Monitoring vine water status

Part 1: Some physiological principles

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In a nutshell

- Moving toward precision irrigation is a way to optimise the use of available water resources while improving the consistency of fruit quality
- Combining measures of vine water status and soil moisture will provide information to manage irrigation appropriately
- Limited tools are available to measure vine water status, the pressure chamber is currently among the most efficient

Introduction

Water is a precious resource and the efficient application of irrigation water to vineyards is a necessary objective for environmental sustainability and vineyard profitability. Furthermore, the judicious use of water is an important 'lever' used to influence fruit and wine composition. Reduced water allocations and rising power costs provide additional incentive to implement irrigation programs that maximise water use efficiency. Balanced against these factors are the water needs of the vine, and the impact of water availability on growth and berry development. Monitoring of vine and soil moisture status provide practical methods by which irrigation strategies can be refined to suit production and fruit quality requirements of a vineyard.

What do we have in the tool box?

Direct visual observation of grapevine canopies is a simple method for monitoring the water status of the vine. Actively growing shoot tips carrying firm, turgid tendrils indicate that the vine water status is adequate. A decrease or cessation in shoot growth along with the wilting of tendrils or leaves indicate a water deficit. In some varieties, leaves may also orient away from the sun's direct rays under water constraints. The burning of leaf margins or the withering and dehiscence of the shoot tip indicate that the vine has received a significant amount of water stress.

These visual symptoms are helpful and can be used as a straight forward stress index that is based on the fact that growth is one of the most sensitive processes to water status. However, precision irrigation is better managed using techniques that measure vine water status directly, or indirectly via other processes that depend on vine water status (Table 1). These measured parameters are time dependent and can vary rapidly through the day, therefore knowledge of the processes

Functional apex *Necrosis of apex*

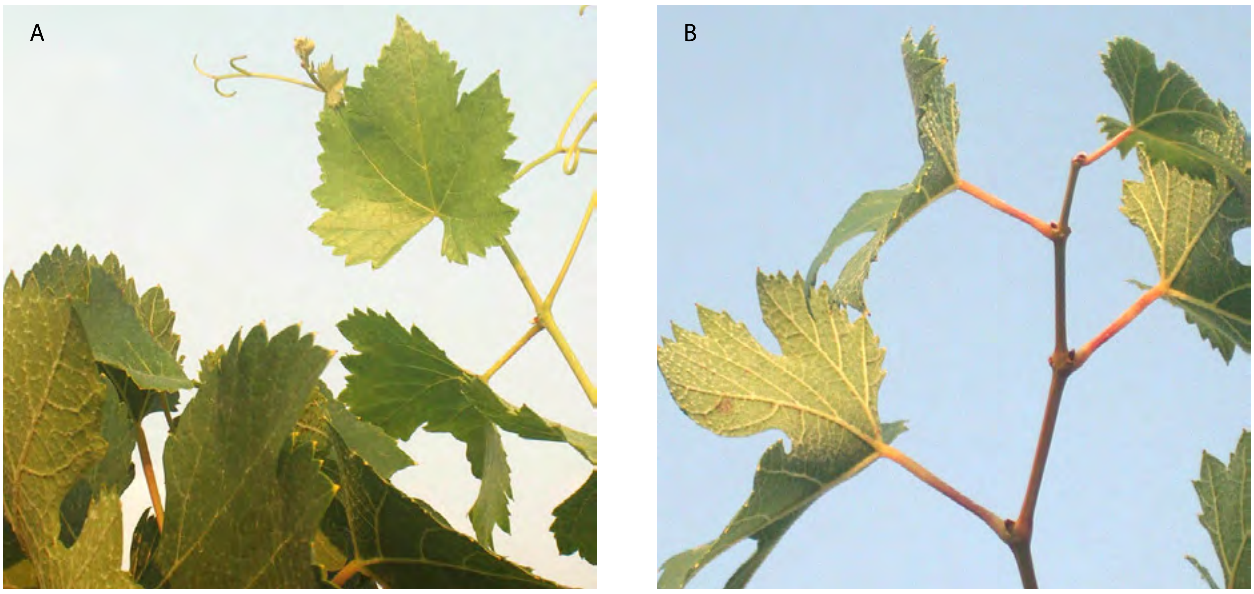

Figure 1. *Example of two extreme situations of vine water status. (A) Well-watered vine with functional apex, and (B) a vine under water stress with the apex dead and missing. Other visual signs can be used to give an indication of vine water status and the reader is referred to Smart, 2003 for further information.*

being monitored is needed to avoid potential pitfalls. Only three of the techniques listed below measure water status directly in the strict sense: the pressure chamber (also called Scholander pressure chamber), and leaf/stem psychrometers both measure water potential, while turgor patch clamp probes measure leaf turgor pressure. The other techniques listed measure processes such as growth, transpiration or swelling and shrinking that respond to vine water status, but in a variety dependent way. Some of these are already in practical use by the industry, while others are limited to the scientific community as the instruments are either complex or the results require significant post-collection data processing and interpretation. A number of new methods are under development, and several of these show potential as future irrigation management tools. For further information on NIR spectroscopy see DeBei *et al*. 2011, the leaf patch clamp pressure probes see Zimmerman *et al*. 2009, and infrared thermography see Jones *et al*. 2002.

Table 1. *Plant based options to measure vine water status directly or indirectly*

Practical	Scientific	Under development for industry use
Visual canopy characteristics (effect of water status on growth)	Sapflow sensors (sap flow velocity)	NIR Spectroscopy (calibrated to water potential or water content)
Pressure chamber (leaf or stem water potential)	Stomatal conductance (porometer or IRGA)	Dendrometers (trunk diameter)
	Leaf relative water content (measured by weighing and comparing to fully hydrated leaves)	Leaf patch clamp pressure probes (leaf turgor)
	Psychrometer (leaf or stem water potential)	Infrared thermography (leaf temperature)

This list does not include the indirect soil-based or climate-based methods for assessing vine water requirements. Soil-based instruments measure the volumetric soil water content (using neutron probes or time domain reflectometry) or soil water tension (using tensiometers or psychrometers). These instruments require the precise installation procedures including the correct positioning and can be useful once calibrated with plant based vine water status measurements. Soils are heterogeneous in terms of structure and depth which will affect the water holding capacity and the development and depth of the root system. This addresses the question of the number of probes which are needed to monitor irrigation and the relationship between soil moisture and the vine water status. The accuracy of the vine water management will depend on the level of precision of the water measurement. This decision belongs to the growers and wineries as to the most appropriate method for their situation.

The climate-based approach calculates the evapotranspiration (ET) and this includes evaporation from the soil and transpiration from the plant.

A reference ET (ET_0) refers to the ET from a hypothetical crop surface such as grass grown without any water stress. This can be measured using pan evaporation or calculated using the Penman-Monteith equation which integrates temperature, humidity, wind speed and solar radiation. However, the ET_0 needs to be adapted to grapevines and this is achieved by multiplying ET_0 by a crop coefficient (K_c) so that $ET_c = ET_0 \times K_c$. K_c is dependent on variety, climate, canopy size (developmental stage) as well as canopy architecture. Planting density and the soil type also need to be considered. Because of the use of generic crop coefficients, exclusively using a climate based method for scheduling irrigation can lead to substantial accumulation of errors resulting in over or under watering. Therefore, it is recommended to use this approach conjunction with some other soil or plant measurements.

In a nutshell

- Vine water status and irrigation has to be managed according to the developmental stage of the vine
- Root and leaf function regulate vine water status
- Soil properties and climate (temperature) impact on vine water status

Managing water status according to the developmental stage of the vine or fruit

The budburst to flowering period is a very active period of shoot and root growth, and it is important that vines start the season with high soil moisture. Winter rainfall may be sufficient to refill the profile, but if a dry winter is forecasted, irrigation leading into dormancy is advised. At the very least, vines should be irrigated several weeks before budburst if soil moisture has not been replenished over winter. Water constraints through budburst will result in uneven and reduced spring shoot growth that impact on canopy size for the remainder of the season. As the spring progresses, water constraints will also prevent normal flower development and therefore will have a negative impact on crop potential during the current and the following season. Fruit set is highly sensitive to any water constraints and therefore it is recommended that water be applied if soil moisture is low through this period. Between fruit set and veraison, vine water status can be regulated depending on the desired outcome. No water constraints should be applied to achieve maximum fruit growth, however if smaller fruit and reduced shoot growth are desired a limited amount of water constraint can be applied. Reduced shoot growth can lower canopy density and thus increase light exposure and air circulation around the fruiting zone. If, however, the water deficit is too great, leaf dehydration will occur and berry development may slow. Important flavour precursors also accumulate in the fruit during the pre-veraison period and this process is sensitive to water deficits. Sugar accumulation into the berries between veraison and harvest is highly dependent on healthy, functioning leaves, bunch microclimate and vine water status. During the post-harvest period, vines are able to rebuild their carbohydrate reserves in preparation for the following season if the temperatures are adequate and the vines are not dehydrated.

Root and leaf functioning control vine water status

Variety differences in the ability to withstand water stress can vary according to rooting volume and depth, the efficiency and ability to conduct water through the vascular tissues, and stomatal control of water loss from the canopy. Stomata are microscopic pores on the underside of grapevines leaves that allow gas exchange between the leaf and the atmosphere. When the stomatal pores are open, carbon dioxide is able to enter the leaf to supply photosynthesis but at the same time water escapes and, if not controlled, the vine may become water stressed. Some varieties such as Semillon do not close their stomata sufficiently when the evaporative demand is high (Rogiers *et al*. 2012) and therefore they require more water to prevent leaf and fruit damage. These varieties are called anisohydric, and are "optimistic" in the sense that water supply is needed in the short term if the vine is not to suffer damage. Other varieties such as Grenache close their stomata sooner with water stress and therefore they are able to conserve water and maintain their hydrated state for longer. These varieties are called isohydric, and are "pessimistic" in the sense that water supply is not necessarily required in the short term. Irrigation scheduling must therefore take into consideration these variety differences with careful monitoring and management of the anisohydric varieties that may rapidly develop water stress. Isohydric varieties may be somewhat more tolerant in the short term, however, heat waves may require high transpiration to allow leaf cooling and the more anisohydric Shiraz can increase transpiration by opening stomata under high temperature if the vine is well supplied by water. Furthermore, avoiding north-south row orientation in very warm viticultural regions will prevent the burning of the western side of the canopy in the late afternoon. Variety/rootstock combinations will also impact on how much water is required

To maintain a desired vine water status, knowledge of soil and climate matter

When scheduling irrigation it is important to consider the combined effects of soil water holding capacity, canopy size and evapotranspiration on vine water status. Under high evapotranspiration (warm, dry days) the water applied must balance that which is lost from the vines through transpiration and evaporation from the soil. If water supply does not match demand, vine water status will progressively decline to the point that growth and photosynthesis are inhibited and leaves lose the ability to cool through transpiration. For this reason irrigation, and maintaining vine water status through heat events, is critical. Nocturnal water loss through the stomatal pores on the leaves can also be significant on warm and windy nights, sometimes up to 10% of whole day water loss. Again there are variety differences in how much water can be lost during the night. Similar to daytime water use, Semillon loses more water during the night than Grenache (Rogiers *et al*. 2009).

In a nutshell

- Important fruit compounds are derived from the vine leaf (sugar, potassium) and root (water, minerals) and depend on the vine water status
- Most of the major compounds involved in fruit quality are biosynthesized prior to veraison by the berry itself but are dependent on vine water status (tannin, aromatic precursors, organic and amino acids)
- Important compounds are accumulated (potassium, nitrogen, water, sugar) from veraison to harvest and are highly influenced by vine water status

Berry metabolism and composition is regulated by water and temperature

Complex and, often, poorly understood processes occurring in the grapevine during berry growth and development (i.e. from flowering to veraison and veraison to ripening-harvest) contribute to final fruit composition. Berry development typically follows a double sigmoid growth pattern (Figure 2) consisting of two distinct growth phases separated by a lag phase (Coombe 1992). Important compounds such as tannin, amino and organic acids as well as those responsible for aroma, for example methoxypyrazines in cultivars including Sauvignon Blanc, Cabernet Sauvignon and Merlot, are biosynthesised during the first growth period. Other compounds are biosynthesised from veraison

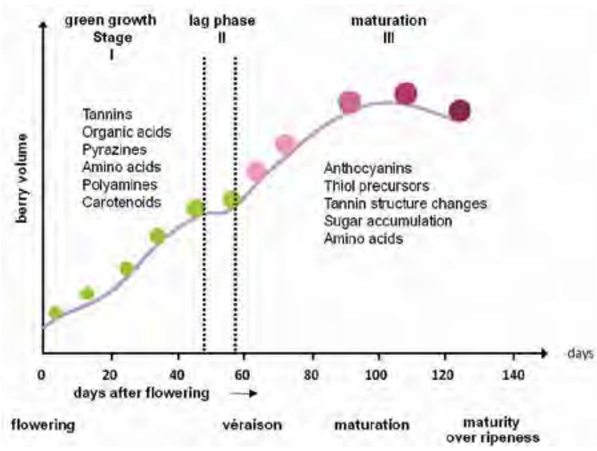

Figure 2. *Examples of organic compound accumulation and change during the fruit development.*

(berry softening) to harvest (Figure 1). Important compounds such as water, minerals, nitrogen and sugar are imported from the vine (leaf and root) to the fruit and one of the main drivers of vine and fruit metabolism is water.

Some varieties such as Shiraz can undergo visual signs of weight loss (seen as shriveling) during the later stages of ripening. This phenological stage of development is accompanied by the concentration of the existing sugars in the fruit and other changes in flavours and aromas. Depending on the desired wine style, shriveling can be a positive or negative process during late ripening.

The extent of shriveling is dependent on the amount of water entering the berry through the vascular system in comparison to the amount that is lost through the skin. The loss of water through the skin, and thus shriveling, is greater in exposed fruit, especially when the evaporative demand is high. Interestingly Shiraz berries do not loose water from the skin any faster than other varieties that do not shrivel, therefore the difference seems to lie in the way water is supplied to the berry late in ripening. Rain and irrigation can to some extent reverse the shriveling trend and temporarily increase the fresh weight of berries. This is dependent, however, on many factors such as maximum berry size, the degree of shriveling, the amount of water applied, the humidity and the number of days after the onset of weight loss.