Review of methods to assess vine water status

**Assessing the water status of the vine is crucial for optimizing cultivation practices and irrigation strategies while ensuring environmentally and economically sustainable viticulture.
In view of the most recent results in the literature, this article critically reviews the main measurement methods carried out directly on plants.**

Visual observation

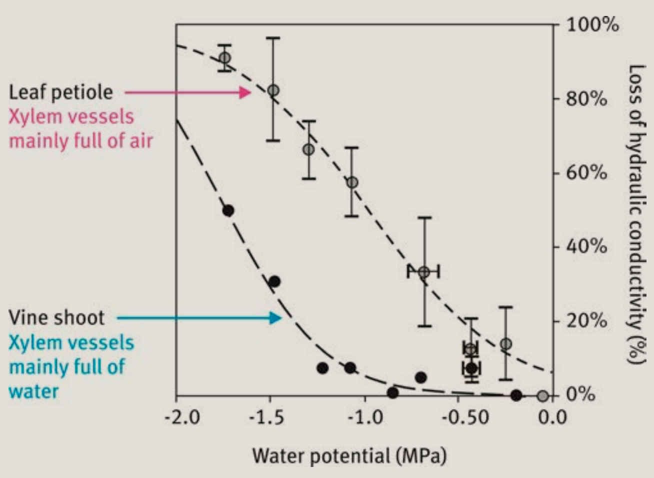
The simplest way to assess the water status of a vine is by direct visual field observation. The loss of turgor first noticeable in tendrils followed by the slowing down of vegetative growth is among the earliest responses of a plant sensing a limiting water supply. This slackening of shoot growth can be primarily noticed by simply observing the shoot apical meristem or apex of vines. However this method can not be applied for irrigation needed after shoot growth ends once meristem is cut or has dried up.

Pressure chamber

Vine xylem potential (Ψ) is the tension (ie. a negative pressure) under which the water (xylem) circulates from the roots to the leaf air interface where it gets vaporized. Xylem potential can be measured at the petiole level to reflect leaf or stem water potential.

To maintain a continuous water flow from the roots to the leaves, where it is transpired through the stomata, the tension of the water column inside the vine gradually increases from soil- root to leaf- air interface (ie. water potential gradually decreases). When xylem tension gets too high, air bubbles insides the xylem vessels form, resulting in leaf petioles becoming gradually disconnected from the shoot. This phenomenon is called cavitation and is measured as loss of hydraulic conductivity (Hochberg et al., 2017 ; Charrier et al., 2016). As xylem potential decreases, hydraulic disconnection between petiole and shoot increases as shown by xylem vulnerability curves (Figure ❶). Figure ❶ shows that when xylem potential is near -12 bars at the petiole level, only 50% of the xylem vessels remains full of water. The remaining 50% is no longer contributing to water conductivity between the leaf and the shoot. As leaves gradually disconnect from the shoot, cavitation induced by high water tension does not propagate to the shoot, the leaf acts as a "hydraulic fuse". Due to leaf hydraulic segmentation, leaf water potential is useful to assess leaf level water stress but does not necessarily reflect the vine water status perceived by the other organs like shoots (Figure ❶).

❶ **Petiole and shoot xylem vulnerability curve (adapted from Charrier et al., 2016).**



Despite its limitation to estimate irrigation needs, pressure bombs measurements, due to their portability and mechanical simplicity, are largely used to assess leaf water potential and are subdivided into 3 measurement protocols.

Leaf water potential Ψleaf

Usually taken at solar noon, on a well-exposed adult leaf. The drawback of this very quick assessment during a convenient time of the day is that homeostasis between leaf water potential and soil water potential underlies rapid temporal fluctuations as a function of environmental conditions (such as passing clouds).

Stem water potential Ψstem

It is determined by enclosing a leaf in an aluminum foil bag for 45–120 min prior to the measurement. This way, the leaf reduces its transpiration and equilibrates its water potential to the stem water potential (but not necessarily to the shoot water potential as this varies with petiole loss of hydraulic conductivity). Stem water potential is sensitive to vapor pressure deficit and integrates the combined effect of soil and tissue water availability in one hand and climatic demand on the other hand.

Predawn leaf water potential ΨPD

It is measured just before sunrise on adult leaves as ΨPD attains its daily maximum level predawn. It is assumed that plant and soil water potential reach an equilibrium overnight. However, ΨPD remains affected by nighttime transpiration, water transfers between organs and vapor pressure deficit (VPD) ; Coupel-Ledru et al., 2016 ; Rogiers et al., 2009. Thus, ΨPD reflects soil water refilling effect on xylem potential but does not necessarily reflect the amount of soil moisture available at the root level, particularly during warmer nights.

ΨPD, Ψstem and Ψleaf can represent equally viable methods of assessing leaf water status.

However, those measurements can be disconnected from whole vine water status, particularly in semi-arid situations prone to cavitation and do not provide the grower with a reliable information about the stock of water remaining in the soil nor about how much water to apply.

In Table ❶ commonly observed values of vine leaf water potential and the associated empirical water stress estimation is summarized from different studies (van Leeuwen et al., 2009 ; Carbonneau,1998 ; Lovisolo et al., 2010, 2016).

Carbon isotope discrimination

This parameter is measured on sugars in plant organs, berries, must or wines and shows a correlation with leaf water potentials measured during the previous season. It is typically performed at the end of the growing season and is therefore not well-adapted for day-to-day irrigation or agronomic management.

It is a valuable tool to evaluate the effect of previous season management strategies on carbon assimilation which is related to nitrogen and water deficits.

Sap flow-based measurement

Sap flow is the movement of water inside the xylem from the roots to the leaves, where it is transpired through the stomata. Sap flow directly measure the amount of water use at the whole vine level. Two methods of measurement exists.

Thermal dissipation probe method

This method uses probes inserted as needles into the vine. Vergeynst et al. (2014) showed that circumferential and radial variation of sap flux density can lead to both under- and overestimations of sap flow. Furthermore, sap flux density can be underestimated when the heated needle is in contact with non-conducting tissues. Therefore, thermal dissipation probe method is not for commercial use.

The stem heat balance method

The sap flow sensor design consists of a heated sleeve wrapped around the stem (Lascano et al., 2014a). Heat is provided uniformly and radially across the stem section; the sleeve is flexible and maintains a snug fit between the stem and thermocouple during stem diurnal contractions (Photo ❶). Sensors can be applied over stems slightly bent or even when partially necrotic as it is sometimes observed in response to pruning injuries. Because the entire stem section is heated, the heat balance method can be applied even if sap flow trajectory through the stem is tortuous. Results (Zhang et al., 2011) show that the stem heat balance is a reliable method to compute

❶ Close-up on a sap flow sensor placed on a lateral vine branch. The heating tab surrounds the entire section of the branch. Temperature sensors measure the amount of heat displaced by the sap.

❶ Water potential values (Ψ) to appreciate leaf vine water status. Adapted from Carbonneau (1998), Lovisolo et al. (2010, 2016) and van Leeuwen et al. (2009).

	ΨPD (MPa)	ΨStem (MPa)	ΨLeaf (MPa)
No water deficit	> -0.2	> -0.6	> -0.9
Mild water deficit	-0.2 to -0.3	>-0.6 to -0.9	-0.9 to -1.1
Moderate water deficit	-0.3 to -0.5	-0.3 to -0.5	-1.1 to -1.3
Moderate water deficit to severe water stress	-0.5 to -0.8	-1.1 to -1.4	-1.3 to -1.4
Severe water stress	< -0.8/0.9	<-1.4	< -1.4

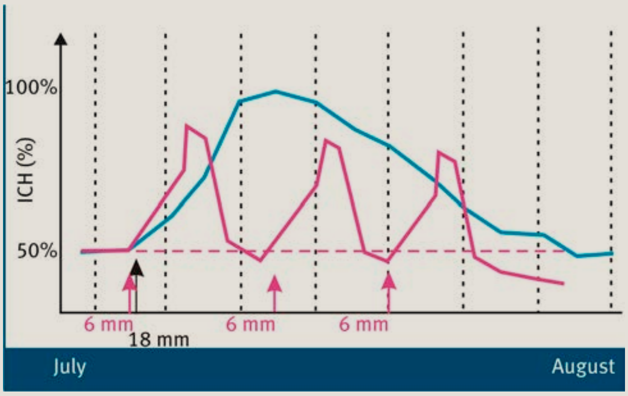
vine water use (ie. transpiraiton) separately from the other components of evapotranspiration (such as soil evaporation or cover crop transpiration) . For those reasons non-intrusive sap flow sensors has been successfully adopted as a practice to drive irrigation strategies (Ginestar et al., 1998 ; Scholasch, 2018) (Figure ❷).

Conclusion

Water potential measurements as an index for irrigation control are challenging due to the effect of environmental fluctuations on hydraulic conductivity between the leaf and the shoot. This methodological drawback is particularly acute in a context of temperature warming and increased aridity where irrigation must be managed with greater precision.

As heat waves are getting more frequent, irrigation strategy must account for vapor pressure deficit variations effect on actual vine water use, and ideally should be varietal dependent (Scholasch, 2019). ■

❷ Effect of small vs large irrigation volume on vine water use (ICH indicates the ratio actual transpiration over potential transpiration).



ICH is the Water Comfort Index. This ratio is calculated daily as the ratio between actual measured transpiration and potential transpiration (expected from the climate analysis). When the ICH is low, the cooling capacity of the foliage is low. Therefore, during heat waves, the risk of burning and disruption of photosynthetic functioning is greater.
The pink curve shows that the ICH reaches more frequently low values that may disturb plant functioning and fruit ripening.
The pink curve shows the variations in the ICH ratio when small volumes are applied (6 mm); the blue curve shows the variations in the ICH ratio when a large volume (18 mm) is applied.

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Further reading...

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Assessment of vine water status is crucial to optimize cultural practices and irrigation strategies.

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