MONITORING OF GRAPEVINE STEM POTENTIALS WITH AN EMBEDDED MICROTENSIOMETER

Authors: Alan N. LAKSO[1,2*], Michael SANTIAGO[2], Maryrose LUND[2], Abraham D. STROOCK[2,3]

[1]Horticulture Section, School of Integrative Plant Sciences, Cornell University Agritech, Geneva, NY 14456 USA
[2]FloraPulse Co., 720 Olive Drive Suite E, Davis CA, 95618 USA
[3]School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, NY 14853, USA.

*Corresponding author: anl2@cornell.edu

Abstract:

Context and purpose of the study - Vine water status is a crucial determinant of vine growth, productivity, fruit composition and terroir or wine style; therefore, regulating water stress is of great importance. Since vine water status depends on both soil moisture and aerial environment and is very temporally dynamic, direct measurement of vine water potential is highly preferable. Current methods only provide limited data. To regulate vine water status it is critical to monitor vine water status to be able to: (1) measure vine water status to predict the effect of water stress on the overall vineyard performance and fruit quality and optimize harvest management and wine-making (2) properly regulate the water status to impose for a desired fruit quality or style (3) determine if water management has reached the desired stress level.

Material and methods - We have developed a microchip microtensiometer sensor (5x5 mm) housed in a cylindrical probe that is connected to a datalogger or to a dedicated logger with wireless communication and power module. The chip is a MEMS (microelectromechanical systems) microfluidic device with the same measurement principle as the classic soil tensiometer, but it operates over a range of more than 50 bars. The sensor is embedded into the trunk of vines and continuously monitors stem water potential. With the wireless logging, real-time monitoring of stem potentials is available online. Testing in field grown grapevines has been done over several years and compared well to pressure chamber measurements of stem potential.

Results - Field tests with embedded sensor probes in vineyards demonstrated continuous measurements over several months under a range of weather and water stress levels. Pressure chamber readings of stem potential in the monitored vines were well correlated to the sensor output. Though a sensor installation is recommended for one growing season, multiple years of measurement have been found. Results have been most consistent with diffuse porous woody species with very small vessels. Sources of variability in the success of the sensor in grape stems are not clear, but appears to relate to the inherent variability in grape stems and possibly to embolisms of very large vessels. A sensor version with a much smaller installation hole for young vines and small stems has been developed and is being tested with promising results. This precision data on plant water stress will support precision water management, and will support new understanding of plant responses to water and environment. The microtensiometer sensors are available commercially by FloraPulse Co.

Keywords: Water relations, Sensors, Stem water potential, Irrigation management, Precision management.

1. Introduction

Vine water status is well known to be a crucial determinant of vine growth, productivity and basic fruit composition (Williams and Matthews 1990, Deloire et al., 2004; Chapman et al. 2005; Reynolds et al. 2007). Recent evidence that water status is also a critical component of "terroir" or wine style (van Leeuwen, et al., 2004; Van Leeuwen et al. 2020). Thus it is important to: : (1) measure vine water status to predict the effect of water stress on the overall vineyard performance and fruit quality and optimize harvest management and wine-making, (2) properly regulate the water status to impose for a desired fruit quality or style and (3) determine if water management has achieved the desired level of water stress.

The only current practical method to directly estimate vine stress in the field is the measurement of leaf or stem water potential by the pressure chamber (Turner, 1988). It is a good measurement and is portable, but it is manual, slow and considerable operator error can occur in selection of tissue and measurement procedures. It is used to estimate the water potential of exposed leaves; if the leaf is stopped from transpiring by enclosing in dark bag, stem potential is estimated. Measured pre-dawn when there is no transpiration, it is considered to estimate the effective soil water potential of the root system, though in heterogeneous soils it likely represents the wettest root zone (Ameglio et al., 1999). Leaf and stem potentials have been compared and found to generally well correlated though there may be conditions and times of the day where they differ (Chone et al., 2001; Rienth and Scholasch 2019; Shackel 2007, 2011; Van Leeuwen et al. 2009, 2010; Williams 2017). Although all measures are useful, the large meta analysis by Santesteban et al. (2019) and our experience has concluded that stem potential either predawn or mid-day is the best integrator of vine water status, especially in non-irrigated vineyards with variable soils.

A significant limitation to the pressure chamber use at infrequent intervals is that the vine water status varies dynamically with the current weather as well as with soil moisture. To adequately measure such a dynamic system requires continuous or high frequency measurement. Given these limitations of existing techniques to measure water potential in soils and plants, an ideal sensor should be:

- capable of direct measurement of vine water potential.
- accurate (0.01 MPa or better) over the full physiologically-relevant range of vine potential (0 to -2 MPa).
- produce continuous, real-time measurements over extended periods (months to years).
- simple to install and operate with minimal sensitivity to temperature variations and contaminants.
- small to minimize disruption of tissue upon embedding.
- reasonable cost to manufacture and deploy; many sensors may be needed to resolve spatial variations.
- compatible with wireless networks for real-time data collection and spatial integration.

At Cornell University we researched a microelectromechanical system (MEMS) microchip sensor to address these requirements. FloraPulse company has developed the sensor into a practical field instrument.

2. Material and methods

A microfluidic MEMS-based platform was used to create a miniaturized tensiometer (Pagay et al., 2014) that has the same basic principle as the classic soil tensiometer. The sensor chip has an extremely small water volume, about 5-10 nanoliters, and the pressure is measured by a tiny piezoresistive pressure transducer. The exchange surface to the environment is made of porosified silicon with pores of only a few nanometers that provides a potential range of water potential measurements exceeding 50 bars or 5 MPa. The 5x5 mm microtensiometer chip is housed in a cylindrical probe that holds the chip in position with an edge that exchanges water with the plant (Fig. 1). The probe is then held by a metal sleeve with barbed extensions which are driven into the stem, serving as a drill guide for the flat-end drill bit that makes a hole. Before insertion of the probe, a slurry of fine kaolin clay is placed in the hole to provide a more uniform hydraulic connection to the xylem tissue. After inserting the probe the slotted cap provides protection and spring-loaded pressure on the probe to maintain contact with the xylem.

The data stream from the sensor can be logged by common dataloggers, or a solar-powered, wireless datalogger can collect and send data real-time to a cloud server. A user interface allows the user to monitor the stem potentials real-time or plot only the daily minima and maxima.

3. Results and discussion

Field testing in vineyards and several other fruit crops has been done over several years with several cooperators (Blanco and Kalcsits, 2023; Conesa et al., 2023; Lakso et al., 2022; Pagay 2022;). The results In general have been most consistently accurate in species with more uniform xylem having many small vessels such as apple and almond. Results have been less consistent with grapevines. Variation of the vine stem anatomy appears to be a source of variation. Besides inconsistent stem structure and thick variable bark, grapevines also have large vessels in variable arrangements which may lead to single and chains of embolisms of the very large vessels that may disrupt the hydraulic interface with the sensor (Broderson et al., 2013; Gambetta et al., 2020).

The frequency of sampling can be chosen by the user. An example of 10-minute sampling from a New York vineyard is shown in Figure 2, showing the ability to document stem potentials in quite erratic humid climates. Such high-frequency data is valuable for detailed analysis of Soil-Plant-Atmosphere Continuum modeling of cropping vines under natural field conditions. The key points of predawn maxima and mid-afternoon minima (around 17:00 daylight time in this example) can be extracted and plotted on the user interface. One of the unusual values of monitoring water potentials in irrigated vineyards at this frequency is to determine if an irrigation actually achieves the desired goal in terms of vine water status and resulting vine growth or fruit composition. The current sensor is used with stems >5 cm diameter to avoid excessive wounding. However, sensor version with a much smaller installation hole (2-4 mm) for young vines and small stems or cordons has been developed and refined, and is being tested with good results. The microtensiometer sensors are available commercially by FloraPulse Company.

4. Conclusions

This precision data on vine water stress that the microtensiometer provides will support better physiological understanding of vine responses to water, environment and cultural practices. For growers it will improve the ability to precisely manage water whether maintaining good water status with no waste or regulating a water deficit for vine management or fruit quality (Lakso et al., 2022).

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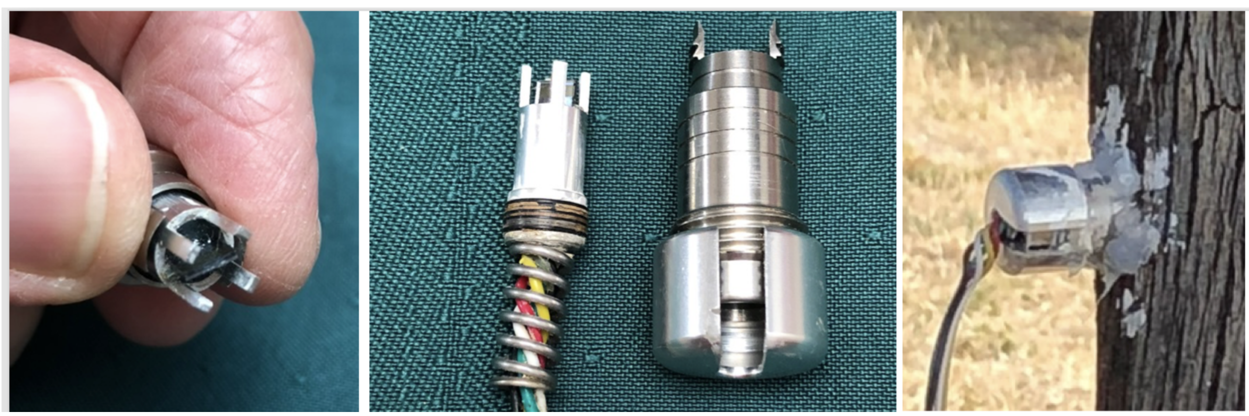

Figure 1: The microtensiometer chip (upper left), housed in a protective cylindrical probe exposing the water exchange surface (arrow). Right, the sensor probe and the sleeve that is driven into the stem, provides a drill guide for drilling an installation hole, and an installation in a grape trunk (lower left).

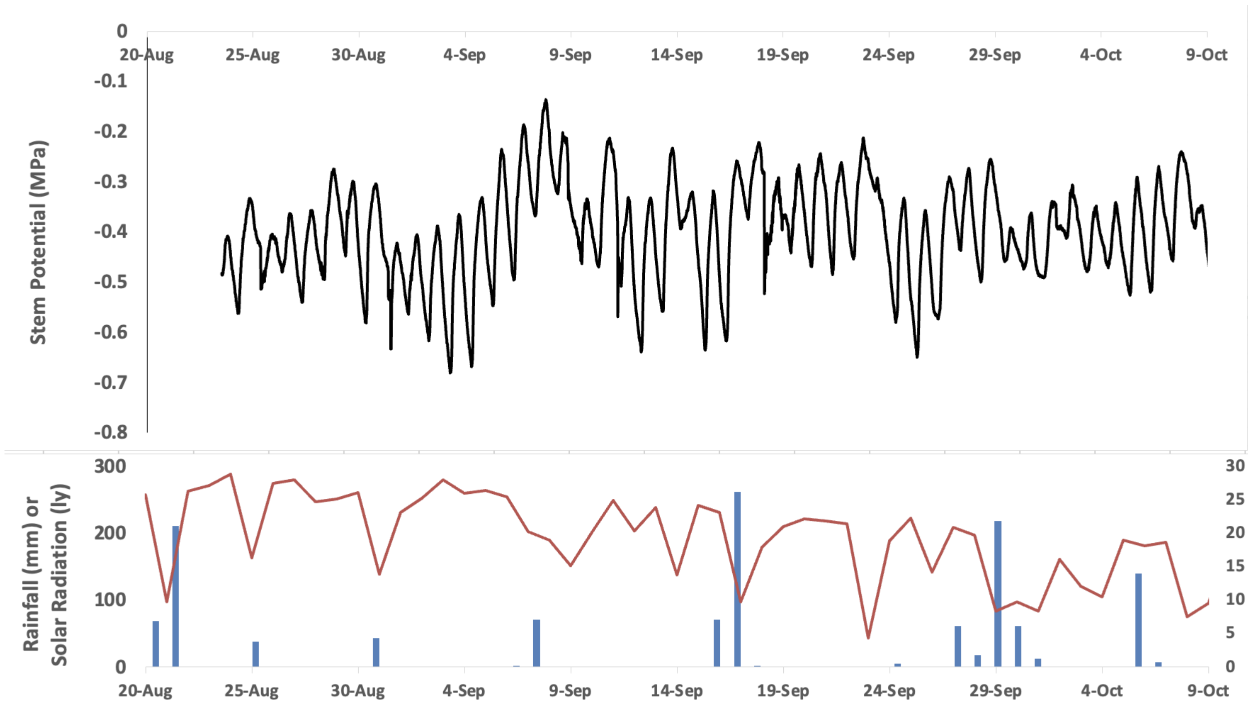

Figure 2: Example of a 10-minute data stream from a humid climate vineyard in New York, USA with rainfall and radiation data.