Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 1, 2022
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

THE INFLUENCE OF WATER STRESS GRAPEVINE UNDERSTANDING THE PLANT'S RESPONSE FROM LEAF TO WHOLE PLANT

Andrei TANASE[1, 2], Adrian ASANICA[2], Dorin SUMEDREA[1], Anca ONACHE[1], Alina FLOREA[1]

[1]National Research and Development Institute for Biotechnology in Horticulture
Stefanesti - Arges, Bucuresti-Pitesti Street, No 37, Arges, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: andrei.tanase1990@yahoo.com

Abstract

Of all the fruit crops of horticultural importance, the grapevine (Vitis vinifera L.) stands out as the most tolerant drought. However, there is relatively little information on grapevine responses to water stress tolerance. Climate change is probably the most discussed issue today. Climate change includes uneven distribution of regional water, extreme weather events (heat waves, heavy rains, hail, frost, and strong winds), and increasing droughts. This analysis summarizes the latest results on grapevine drought responses, the impact of water scarcity on the physiology of the grapevine and its fruit, and highlight some potential solutions in brief and medium-term in grapevine plantations.

Key words: *water deficit, Vitis vinifera L, viticulture, drought.*

INTRODUCTION

Climate change scenarios predict that Central Europe, including Romania, will be affected by water constraints, especially in southern Europe, changing rainfall patterns, and will suffer from summer drought (Serra et al., 2014). Drought indicates the state of a biological system in which the water requirement is below the optimal values and works in terms of absorbing a considerable variable power depending on the growth phase and the stage of development. This phenomenon can be considered meteorological, hydrological, agricultural and economic. Many scientists report a rise in temperature in Europe, e.g. Guedon &Legave (2008) with about 1.1-1.3°C in France, Blanke & Kunz (2017) with 0.6°C and Waldau & Chmielewski (2018) with 1.9°C in different regions of Germany.

Adaptation of fruit crops grown in temperate areas in many places will be endangered in the future due to climate change, with warmer winters and earlier springs (Wenden et al., 2017, Florea et al., 2020). Climate data for the investigated region were first reported in Romania about two decades ago (Păltineanu et al., 2000, Florea et al., 2020), and the warming trend was observed by Păltineanu et al. (2011, 2012), later by Florea et al. (2020). Studies reported by Busuioc et al. (2015) highlight a trend of increasing air temperature in the period 1962-2010 in Romania, while Chitu et al. (2015) and Florea et al. (2020) highlighted the increased variability of seasonal and annual extreme temperature trends over the last three decades in the study region. Chmielewski (2004) mentions that the phenological stages of German crops have shown an advanced trend due to heating

In other parts of Europe, such as France, an advance in flowering tree species has been reported for some fruit tree species due to rising temperatures from January to April. Also in Germany, Chmielewski et al. (2011) showed an advance of the beginning of apple blossoming from 1989 to 2011, caused by climate change in the studied areas, and Rivero et al. (2017) in Scandinavia. Similar studies have been performed by Slavko Bernáth et al. (2021) which analyze the period 1985 to 2018 for the vine and report an earlier budding by five to seven days, the earlier onset of flowering by 7 to 10 days, the earlier softening of the berries by 18 days and dates of advanced harvesting with 8 to 10 days on average.

In the many Mediterranean and south-eastern areas of Europe, with low rainfall, often below 250 mm per year (Williams & Matthiews, 1990), and the negative effects of climate change could be exacerbated, water scarcity has become a problem. Recent studies show that limiting water availability in vine cultivation can affect productivity (Chai et al., 2015; Pérez-Pastor et. al., 2014, 2016), moderate water scarcity can reduce yield, but with benefits some aspects of fruit quality; Severe water shortages lead to low yields and lower fruit quality, while the absence of water exacerbates these negative aspects, thus harming the proper production of crops. Consequently, water storage has become a major environmental challenge to limit the expansion of irrigated agriculture (Williams et al., 2003). Some drought tolerance studies of cultivated vine genotypes have focused on key agronomic indicators, such as grape yield and physico-chemical composition (fruit quality indicators), while others have focused on the physiology of grapes to the finer scale of plants, such as stomatal regulation, carbon assimilation, etc. However, it remains an open and critical question for water management in vineyards and how different varieties respond to drought and water needs, fruit growth, yield, and quality. Although the yield is affected by drought, a recent meta-analysis reported by Dayer et al. (2020) suggests that this decrease may be specific to the variety. Recent work on plant physiological indicators suggests that all genotypes can regulate the use of vine water (ie stomatal conductance) to protect against more severe damage, through physiological indicators provided by the petiole cavity or leaf, even fall (Hochberg et al., 2017b; Dayer et al., 2020). Despite studies to date, it is unclear to what extent differences in the regulation of vine water use between varieties result from innate genotypic differences, or environmental (Hochberg et al., 2018).

In addition, although the exact mortality rates for grapes are not known, vines appear to almost always operate within a “safe” margin of water potential in which stem cavity is extremely rare (Charrier et al., 2018). Thus, many gaps remain in understanding what constitutes a drought-adapted vine variety, which makes it even more difficult to address future climate challenges.

Therefore, in this review, we summarize the current state of research on techniques for the physiology of drought stress on the vines, the impact on the whole plant and leaves, and fruit composition to make the best decisions on vine irrigation, time, the timing of irrigation.

Visual observation

The first way to assess the condition of a vine's water is to look directly at the field of view. One of the earliest responses of a plant that has a water supply limit is the loss of turgidity first, followed by a slowdown in vegetative growth (Markus Rienth &Thibaut Scholasch (2019). Such an assessment can be made systematically, in which 30-50 peaks per plot are observed visually and then classified into three groups, as follows: a straight-growing apex, where the first expanded leave is small and well beneath the apex; then a slowing down of growth with the first expanded leave covering the apex; until where the apex has dropped and shoot growth has completely ceased (Rodriguez-Lovelle B. et al., 2018)

However, this method cannot be applied for the necessary irrigation after the growth of the shoots ends once the meristem is cut or dried (Keller, 2010), moderate water deficit leads to wilting and even their subsequent abscission when the water deficit becomes severe. (Keller, 2010; Rodriguez-Lovelle et al., 2018).

Intelligent methods for monitoring, early diagnosis of water stress in viticulture based on multisensory soil-plant-air techniques

Classical methods of monitoring crop water stress include "in situ" measurements of soil water content, taking into account plant properties and meteorological variables, to estimate the amount of water lost from the plant-soil system over some time. These methods are time-consuming and produce timely information that provides inaccurate indications of the general state of the system in question (Jackson, 1982) unless a very large number of samples are processed.

Precision agriculture is doing everything possible to increase efficiency, productivity, and profitability in many agricultural production systems while minimizing the unwanted impact on biocenosis and natural biotope. Real-time crop status information will provide a solid basis for farmers to adapt to strategies at all times. Instead of making decisions based on a hypothetical state of the environment, an approach in precision agriculture recognizes the differences and regulates management actions. Phyto-monitoring is an information management technology that provides fruit plants with real-time, invaluable information about both the dynamic physiological state of the crop and continuous analysis of plant growth trends, real-time information on moisture dynamics, soil, and microclimate conditions. Precision agriculture is doing everything possible to increase efficiency, productivity, and profitability in many agricultural production systems, while minimizing the unwanted impact on biocenosis and natural biotope. Real-time crop status information will provide a solid basis for farmers to adapt to strategies at all times. Instead of making decisions based on a hypothetical state of the environment, an approach in precision agriculture recognizes the differences and regulates management actions. Phyto-monitoring is an information management technology that provides fruit plants with real-time, invaluable information about both the dynamic physiological state of the crop and continuous analysis of plant growth trends, real-time information on moisture dynamics, soil, and microclimate conditions.

Both gas exchange and fluorescence can be used to detect water stress in C4 photosynthetic plants. However, in C3 photosynthetic plants, the exchange of gas from the leaves will measure water stress in the very early stages, while standard methods based on chlorophyll fluorescence will only detect moderate or severe water stress. There is a fluorescence test for measuring water stress very early, but it involves the use of several leaves, and the combination of thermal and water stress (Burke, 2007).

The Fs indicator of chlorophyll fluorescence, a component of "Fv / Fm" (also known as F / FM, or Fms - FS / SMF), has been reported as the most sensitive moderate water stress test (Flexas 1999). and (Flexas, 2000).

PI, or "performance index", has been shown to detect water stress after about seven days (Zivcak et al., 2008), and Fv / Fm is insensitive to water stress.

Another method of investigation to identify water stress in time is by measuring the turgor pressure in the leaves.

This can be done using a newly developed magnetic clamp leaf pressure probe (LPCP), which provides information on the relative pressure changes (PC) due to turgidity in monitored plants at PC> 50 kPa. PCP probe

Is an instrument that allows relative measurements changes in leaf turgidity pressure or - after calibration against the cell turbidity pressure probe (Zimmermann et al. 2004, Rüger et al., 2010) - absolute changes in turbidity pressure. Records on tall vines in greenhouse conditions and the first measurements on vines showed that the changes in turgidity pressure in response to environmental changes and / or watering was reflected in the LPCP probe patch outlet pressure.

The theory shows (Zimmermann et al., 2008) that the outlet pressure (Pp) sensed by the probe is inversely proportional to the PC. Under a turgid pressure of approx. 50 kPa, the Pp indicator collects valuable information about the interaction between air and water supply to the leaves. The probe is non-invasive and able to operate automatically and continuously in real field conditions (Fernandez et al., 2011).

The probe signals are sent over the mobile network to an Internet server, in which case the data is stored and viewed graphically or as tables in real-time.

Export functions allow data to be retrieved from personal assessment software (Zimmermann et al., 2008). The evaluation of the time constants in the turgescence pressure recovery phase can give some information about the dynamics of water supply to the trees, in extremely variable field conditions.

SPAC (soil-plant-atmosphere continuum) is the system that allows water to move from the soil through plants to the atmosphere.

This system characterizes the state of the water in its various components, as expressions of the energy level or water potential of each. Modeling water transport between SPAC components is similar to studies on water potential gradients between segments. The concept of the soil-plant-atmosphere continuum (SPAC) was first proposed by Phillip in 1966.

Since then, the fundamentals of soil physics have been enriched, for example, by Hillel (1980). Allen et al. (1998) presented and updated the methodology for calculating culture evapotranspiration (ETc). This plant parameter depends on both the reference evapotranspiration (ETo) and the stage of development of the plants for each species. Sweating is a process that unites the flow of water in the SPAC system (Allen et al., 1998).

Grapevine drought responses

Stomatal regulation of water use

Stomata are those tiny pores on the surface of the leaves that control the exchange of gases between the plant and the atmosphere (Darwin, 1898). Stomata are key players in a plant's response to drought. The xylem makes it possible for water to flow from the ground into the atmosphere under tension (that negative tension (Tyree, 1997), pulled by the more negative water potentials (Ψ) in the leaf tissues where water is transpired into the atmosphere through stomata (Zimmermann, 2002), Figure 1.

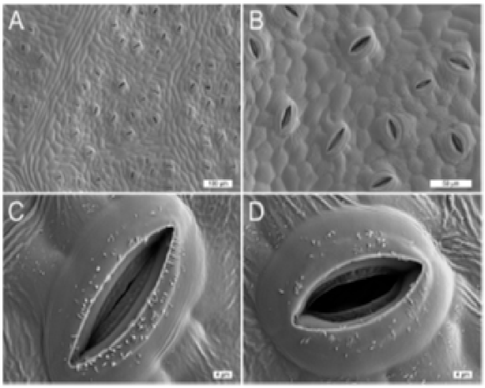

Figure 1. Cryo-scanning electron microscopy images of the underside of a grapevine (Vitis rupestris) leaf at various magnifications. Islands of stomata (A) are visible in between leaf vascular traces, and there is ample aperture diversity (B) of stomata in more closed (C) or open (D) states. Scale bars are shown in each panel

Darwin (1898) suggests avoiding water potential (Ψ) critically and emphasizing water conservation, the stomata being the first to feel prolonged drought, the phenomenon of transpiration being intense during this period. Jordan et al., (1975), later Patakas et al. (1997) indicated that mature leaves close stomata below Ψ lower compared to younger leaves, as mature leaves have more lignified cell walls and a potential for more negatively dissolved, allowing them to maintain perspiration while sustaining the low strain (Hsiao et al., 1976; Patakas and Noitsakis, 2001). The response of the stomatal conductance (gs) to the water potential (Ψ) is considered a basic physiological characteristic of a species (Brown et al., 1976; O'Toole & Cruz, 1980), these (gs) being frequently reduced to the water potential. water, up to 50% or 75% stomatal closure (Ψgs50 or Ψgs25, respectively; Klein, 2014) Transpiration is controlled by the stomata, being abundant on the lower part of the leaves, the stomata open and close actively to allow or restrict the exchange of gases. The stomata are often closed at night, photosynthesis being slowed down because there is no sunlight. With humidity during the day, however, sunlight stimulates them to open up to allow the vine to take up carbon (CO2) for photosynthesis and release oxygen (a byproduct of photosynthesis) and water vapor (Tim Martinson & Alan Lakso, 2018).

Without this reduction in transpiration, the rapid flow could lead to large disturbances of the plant, more precisely to large decreases in pressure between the soil and the leaves (ie, Ψ more and more negative). Irrigated vineyards typically operate in a safe range of water potential (Figure 2, Ψ stem> -1.5 MPa, adapted from Charrier et al., 2016) that do not lead to cavitation or turgor loss in vineyards non-irrigated rarely exceed these values (Charrier et al., 2018). When poor irrigation strategies are used, especially in vineyards grown for the production of red wine grapes, they normally target water deficit levels (Ψ stem -1.2 to -1.4 MPa) which are sufficient. large to decrease stomatal conductance (gs), that are certainly great enough to decrease stomatal conductance (gs), transpiration, photosynthesis, and ultimately fruit yield (Figure 2).

More severe water deficiency (Ψ stem <−1.6 MPa) can lead to loss of turgidity and xylem cavity, which could lead to leaf loss and eventually vine decline.

Relatively recent studies report that vine genotypes are different, their stomata reacting differently to water deficiency (Lavoie-Lamoureux et al., 2017; Charrier et al., 2018; Levin et al., 2019; Dayer et al., 2020). Thus, some varieties tend to close their stomata earlier than others. Regardless of these differences in vine varieties, all close their stomata in response to water deficit in a relatively narrow range of water potential compared to the width of plant taxa in general (Lavoie-Lamoureux et al., 2017; Martin-StPaul et al., 2017). Understanding the basic mechanisms that determine the regulation of stomata in drought conditions allows the identification of targets that could be used to grow more drought-tolerant varieties and / or rootstocks.

Extreme drought

McDowell et al., (2008) state that high levels of embolism in perennial organs, also known as "hydraulic failures", lead to plant decline, as vines can die from prolonged drought and extreme water deficits 2, stem $\Psi < -2$ MPa) leading to the loss of a large or the entire roof and the crop in the current season.

In potted-plant experiments even when vines are stressed to levels that result in nearly complete defoliation and 100% loss of conductivity due to embolism in stems, a large percentage of vines still regrow the following season (Tombesi et al., 2018; Charrier et al., 2018).

Knipfer et al., (2015), later Nardini et al., (2017) highlight in their studies the ability of vines to recover from and/or repair extensive embolism over winter may involve their ability to refill embolized xylem vessels in the stem except for leaves and petioles that do not appear to be recovering from embolism (Hochberg et al., 2016; Hochberg et al., 2017a).

One concern is cavitation fatigue, in which previous cavitation events lead to an increase in cavitation vulnerability (Hochberg et al., 2017b). In terms of season-to-season transfer effects on fruit production, water deficits can sometimes lead to a decrease in production in the following season (Williams & Matthews, 1990; Dayer et al., 2013), but so far, few studies have investigated the deferral effects of more severe drought events (Tombesi et al., 2018).

Pressure chamber

The xylem potential of the vine (Ψ) is the negative pressure or pressure under which water flows from the roots to the interface with the leaf air through the xylem and is then vaporized. Thus, the xylem potential can be measured at the petiole to reflect the potential of water from leaves or stems.

To maintain a continuous flow of water 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 the soil-root interface to the leaf-air interface. When the tension of the xylem becomes too high, air bubbles form inside the xylem vessels, thus leading to the gradual disconnection of the petioles of shoot leaves. This phenomenon is called cavitation and is measured as a loss of hydraulic conductivity (Hochberg et al., 2017b; Charrier et al., 2016).

Figure 2 shows the ximel's vulnerability curves, which show that as the xylem potential decreases, the hydraulic disconnect between the petiole and the shoots increases.

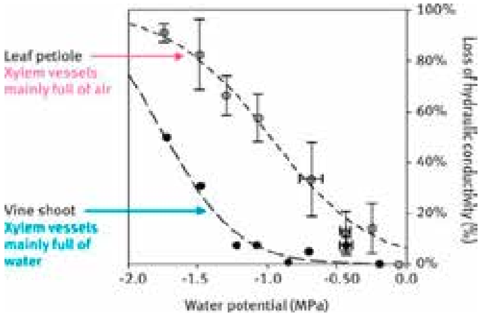

Figure 2. Petiole and shoot xylem vulnerability curve (adapted from Charrier et al., 2016)

When the xylem potential is close to -12 bar at the petiole, only 50% of the xylem vessels remain filled with water, and the remaining 50% no longer contribute to the conductivity of the water between the leaf and the shoot (Figure 2).

Based on measurements using a hydraulic apparatus, the water potential leading to 50% loss of conductance (Ψ_{50}) of petioles was −1.56 MPa for grapevine and −2.77 MPa for red oak (Holbrook, 2017). Sperry (1998) evaluates the potential of water leading to a 50% loss of conductivity ($\Psi50$; MPa) using three different methods: bench dehydration in combination with hydraulic measurements (Sperry et al., 1988) of petioles, optical measurement of dehydrating leaves, or gas injection in combination with optical measurement.

Leaf water potential (Ψleaf)

This assessment is usually done at noon, on the forehead of an adult well exposed to the sun, being a fairly quick measurement. The disadvantage of this assessment is that homeostasis between the water potential of the leaves and the water potential of the soil is the basis of rapid temporal fluctuations depending on environmental conditions (such as passing clouds).

Leaf Ψ is a convenient measurement with the use of a leaf pressure chamber. Jones (1990) a suggested that the leaf may be an erroneous indicator of the state of the plant's water, because the homeostasis of the leaf can occur under different soil and environmental conditions.

Vine varieties have been shown to vary in their homeostasis in declining leaves. The differential response between varieties is considered to be related to the abscisic acid of the leaves and xylem and the hydraulic regulation (Dayer et al., 2020). Schutz (2003) found in a study of vine varieties for wines that the Syrah variety (syn. Shiraz) proved to be relatively anizohydric compared to Grenache, which was almost isohydric. Based on these physiological responses, the use of Ψleaf for irrigation scheduling of relatively isohydric plants may underestimate their true water stress and therefore irrigation requirements potentially leading to a vicious cycle. (Dayer, et al., 2020);

Stem water potential (Ψstem)

It is determined by enclosing a leaf in an aluminum foil bag for 30- 120 min before the measurement (Delloire et al., 2020). 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 on the one hand and climatic demand on the other hand. The water potential of the strain is sensitive to the vapor pressure deficit and integrates the combined effect of soil and tissue water availability, on the one hand, and climate demand, on the other (Delloire et al., 2020). Chone (2001) states that there is a correlation between the water potential of the stem and the climatic conditions and the transpiration of the plant.

Pre-dawn leaf water potential (ΨPD)

The measurement is made just before sunrise on the adult leaves, when the state of the living water is at its maximum (Deloire, 2020). The advantage of pre-dawn water potential measurements is that they are stable, regardless of climatic conditions, and are closely related to the condition of the groundwater in the vicinity of the roots (Deloire, 2020).

Table 1. Pre-dawn leaf water potential and grapevine water status (Carbonneau, 1998; Lovisolo et al., 2010, 2016 adapted after Deloire et al., 2020)

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

However, ΨPD remains affected by night transpiration, water transfers between organs, and vapor pressure deficit (VPD), (Coupel-Ledru et al., 2014; Rogiers et al., 2012).

Carbonneau (1998), quoted by Deloire et al. (2020) assesses the PLWP threshold for the degree of water deficit following a study of over 20 years, conducted in several vineyards. Table 1 provides answers on vine physiology and grain maturation as PLWP decreases (Carbonneau, 1998).

Sap flow-based measurement

One way to measure crop water status, which is essential for optimized irrigation scheduling, is to manually measure water from leaves or stems (Shackel, 2011; Williams & Baeza, 2007), using a Scholander pressure chamber invented in the 1960s. (Scholander et al., 1965). In precision agriculture these limitations given by manual technique are used precision electronic sensors inserted on plants to continuously measure the state of the culture water developed on the basis of various detection methods. These sensors applied to fruit crops include either sap flow sensors

(Ginestar et al., 1998), thermal diffusivity sensors (Pagay & Skinner, 2018), dendrometers (Corell et al., 2014), or thermal or infrared sensors. (Jones, 1999; Pagay, 2021).

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

1. The thermal dissipation probe method

The sap flow is the movement of water inside the xylem from the roots to the leaves, where it has transpired especially through the stomata. The sap flow measures the amount of water used in the whole vine. Vergeynst et al. (2014) showed that the circumferential and radial variation of the sap flow density may be due to the overestimation of the sap flow. In addition, the sap flow density may be underestimated when the heated needle is in contact with non-conductive tissues. Therefore, this method is little used, not being able to be used in commercial use.

2. The stem heat balance method

In this process, the sap flow sensor design consists of a heated sleeve wrapped around the stem (Lascano et al., 2016). By this method the heat is supplied uniformly and radially on the section of the rod; the sleeve is flexible and maintains a perfect fit between the stem and the thermocouple during the diurnal contractions of the stem (Figure 3, after Ginestar et al., 1998; Scholasch, 2018).

Figure 3. 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 (after Ginestar et al., 1998; Scholasch, 2018)

The sensors are easy to apply, either over slightly bent stems or even when they are partially necrotic, as is sometimes seen in response to cutting lesions. Because the entire section of the stem is heated, the method of heat balancing can be applied even if the trajectory of the sap flow through the stem is sinuous. Zhang et al. (2011) show that the thermal balance of the stem can be a reliable method for using vine water.

Figure 4. Close up view of an individual microtensiomete. MT data of trunk water potential (Ψtrunk) (Vinay Pagay, 2021)

The potential consequences of drought on vegetative growth and yield

Many studies have shown that stress caused by prolonged drought can lead to decreased vigor, yield, poor fruit quality (Romero et al., 2004; Alves et al., 2013; Gerós et al., 2015), and may even induce changes in key metabolic pathways (Roby et al., 2004; Romero et al, 2010), changes in the abundance of transcripts and metabolites involved. in the metabolism of phenylpropanoid, isoprenoid, carotenoid, amino acids and fatty acids (Oliveira et al., 2003; Deluc et al., 2009; Savoi et al., 2016) . All these responses of the vine plant depend on several factors such as varieties, crop load, vineyard age, soil type, phenological stage or canopy development (Cook et al., 2015, Ojeda et al., 2002). Other researchers Keller et al., 2008; Castellarin et al., 2007) mention that water stress can have a positive impact on the composition of berries by improving sugars, flavors and color. Under these conditions, irrigation can have a great influence on the yield of the vine, the quality of the grains and the sensory characteristics of the wine (Matthews , et al., 1990; Keller et al, 2006; Keller et al., 2008).

- Reduction in vegetative growth and hence in the exposed leaf area.
- Reduction in the growth of lateral shoots, with positive or negative consequences depending on the climatic conditions (increased exposure of the bunches to sunshine, reduced activity of carbon sinks or sources depending on the stage).
- In the case of severe and early water deficit, uneven budburst and a reduction in the fertility of latent buds on the growing primary shoots (Guilpart, 2014);
- Deterioration in the growth of inflorescences and flowers in year N + 1 (for which the primordia were formed in the latent buds in year N), which may lead to fertilization defects including coulure (poor fruit set) and millerandage (uneven berry development and ripening), (Deloire &Pellegrino, 2021).
- Severe water deficiencies during a growing season can lead to both inhibition of the biosynthesis of primary metabolites (organic acids, sugars) (Wang et. al., 2003), and disruption of berry ripening dynamics (Antalick et al., 2021)
- Severe water deficiencies can lead to inhibition of the biosynthesis of secondary metabolites (phenols, flavor precursors) before and after the test, although it is known that the content of anthocyanins in berries is favored at moderate levels of water deficiency.
- Change in the aromatic profile of the wine when more than 20% of the berries are wrinkled (Šuklje et al., 2016).
- Water deficiencies during fruit formation can lead to uneven growth of berries which can affect wine style (Antalick et al., 2021).
- An earlier harvest, which is mainly due to the overall concentration of sugar in berries (ie Brix or potential alcohol) which is used to determine the date of harvest, rather than the daily accumulation of sugar per grain, resulting in more sugar per grain (mg/berry).

CONCLUSIONS

This analysis summarizes the latest results on the responses to drought on vines, the impact of water shortages on the plant, and fruit production and composition. Based on the results provided by us in this review, the following conclusions can be drawn**:** 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 heatwaves become more frequent, the irrigation strategy must take into account the effect of variations in the vapor pressure deficit for optimal use of vine water and, ideally, should be taken into account depending on the variety and rootstock (Scholasch, 2019). Therefore severe water deficiencies should be avoided (water stress from the beginning of the bud until after harvest.Water potential is considered the best indicator of plant water status, being the integrated result of above-ground and subterranean environmental conditions, promising as an essential variable of the model to which other plant processes respond. In this review we wanted to highlight some of the physiological processes that are mechanically related to the potential of water.

The following aspects should be considered when analyzing the impact of water status on the functioning of the vine (vegetative growth; fertility/yield of the vine; fruit growth and composition; categories and aromatic profiles of wines (Deloire &Pellegrino, 2021):

- The period of onset of water deficit during the phenological stages (van Leeuwen et al., 2009).
- The intensity of water deficit (deficit versus stress).

Irrigation management is crucial for grape quality. Therefore, excessive irrigation can cause loss of quality due to high yields, vigorous tree growth and sparse grains (van Leeuwen et al., 2009)

Quality production on irrigated vines can only be achieved when a moderate water deficit is mentioned (van Leeuwen et al., 2009).

The condition of the vine water is most accurately assessed by the use of physiological indicators. This analysis highlighted research showing that the water potential of the phloem , stomatal conductance, leaf are ways to assess the state of water in plants and can be precise tools for irrigation management. van Leeuwen et. al, 2009)

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration-guidelines for computing crop water requirements. *FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome.*

Alves, F.; Costa, J.; Costa, P.; Correia, C.; Gonçalves, B.; Soares, R.; Moutinho-Pereira, J. Grapevine Water Stress Managem Alves, F.; Costa, J.; Costa, P.; Correia, C.; Gonçalves, B.; Soares, R.; Moutinho-Pereira, J. (2013). Grapevine Water Stress Management in Douro Region; ADVID: Vila Real, Portugal, ent in Douro Region;

Antalick G., Šuklje K., Blackman J.W., Schmidtke L.M. Deloire A., (2021). Performing sequential harvests based on berry sugar accumulation (mg/berry) to obtain specific wine sensory profiles, *OENO One*, https://doi.org/10.20870/oeno-one.2021.55.2.4527

Atauri, I.G.C., Brisson, N., Baculat, B., Seguin, B., Legave, J.M., Calleja, M., Farrera, I., Guedon, Y. (2010). Analysis of the Flowering Time in Apple and Pear and Bud Break in Vine, in Relation to Global Warming in France. *Acta Horticulturae, Volume 872: 61-68.* DOI: 10.17660/ActaHortic.2010.872.5. https://doi.org/10.17660/ActaHortic.2010.872.5

Blanco, O.; Faci, J.M.; Negueroles, J. (2010). Response of table grape cultivar 'Autumn Royal' to regulated deficit irrigation applied in the post-veraison period. *Spanish J. Agric. Res*. 8, 76–85.Blanke, M.M.,

Kunz, A. (2017). Cherry phenology as a bioindicator for climate change. Acta Horticulturae, Vol. 1162: 17. DOI:10.17660/ActaHortic.2017.1162.1.

Busuioc, A., Dobrinescu, A., Birsan, M.V., Dumitrescu, A., Orzan, A. (2015). Spatial and temporal variability of climate extremes in Romania and associated large-scale mechanisms. *International Journal of Climatology*.

Burke J., (2007) Evaluation of Source Leaf Responses to Water-Deficit Stresses in Cotton Using a Novel Stress Bioassay, *Plant Physiology*, Jan. 2007, Vol 143, pp108-121;

Brown, K.W., Jordan, W.R. & Thomas, J.C. (1976) Water stress induced alterations of the stomatal response to decreases in leaf water potential. *Physiologia Plantarum,* 37, 1– 5.

Cantu D, Walker MA, eds. The grape genome. Cham: Springer, 223–245.

Castellarin, S.D.; Pfeiffer, A.; Sivilotti, P.; Degan, M.; Peterlunger, E.; Di Gaspero, G (2007). Transcriptional Regulation of Anthocyanin Biosynthesis in Ripening Fruits of Grapevine under Seasonal Water Deficit. *Plant Cell Environ*., 30, 1381–1399

Charrier G, Delzon S, Domec JC, et al. (2018). Drought will not leave your glass empty: Low risk of hydraulic failure revealed by long-term drought observations in world's top wine regions. *Science Advances* 4

Chai, Q.; Gan, Y.; Zhao, C.; Xu, H.-L.;Waskom, R.M.; Niu, Y.; Siddique, K.H.M. (2015) Regulated deficit irrigation for crop production under drought stress. A review. *Agron. Sustain*. Dev. 2015, 36, 3. eaao6969.

Chitu, E., Giosanu, D., Mateescu, E. (2015). The variability of seasonal and annual extreme temperature trends of the latest three decades in Romania. *Agriculture and Agricultural Science Procedia.* Volume 6: 429–437. https://doi.org/10.1016/j.aaspro.2015.08.113

Chmielewski, F.M., Müller, A., Bruns, E. (2004). Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. *Agric. and Forest Meteorology* 121: 69–78. https://doi.org/10.1016/S0168-1923(03)00161-8

Chmielewski, F.M., Blumel, K., Henniges, Y., Blanke, M., Weber, R.W.S., Zoth, M. (2011). Phenological models for the beginning of apple blossom in Germany. Meteor. *Zeitschrift,* 20(5): 487-496. DOI: 10.1127/0941-2948/2011/0258

Chone X., Van Leeuwen C., Dubourdieu D. &, Gaudillere J.P. (2001). Stem water potential is a sensitive indicator of grapevine water status. *Annals of Botany*, 87 (4), 477-483

Corell M, Giron IF, Galindo A, Torrecillas A, Torres-Sanchez R, Perez-Pastor A, Moreno F, Moriana A. (2014). Using band dendrometers in irrigation scheduling Influence of the location inside the tree and comparison with point dendrometer. *Agricultural Water Management* 142, 29-37.

Cook, M.G.; Zhang, Y.; Nelson, C.J.; Gambetta, G.; Kennedy, J.A.; Kurtural, S.K. (2015). Anthocyanin Composition of Merlot Is Ameliorated by Light Microclimate and Irrigation in Central California. *Am. J. Enol. Vitic.*, 66, 266–278.

Coupel-Ledru A, Lebon É, Christophe A, Doligez A, Cabrera- Bosquet L, Péchier P, Hamard P, This P, Simonneau T. (2014). Genetic variation in a grapevine progeny (*Vitis vinifera* L. cvs Grenache×Syrah) reveals inconsistencies between maintenance of daytime leaf water potential and response of transpiration rate under drought. *Journal of Experimental Botany* 65, 6205–6218.

Dayer S, Herrera JC, Dai Z, Burlett R, Lamarque LJ, Delzon S, Bortolami G, Cochard H, Gambetta GA. (2020). The sequence and thresholds of leaf hydraulic traits underlying grapevine varietal differences in drought tolerance. *Journal of Experimental Botany* 71, 4333–4344.

Dayer S, Prieto JA, Galat E, Perez Peña J. 2013. Carbohydrate reserve status of Malbec grapevines after several years of regulated deficit irrigation and crop load regulation. Australian Journal of Grape and Wine Research 19, 422–430

Darwin F. 1898. Observations on stomata. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 190, 531–621.

Deluc, L.G.; Quilici, D.R.; Decendit, A.; Grimplet, J.; Wheatley, M.D.; Schlauch, K.A.; Mérillon, J.-M.; Cushman, J.C.; Cramer, G.R. Water Deficit Alters Differentially Metabolic Pathways Affecting Important Flavor and Quality Traits in Grape Berries of Cabernet Sauvignon and Chardonnay. BMC Genom. 2009, 10, 33.

Deloire Alain, Anne Pellegrino, Suzy Rogiers (2020). A few words on grapevine leaf water potential. *IVES Technical Reviews vine&wine.*

Ezzahouani, A. & Williams, L.E. **2007**, Effect of irrigation amount and preharvest cutoff date on vine water status and productivity of Danlas grapevines. *Am. J. Enol. Viticu*l. 58, 333–340.

Fernández J.E., C.M. Rodriguez-Dominguez, A. Perez-Martin, U. Zimmermann, S.Rüger, M.J.Martín-Palomo, J.M. Torres-Ruiz, aM.V. Cuevas, C. Sann, W. Ehrenberger, A. Diaz-Espejo,(2011). Online-monitoring of tree water stress in a hedgerow olive orchard using the leaf patch clamp pressure probe. *Agricultural Water Management Volume 100*, Issue 1, Pages 25-35

Flexas Jescalona, J. M. & Medrano H. (1999). Water stress induces different levels of photosynthesis and electron transport rate regulation in grapevines. *Plant, Cell & Environment Volume 22* Issue 1 Page 39-48,

Flexas J. S, Mj Briantais, Z Cerovic, H. Medrano, I Moya, 2020. Steady-State and Maximum Chlorophyll Fluorescence Responses to Water Stress In Grape Vine Leaves: A New Remote Sensing System*"*, *Remote Sensing Environment* 73:283-270;

Florea Alina, Chitu Emil and Paltineanu Cristian, (2020). Dynamics of phenological stages due to climate change in plum trees in southern Romania *Acta Hortic*. 1289,205-212

Gambetta GA. (2016). Water stress and grape physiology in the context of global climate change. *Journal of Wine Economics* 11, 168–180.

Gerós, H.; Chaves, M.M.; Gil, H.M.; Delrot, S. (2015) Grapevine in a Changing Environment: A Molecular and Ecophysiological Perspective; John Wiley & Sons: Hoboken, *NJ, USA*,; ISBN 1-118-73601-X.

Ginestar, C., Eastham, J., Gray, S., Iland, P., (1998). Use of Sap-Flow Sensors to Schedule Vineyard Irrigation. I.Effects of Post-Veraison Water Deficits on Water Relations, Vine Growth, and Yield of Shiraz Grapevines, *American Journal of Enology and Viticulture*, 49(4), p. 413-420

Guilpart, N., A. Metay, and Gary C., (2014). Grapevine bud fertility and number of berries per bunch are determined by water and nitrogen stress around flowering in the previous year. *European Journal of Agronomy*, 2014. 54: p. 9-20.

Guedon, Y., Legave, J.M. (2008). Analyzing the time-course variation of apple and pear tree dates of flowering stages in the global warming context. *Ecological Modelling 219(1-2*): 189-199. DOI: 10.1016/j.ecolmodel.2008.08.010

Hannah L, Roehrdanz PR, Ikegami M, Shepard AV, Shaw MR, Tabor G, Zhi L, Marquet PA, Hijmans RJ. 2013. Climate change, wine, and conservation. *Proceedings of the National Academy of Sciences,* USA 110, 6907–6912.

Hillel Daniel, (1980). Fundamentals of Soil Physics. *Hardcover ISBN*: 9780123485601. eBook ISBN: 9780080918709

Hochberg Uri, Fulton E. Rockwell, N. Michele Holbrook, and Hervé Cochard (2018). Iso/Anisohydry: A Plant– Environment Interaction Rather Than a Simple Hydraulic Trait. *Trends in Plant Science*, (2018), Vol. 23, No. 2

Hochberg U, Windt CW, Ponomarenko A, Zhang YJ, Gersony J, Rockwell FE, Holbrook NM. (2017a). Stomatal closure, basal leaf embolism, and shedding protect the hydraulic integrity of grape stems. *Plant Physiolog*y 174, 764–775

Hochberg U, Bonel AG, David-Schwartz R, Degu A, Fait A, Cochard H, Peterlunger E, Herrera JC. (2017b). Grapevine acclimation to water deficit: the adjustment of stomatal and hydraulic conductance differs from petiole embolism vulnerability. *Planta* 245, 1091–1104.

Hochberg U, Herrera JC, Cochard H, Badel E. (2016). Short-time xylem relaxation results in reliable quantification of embolism in grapevine petioles and sheds new light on their hydraulic strategy. *Tree Physiology* 36, 748–755

Jackson RD ,1982. Canopy temperature and crop water stress. *Adv Irrig* 1:43–85;

Jones HG. 1999. Use of infrared thermometry for estimation of stomatal conductance as a possible aid to irrigation scheduling. *Agricultural and Forest Meteorology* 95, 139-149

Jordan, W.R., Brown, K.W. & Thomas, J.C. (1975) Leaf age as a determinant in stomatal control of water loss from cotton during water stress. *Plant Physiology*, 56, 595– 599.

Keller M., (2010). The Science of Grapevines*; Anatomy and Physiology: Elsevier Inc.*

Keller, M.; Smithyman, R.P.; Mills, L.J. (2008). Interactive Effects of Deficit Irrigation and Crop Load on Cabernet Sauvignon in an Arid Climate. Am. J. *Enol. Vitic*., 59, 221–234.

Keller, M.; Smith, J.P.; Bondada (2006), B.R. Ripening grape berries remain hydraulically connected to the shoot. J. *Exp. Bot.,* 57, 2577–2587.

Knipfer T, Eustis A, Brodersen C, Walker AM, McElrone AJ. (2015). Grapevine species from varied native habitats exhibit differences in embolism formation/repair associated with leaf gas exchange and root pressure. Plant, Cell & Environment 38, 1503–1513

Lascano R., Goebel, T.S., Booker, J., Baker, J.T., Gitz, D.C., (2016). The stem heat balance method to measure transpiration: evaluation of a new sensor, *Agricultural Sciences*, 7(9), p. 604-620

Lavoie-Lamoureux A, Sacco D, Risse PA, Lovisolo C. 2017. Factors influencing stomatal conductance in response to water availability in grapevine: a meta-analysis. *Physiologia Plantarum* 159, 468–482.

Levin A.D., Deloire A., Gambetta G.A., (2020). Does water deficit negatively impact wine grape yield over the long term? IVES Technical Reviews, https://doi.org/10.20870/IVES-TR.2019.4029

Levin AD, Williams LE, Matthews MA. 2019. A continuum of stomatal responses to water deficits among 17 wine grape cultivars (*Vitis vinifera*). *Functional Plant Biology*, 47, 11–25.

Lovisolo C., Perrone, I., Carra, A., Ferrandino, A., Flexas, J., Medrano, H. and Schubert A., 2010. Drought-induced changes in development and function of grapevine (Vitis spp.) organs and in their hydraulic and non-hydraulic interactions at the whole-plant level: a physiological and molecular update. *Journal of Functional Plant Biology*, 37(2), 98–116. Doi

Lovisolo C., Lavoie-Lamoureux, A., Tramontini, S. and Ferrandino A., 2016. Grapevine adaptations to water stress: new perspectives about soil/plant interactions. *Theoretical Experimental Plant Physiology*, 28(1), 53–66.

Matthews, M.; Ishii, R.; Anderson, M.; O'Mahony, M. Dependence of Wine Sensory Attributes on Vine Water Status. J. Sci. Food Agric. 1990, 51, 321–335

Martin-StPaul Nicolas, Sylvain Delzon2 and Herve Cochard (2017). Plant resistance to drought depends on timely stomatal closure. *Ecology Letters*, (2017). doi: 10.1111/ele.12851

McDowell N, Pockman WT, Allen CD, et al. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? *New Phytologist*, 178, 719–739.

Nardini A, Savi T, Trifilò P, Lo Gullo MA. (2017). Drought stress and the recovery from xylem embolism in woody plants. *Progress in Botany*, 79, 197–231.

Ojeda, H.; Andary, C.; Kraeva, E.; Carbonneau, A.; Deloire, A. (2002). Influence of Pre-and Postveraison Water Deficit on Synthesis and Concentration of Skin Phenolic Compounds during Berry Growth of Vitis vinifera Cv. Shiraz. *Am. J. Enol. Vitic*., 53, 261–267.

Ojeda, H., A. Deloire, and Carbonneau A. (2001). Influence of water deficits on grape berry growth. *Vitis*, 2001. 40(3): p. 141-145.

Oliveira, C.; Silva Ferreira, A.; Mendes Pinto, M.; Hogg, T.; Alves, F.; Guedes de Pinho, P. (2003). Carotenoid Compounds in Grapes and Their Relationship to Plant Water Status. *J. Agric. Food Chem.*, 51, 5967–5971

O'Toole, J.C. & Cruz, R.T. (1980) Response of leaf water potential, stomatal resistance, and leaf rolling to water stress. *Plant Physiology*, 65, 428– 432

Pagay V, 2021. Dynamic aspects of plant water potential revealed 1 by a microtensiometer. Irrigation Science doi: 10.1007/s00271-021-00758-8

Pagay V & Skinner A. (2018). Continuous in situ measurements of crop water stress in 'Shiraz' grapevines using a thermal diffusivity sensor. In: Herppich WB, ed. *International Symposium on Sensing Plant Water Status - Methods and Applications in Horticultural Science*, Vol. 1197, 83-88.

Patakas, A. & Noitsakis, B. (2001) Leaf age effects on solute accumulation in water-stressed grapevines. Journal of Plant Physiology, 158, 63– 69.

Patakas, A., Noitsakis, B. & Stavrakas, D. (1997) Adaptation of leaves of *Vitis vinifera* L. to seasonal drought as affected by leaf age. Vitis, 36, 11– 14.

Păltineanu, C., Chitu, E., Mateescu, E. (2011). Changes in crop evapotranspiration and irrigation water requirements. *International Agrophysics*, 25(4): 369-373.

Păltineanu, C., Chitu, E., Mateescu, E. (2012). New trends for reference evapotranspiration and climatic water deficit. *Internat. Agrophysics* 26: 159-165.

Păltineanu, C., Chitu, E., Tănăsescu, N., Apostol, G. & Pufu, M.N. (2000). Irrigation water requirements for some fruit trees specific to the Arges-Vedea river basin, Romania. *Acta Hort*. 537: 113-119. DOI: 10.17660/ActaHortic.2000.537.10. https://doi.org/10.17660/ActaHortic.2000.537.10

Philip, JR, (1966). Plant water relations: some physical aspects. *Annual Review of Plant Physiology*, 17, 45–268

Pérez-Pastor, A.; Ruiz-Sánchez, M.C.; Domingo, R. (2014). Effects of timing and intensity of deficit irrigation on vegetative and fruit growth of apricot trees. *Agric. Water Manag*., 134, 110–118.

Pérez-Sarmiento Francisco, Jose M. Mirás-Avalos, Rosalía Alcobendas, Juan J. Alarcón, Oussama Mounzer, and Emilio Nicolás (2016). Effects of regulated deficit irrigation on physiology, yield and fruit quality in apricot trees under Mediterranean conditions. *Spanish Journal of Agricultural Research*, 14(4), e1205, 12 pages (2016), eISSN: 2171-9292

Rivero, R., Sonsteby, A., Heide, O.M., Mage, F., Remberg, S.F. (2017). Flowering phenology and the interrelations between phenological stages in apple trees (Malus domestica Borkh.) as influenced by the Nordic climate. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science*, 67(4): 292-302.

Rodriguez-Dominguez C.M., Carins Murphy, M. R., Lucani, C. and Brodribb T.J. (2018). Mapping xylem failure in disparate organs of whole plants reveals extreme resistance in olive roots. *New Phtyologist*, 218(3), 1025–1035.

Roby, G.; Harbertson, J.F.; Adams, D.A.; Matthews, M.A. (2004). Berry Size and Vine Water Deficits as Factors in Winegrape Composition: Anthocyanins and Tannins. *Aust. J. Grape Wine Res*., 10, 100–107.

Rogiers SY, Greer DH, Hatfield JM, Hutton RJ, Clarke SJ, Hutchinson PA, Somers A. (2012). Stomatal response of an anisohydric grapevine cultivar to evaporative demand, available soil moisture and abscisic acid. *Tree Physiology* 32, 249–261.

Romero, P.; Botia, P.; Garcia, F. (2004). Effects of Regulated Deficit Irrigation under Subsurface Drip Irrigation Conditions on Vegetative Development and Yield of Mature Almond Trees. *Plant Soil* 260, 169–181

Romero, P.; Fernández-Fernández, J.I.; Martinez-Cutillas, (2010). A. Physiological Thresholds for Efficient Regulated Deficit-Irrigation Management in Winegrapes Grown under Semiarid Conditions. Am. J. Enol. Vitic. 61, 300–312.

Rüger S., Y. Netzer2, M. Westhoff, D. Zimmermann, R. Reuss1 , S. Ovadiya , P. Gessner, G. Zimmermann , A. Schwartz And U. Zimmermann (2010). Remote monitoring of leaf turgor pressure of grapevines subjected to different irrigation treatments using the leaf patch clamp pressure probe_101 405. *Australian*

Journal of Grape and Wine Research 16, 405–412, 2010

Savoi, S.; Wong, D.C.; Arapitsas, P.; Miculan, M.; Bucchetti, B.; Peterlunger, E.; Fait, A.; Mattivi, F.; Castellarin, S.D. (2016) Transcriptome and Metabolite Profiling Reveals That Prolonged Drought Modulates the Phenylpropanoid and Terpenoid Pathway in White Grapes (*Vitis vinifera* L.). BMC *Plant Biol*.

Scholander PF, Hammel HT, Bradstreet ED, Hemmingsen EA. (1965). Sap pressure in vascular plants - negative hydrostatic pressure can be measured in plants. *Science* 148, 339-346.

Shackel K. (2011). A plant-based approach to deficit irrigation in trees and vines. *Hortscience* 46, 173-177.

Slavko Bernáth, Oleg Paulen, Bernard Šiška , Zuzana Kusá, František Tóth (2021). Influence of Climate Warming on Grapevine (*Vitis vinifera* L.) *Phenology in Conditions of Central Europ*e (Slovakia). Preprints 2021, 2021030340 (doi: 10.20944/preprints202103.0340.v2).

Serra, I.; Strever, A.; Myburgh, P.; Deloire, (2014). A. Review: The interaction between rootstocks and cultivars (*Vitis vinifera* L.) to enhance drought tolerance in grapevine. *Aust. J. GrapeWine Res*., 20, 1–14

Sperry J, Donnelly J, Tyree M (1988) A method for measuring hydraulic conductivity and embolism in xylem. *Plant Cell Environ* 11: 35–40

Šuklje K., Zhang X., Antalick G., Clark A.C., Deloire A., and Schmidtke L.M., (2016). Berry Shriveling Significantly Alters Shiraz (Vitis vinifera L.) Grape and Wine Chemical Composition, *J. Agric. Food Chem.*, 64, 870−880, DOI:10.1021/acs.jafc.5b05158

Tim Martinson &Alan Lakso (2018). Grapes 101. Viticulture and Enology, Issue 34, August 2018

Tombesi S, Frioni T, Poni S, Palliotti A. (2018). Effect of water stress “memory” on plant behavior during subsequent drought stress. *Environmental and Experimental Botany* 150, 106–114.

van Leeuwen C., Tregoat, O., Choné, X., Bois, B., Pernet, D. and Gaudillère J.-P., (2009). Vine water status is a key factor in grape ripening and vintage quality for red Bordeaux wine. How can it be assessed for vineyard management purposes? *Journal International des Sciences de la Vigne et du Vin*, 43, 121–134

Vergeynst, L.L., Vandegehuchte, M.W., Mcguire, M.A., Teskey, R.O., Steppe, K., (2014). Changes in stem water content influence sap flux density measurements with thermal dissipation probes, *Trees*, 28(3), p. 949-955.

Waldau, T., Chmielewski, F.M. (2018). Spatial and temporal changes of spring temperature, thermal growing season and spring phenology in Germany 1951-2015. *Meteorologische Zeitschrift*, (27)4: 335-342. DOI 10.1127/metz/2018/0923.

Wenden, B., Mariadassou, M., Campoy, J.A., Quero-Garcia, J. and Dirlewanger, E. (2017). Statistical analysis of trends in sweet cherry flowering data across Europe. *Acta Hortic*. 1160, 215-220.DOI: 10.17660/ActaHortic.2017.1160.31.

Williams LE & Baeza P. ()2007. Relationships among ambient temperature and vapor pressure deficit and leaf and stem water potentials of fully irrigated, field-grown grapevines. *American Journal of Enology and Viticulture* 58, 173-181.

Williams, L.E.; Matthiews, M.A. (1990) Grapevine. In Irrigation of Agricultural Crops; *Agronomy Monograph No. 30; American Society of Agronomy, Crop Sciences Society of America and the Soil Science Society of America: Madison,* WI, USA,; pp. 1019–1055; ISBN 0-89118-102-4.

Williams, L.E.; Phene, C.J.; Grimes, D.W.; Trout, T.J. (2003). Water use of mature Thompson Seedless grapevines in California. Irrig. Sci., 22, 11–18

Zhang, Y., Kang, S., Ward, E.J., Ding, R., Zhang, X., Zheng, R., (2011). Evapotranspiration components determined by sap flow and microlysimetry techniques of a vineyard in northwest China: Dynamics and influential factors, *Agricultural Water Management*, 98(8), p. 1207-1214,

Živčák M., Brestič M., Olšovská K., Slamka P,(2008). *Performance index as a sensitive indicator of water stress in Triticum aestivum* Plant Soil Environ., 54, 2008 (4): 133–139

Zimmermann, D., Reuss, R., Westhoff, M., Ge_Ner, P., Bauer, W., Bamberg, E., Bentrup, F.-W., Zimmerman, U., 2008. *A novel, non-invasive, online-monitoring,*

versatile and easy plant-based probe for measuring leaf water status. J. Exp. Bot. 59, 3157–3167

Zimmermann, U., Schneider, H., Wegner, L.H. and Haase, A. (2004) Water ascent in tall trees: does evolution of land plants rely on a highly metas table state. *New Phytologist* (Tansley Review) 162, 575–615