (ψ_{SWP} < –1.4 MPa) as stomata close. Nonetheless, table 3 gives some useful reference values for most cultivars and terroir units[4].

Table 3. Stem water potential (measured between 13.30 and 15.30 h), and possible relationship to the level of vine water deficit. The table proposes thresholds for most cultivars and terroir units. However, the recommendations have to be considered in the context of soil type, depth and water content; cultural practices; climate and cultivars.

Class	SWP (Ψ_{SWP}, MPa)	Level of vine water deficit
1	≥ -0.6	No water deficit
2	-0.7 to -1.1	Mild to moderate water deficit
3	-1.2 to -1.6	Moderate to severe water deficit (according to cultivar)
4	< -1.6	Severe to high water deficit (stress)

■ Operational management of vineyard using PLWP and SWP

The recommended vine water status according to phenological stages based on PLWP or SWP are: budburst - flowering: class 1; pea size - véraison: classes 1 to 2; véraison - harvest: classes 1 to 3, depending on the desired yield and style of wine. Class 4 should be avoided, as it may lead to plant and cell damage. For operational management of 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 the plot; (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) the size of the vineyard (the time taken to move among plots); (d) the pre-dawn leaf water potentials are carried out just before daybreak which limits the sampling time; and (e) rainfall event the day before the measurement, or extreme temperatures (*eg.* heat wave) during the day of measurement, are likely to influence leaf water potential results.

■ Take home message

Leaf and stem water potential are used in many viticultural countries to manage vineyard irrigation and to match irrigation to a specific cultivar. It is a useful method for precision irrigation targeted to save water. PLWP and SWP are key physiological indicators of vine water status and form the basis for the calibration of other decision-support tools (Sap flow sensors, IR thermometer, soil moisture probes…). They are also proven methods to understand vine physiology and berry composition in relation to vine water status. Water availability, which affects vine water status and thus vine functioning-physiology, berry composition and wine style/quality, is the result of soil (type, depth & management) and climate (climatic demand & rainfall). Water availability is thus a crucial abiotic factor in unirrigated wine regions. ■

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