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Recurring Benefits of Spatial Agriculture and Digital Biology

Richard Carey

For the past several years, agriculture has been adopting new practices that will aid in the production of needed agricultural products while, at the same time, reducing our environmental footprint. Several universities across the country have been working together to harness their collective resources and obtain funding from governmental sources, such as the USDA, for joint projects. The article about VitisGen3 that I wrote in the July 2023 issue of *WineBusiness Monthly* discussed one example of this type of joint cooperation among institutions. In 2022, the VitisGen3 project received $10 million from a Specialty Crops Grant to develop more resilient grapevine cultivars against plant diseases, such as powdery mildew.

Funding for basic digital biology research was initiated by another major grant in 2021 for a multi-institution, transdisciplinary center to develop systems for two-way communication with plants. Cornell University's Center for Research on Programmable Plant Systems (CROPPS) was the entity to recieve this grant. This research investigates how to sense a plant's biology remotely, along with its immediate ecosystem. The goal is to use the digital data collected from plants to improve growth, nutrition and crop quality. The five-year, $25 million National Science Foundation (NSF) grant will begin a new field of digital biology.

CROPPS will be led by researchers from the Cornell College of Agriculture and Life Sciences, the College of Engineering and the Ann S. Bowers College of Computing and Information Science. Partner institutions include the University of Illinois, Urbana-Champaign (UIUC); the University of Arizona; and the Boyce Thompson Institute at Cornell.

FloraPulse is a product that was developed as a successful achievement of one objective of the CROPPS grant. This product is the first of its kind. It is internally installed in the trunk of a plant and is an accurate water potential measuring device that will provide much needed vineyard management information to improve crop quality and water use savings. In order to understand this device, a review of how plants manage water potential is provided in this article for those who need a refresher on how water gets from the soil to the atmosphere through the plant.

Plant Water Movements

It's important to understand how water moves in plants. Plants have evolved a wonderful system of water transport that is based on the physics of water. Water always travels down an activity gradient, and plants don't have a "little pump" that sucks up water and pumps it to the places it needs to go. An animal's heart pushes blood in different directions, but plants don't have the ability to do that. Higher plants have two systems for moving fluids: the first, phloem, is for nutrition and the second, xylem, is for water transport. Water has the important characteristic of having a slightly off-center arrangement of the hydrogen atoms on the oxygen molecule of water. This arrangement creates a tiny off-center charge on each water molecule. Under the right circumstances, the dislocation of this charge can align water molecules as if they could be linked similarly as a magnet to each other or to other substances. This trait allows water to be attracted to other materials.

Inside the plant tissues, water is transported primarily in the xylem tissue. Water molecules are attracted to these tissues of the plant in exactly the same way that a paper towel attracts water to creep up the towel when dipped into a few drops. The largest volume of plant tissue is made up of the xylem, with all cells in alignment, like water canals running parallel to the stem. The apical tip (growing tip) of the plant creates these xylem cells from the very beginning of a plant's germination. When the roots first form in the soil and come into contact with water, the water goes down its activity gradient into the root from the soil. When the leaves begin to grow, the water moves from the xylem cells in the root down its activity gradient to the leaf. This is how the leaf and other tissues are kept hydrated. Eventually, that water vapor can exit through the stomatal cells of a leaf to the outside world. The "magic" of this occurrence happens just as the water molecule leaves the plant's cell into the atmosphere.

The force that drives this process is called Vapor Pressure Deficit (VPD). Under normal circumstances, the air is not 100% saturated with water. Therefore, the water in the air is less than the content of water in the plant. This difference in water activity gradient is the force that drives water molecules to leave the plant in favor of the air. The instant water molecules leave the plant tissue, the chain in the activity gradient transfers to the next water molecules, reducing the gradient to the next closest neighbor and moving the "chain" of water along the xylem walls and the bulk volume of the cell. This is how water molecules get from the root of a plant to the top of even the tallest trees without the need of a pump. It is also the reason that a tree cannot be taller than about 330 feet. That is the limit of the strength of this activity gradient's force for water. Above that point, the chain breaks, and the water column cavitates.

Box 1: Pascal (Pa) a Standard International unit (SI) unit of pressure. Pounds per square inch (psi) is a non-SI unit of pressure commonly used in the United States.

To convert pascal to psi, you can use the following conversion formula:

1 psi = 6894.75729 Pa. or 6.89 MPa.

Therefore, 1 Pa is equal to 0.000145037738 psi. You may see this number representing the pressure of one atmosphere of pressure.

The Need for a Digital Pressure Bomb

We are all aware that water is one of the primary resources needed for agriculture to succeed. According to the World Bank, up to 70% of fresh water is used in most places by agriculture. Research has shown that over- or under-watering can have a dramatic effect on crop yields and quality. One of the projects that has been included in the CROPPS grant over the last few years involves a sensor that can be embedded into a plant to measure water potential.

Plant water potential (Ψw) measures the potential energy in water that drives its movement in a plant. This definition describes water in a plant as moving from higher to lower water potential; consequently, water potential is noted in negative terms. The water in the leaf is nearly 100% saturated in the interstitial air in the leaf (the air in the leaf spaces between cells). Once outside the leaf cells, its concentration is lower. Therefore, in most cases, a leaf's internal water potential is essentially 100%, and the air outside is not; then calculating the difference between the air outside of the leaf versus inside is in negative energy terms and measured in Pascals (**BOX 1**). The greater the VPD, the greater the deficit and faster the water is removed. This sets the chain of action in a plant that drives the water potential in a negative way.

Historically, plant physiologists measured the water potential of a plant by reversing the process of measuring from a pump. The mechanism used has been colloquially called a "Pressure Bomb." Officially, it is a Scholander Pressure Chamber and was developed in the early 1960s. It is a heavy, cumbersome device that has to be lugged next to the plant tissue under examination. The operator also needs a high-pressure gas cylinder to pressurize the chamber.

The cut end of a leaf, petiole or a stem is placed in the chamber with its end facing up to the outside atmosphere. Gas pressure is introduced into

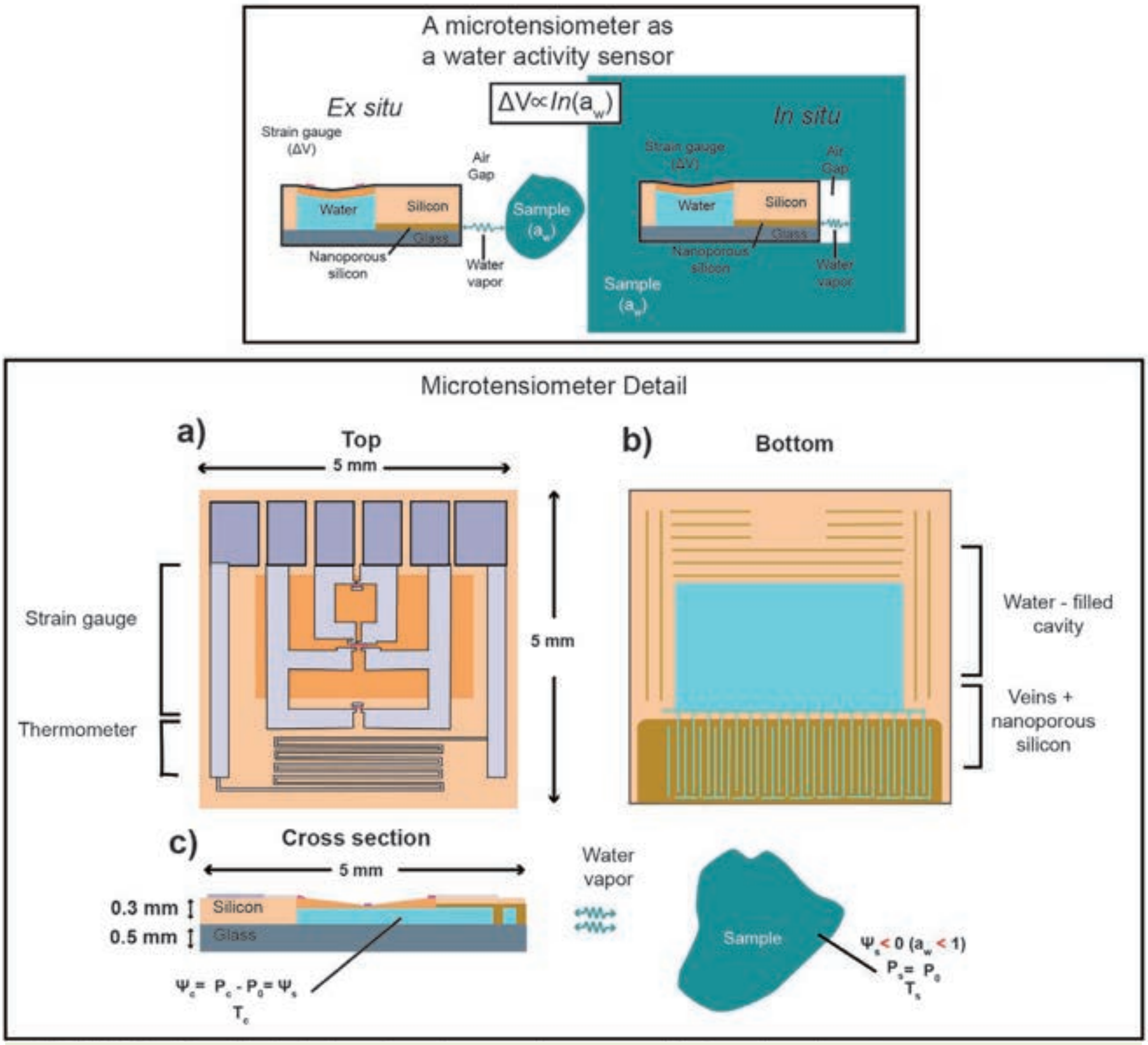

FIGURE 1: This detailed design shows a microtensiometer with functional parts.

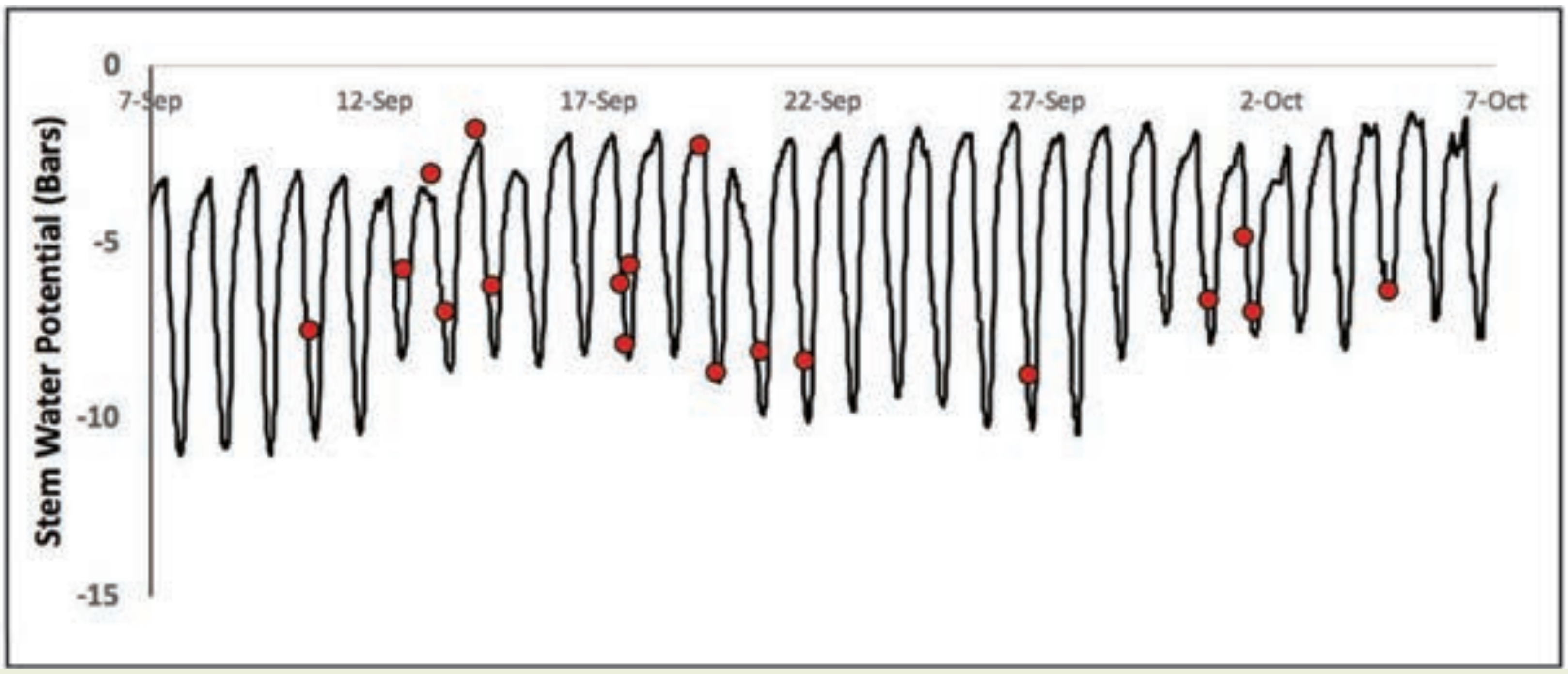

FIGURE 2: An example of the continuous stem potential measurements with the microtensiometer in a grapevine in California with concurrent pressure chamber stem potential readings (dots). A direct field calibration of the sensor was made with the first two pressure chamber readings after installation. Sensor installation made by M. Santiago and pressure chamber data from K. Shackel and V. Volkov.

the chamber and gradually increased until water is pressed out of the stem's petiole. The measurements for a pressure bomb are in Pascals or Bars (**BOX 1**). In this article, measurement will be reported in Pascals. A plant that is fully hydrated will have a very low water deficit of less than a few -kPa. A plant that begins to wilt will have slightly less than -1 MPa. The permanent wilting point of a plant is about -1.5 MPa.

It should be evident from this description that measuring water stress in a plant by this method was difficult and cumbersome, especially on a large scale. It was also destructive because each test has to remove some plant tissue for examination. Until recently, the only effective means of identifying plant water stress was at the entry point of water into the plant. By extrapolation, when water availability in the soil was low, irrigation would supplement the water needed for the plant. Optimizing this protocol was not very effective because there were too many unknown processes that could not be evaluated in real time in a commercial setting.

FIGURE 3: An installed FloraPulse microtensiometer on a grapevine

Transition to Spatial Agriculture

Using spatial agriculture and digital information is required for managing vineyards; adding these automated systems is necessary to provide the data needed to optimize plant health, disease protection and crop quality.

There are several developmental options for measuring the water status in plants, but the one that has received the most traction recently came from work at Cornell University. Emeritus Professor Dr. Alan Lakso, Dr. Abraham Stroock and Dr. Michael Santiago worked on creating a microelectromechanical membrane system (MEMS) to measure water potential, both in situ as well as ex situ. This was the first system to be developed that could accurately measure the full range of potential water deficits in plants. A proof of principle device, created prior to the CROPPS grant, continued to be developed with grant funds into a commercial product. The group formed a company, FloraPulse, to start commercial implementation of this device. The research citations here are listed as a group, with a few extras for fascinating reading for the technically-inclined.[1, 2, 3, 4, 5, 6, 7]

FIGURE 4: A FloraPulse microtensiometer installed on a grapevine with its protection materials and its connection with the data collection and transmission equipment.

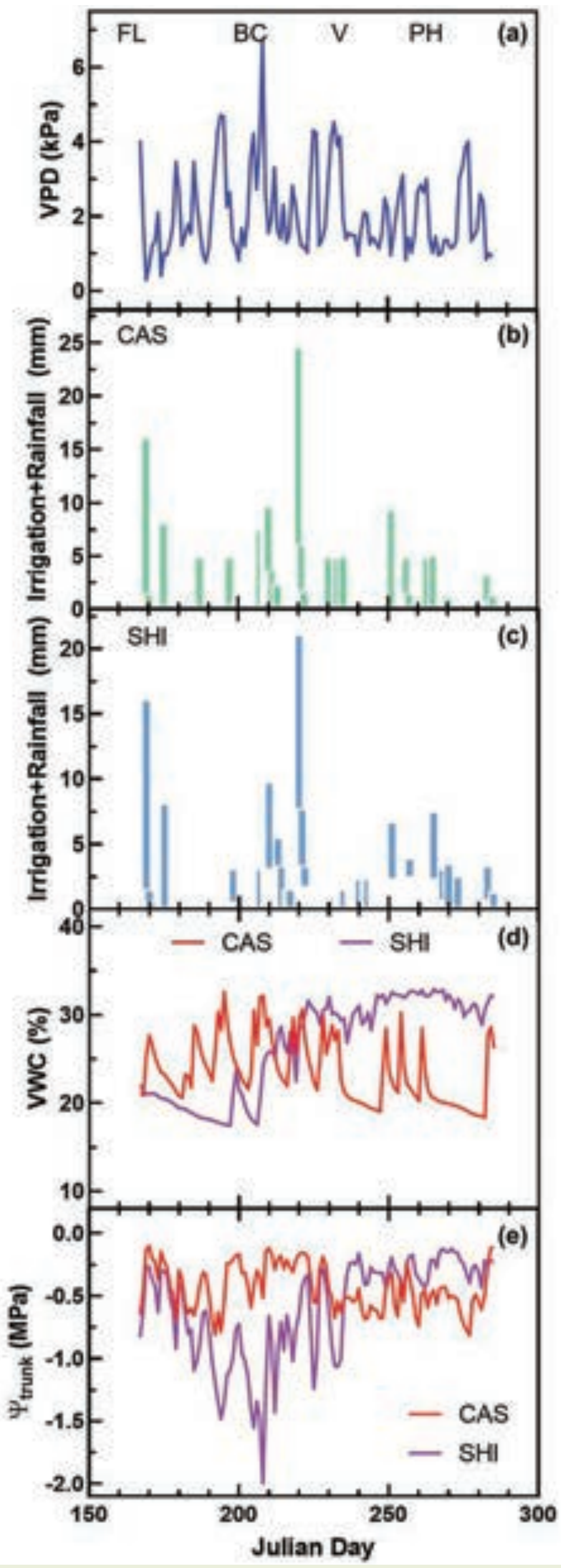

FIGURE 5: Seasonal patterns of (a) vapor pressure deficit (VPD), (b, c) total water incident (irrigation + precipitation), (d) soil moisture (as volumetric water content, VWC) and (e) trunk water potentials (trunk) for Cabernet Sauvignon and Shiraz grapevines during the 2020-21 season. Approximate phenological stages are shown on top of VPD graph: FL = flowering; BC = bunch closure; V = veraison; PH = approximately one week pre-harvest.

Microtensiometer Development

Vinay Pagay et al. first published the basic concept of the tensiometer that could be used to measure water potential continuously in 2014.[1] The tensiometer was updated in 2020 by Winston Black et al.[2] The concept of the microtensiometer was modeled after soil probes, but the goal was to develop one that could get to an extended range of linearity and measure water potential levels (Ψ) found in crops. In 2014, the device was capable of measuring -10 MPa with an acceptable error variation.

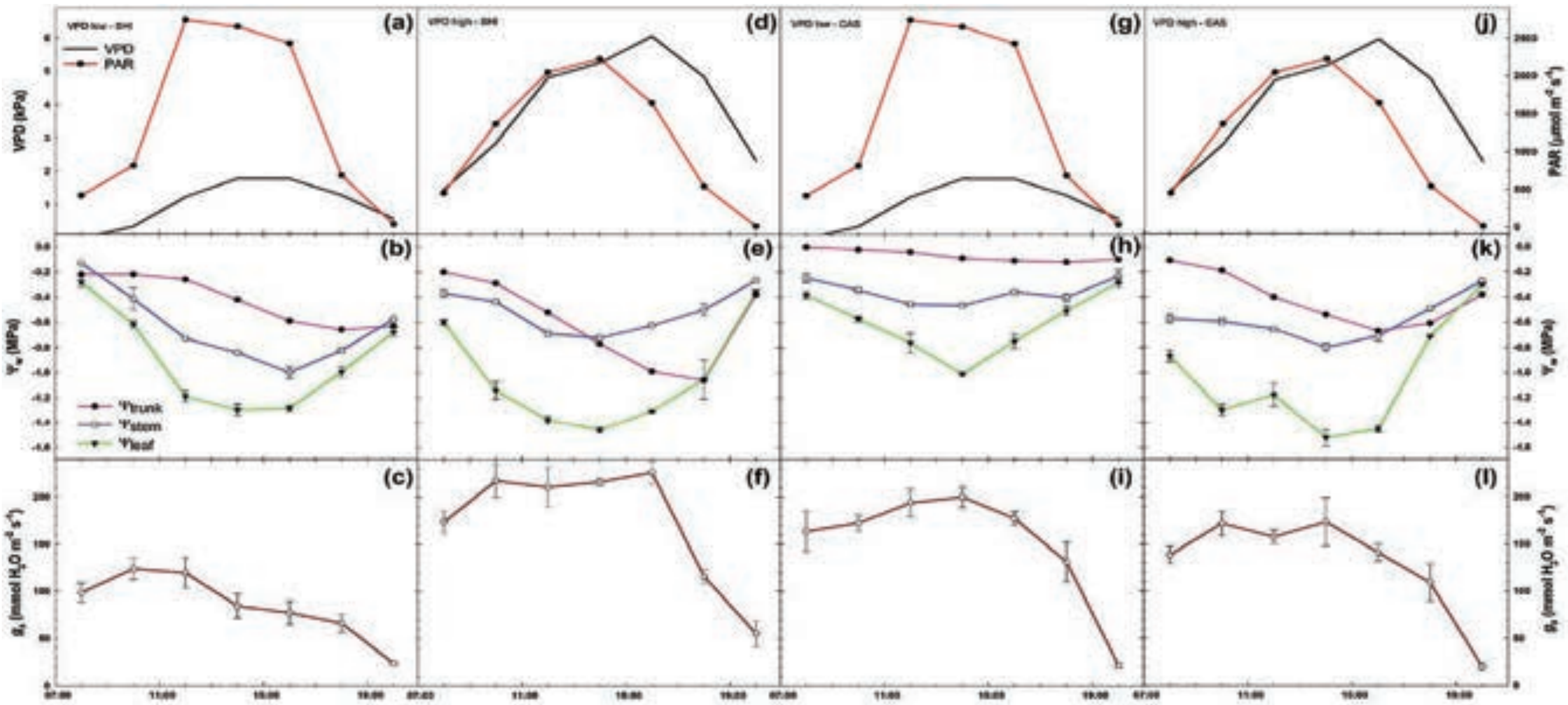

FIGURE 6: Diurnal patterns of VPD, PAR, trunk, stem, leaf water potentials and leaf stomatal conductance (gs) on low- and high-VPD days for Shiraz (SHI) and Cabernet Sauvignon (CAS) grapevines.

The principle of operation is electrically based on a Wheatstone bridge (**FIGURE 1**). In the first experiments, the team examined a number of pore sizes that could emulate the range of stresses that are required to mimic water stress and would work in the xylem tissue of the plant. The researchers created a porous silicone material so that the tensiometer could use the porous nature of the product to allow water to intrude into the pores. After layering other materials onto the silicone block, the team placed a membrane over the pore and created a base for the block and its container. The membrane acted as the strain gauge that provided the ability to measure a deflection in pressure. They then attached electrical connections to a Piezoresistor that measures the deflection of the membrane, which changes the resistance in direct proportion to the level of stress. That output was sent to the Wheatstone

FIGURE 7: The photo on the left is the original size FloraPulse microtensiometer. The center image shows the new microtensiometer in position on a grapevine that is connected to the data transmitter. The right has the small unit installed.

bridge to find the amount of current that it takes to counter the pressure that the plant xylem imparts on the membrane. In these experiments, researchers found that the microtensiometer was accurate to -14 MPa or equivalent to -200 psi.

At this point, researchers needed to validate the measurements they were finding in a plant compared to the traditional method of analysis. The amount of testing needed to validate this type of data is daunting and included multiple tests of pressure bombs in conjunction with the microtensiometer. In (FIGURE 2), Lasko et al. found that there was good to excellent correlation between pressure bomb readings and that of the microtensiometer.[3] Importantly, the best correlations happened at pre-dawn or early morning and mid-day. When there were rapid changes in potentials, there were lesser correlations but still within the same pattern as at pre-dawn. They also looked at the speed of reaction to the changes, which for all practical purposes was close enough to warrant the device.

It is important to protect the microtensiometer. When inserting the device, a hole has to be made in the trunk of a vine with a punch. Once the hole is made and the bark is scraped off the outer surface, a small amount of Kaolin is placed in the hole to mate it with the sensor to protect the membrane surface and also provide plant water contact with the membrane. The hole is sealed with silicone, the vine is wrapped with an insulating material and then a reflective material (FIGURE 3).

The microtensiometer output is wired to the data collection and transmitting device, and the local transmitter sends the collected data to a cloud location. Data can also be retrieved locally if Internet service is not available (FIGURE 4).

Weather and Soil Conditions

An experiment with grapevines was conducted by Pagay in Australia's Coonawarra district where they evaluated the microtensiometers, soil moisture, volumetric water content (VWC) and VPD over a season's duration.[4] Vine water status (Ψ_w) was measured by the microtensiometer. In (FIGURE 5), the Ψ_{trunk} and soil moisture and irrigation all followed closely together and were measured in comparison to VPD. The data from this experiment indicated that Shiraz is more influenced by VPD than Cabernet Sauvignon.

Having continuous water potential readings for grapevines can provide information in relation to other environmental factors that affect the phenological development of vines and especially in relation to the effects of irrigation and its timing (FIGURE 6). This figure from Pagay 2022 is a complex diagram of the comparison between VPD, Ψ, photosynthesis active radiation (PAR) and stomatal conductance, compared to days of both low VPD and high VPD.[4] Data were also collected for Shiraz and Cabernet Sauvignon in Australia. Columns 1 and 3 of this figure show data for low VPD days, and the other two are for high VPD days. For brevity, the review here of this figure outlines only part of the information in this article. A more complete understanding of important details can be found in the original publication.[4]

To set the environmental parameters, the low VPD day temperature was 23°C with a VPD of -1.7 kPa at 1400 H, and on a high VPD day, the temperature was 37°C with a VPD of -6.0 kPa. Shiraz, with an average Ψ for low versus high VPD days, presented a significantly lower Ψ for all three elements of Ψ for trunk, stem and leaf on high VPD days than for low. (Shiraz had a low = -0.66, -0.96 and 1.30 MPa and high = -1.1, -0.7 and -1.5 MPa respectively.)

It's important for vineyard personnel to understand the interrelationships of water potential within grapevine organs to make sense of the simplest readings that can be measured in the field during a season. The FloraPulse microtensiometer is a tool that can help vineyard personnel develop protocols for irrigation timing that will provide the proper phenological development of the vine from bloom to fruit for high-quality grape production. This experiment has shown that there is good agreement between the relationship of Ψ_{trunk} versus Ψ_{stem} but not as good between Ψ_{trunk} versus Ψ_{leaf} averages over a day. However, this will depend on knowledge of what those relationships are between trunk, stem and leaf Ψ. In Pagay 2022, they compared traditional Ψ_{leaf} and Ψ_{stem} to Ψ_{trunk} and now can show that Ψ_{trunk} is more stable over time than either of the other two and is relatively unaffected by external factors.[4] They have found that Ψ_{trunk} is about 1 MPa higher than Ψ_{leaf}, which is probably due to higher hydraulic resistance in that organ. They postulated that the trunk is a central organ in the vine between roots, leaves and stems and, due to its volume, can act as a modifying factor.

In summary, new protocols will need to be developed and verified to provide more information about optimizing the use of microtensiometer data with more definitive and prescriptive information about irrigation optimization.

Initial field work has shown that vineyards and other crops have a significant reduction in water use with 15 to 40% savings.

How to Deploy Microtensiometers

Microtensiometers (MT) are designed to have one unit per irrigation block. Each unit has transmitting capabilities to send Δ data to a controller for the property. This device then will transmit via an Internet connection to the main user interface. The device data can be accessed locally if no remote connection is available.

In most cases, these units are marketed as a subscription service plan. With this arrangement, the customer does not have to worry about technical problems, such as a device not working properly during a season. FloraPulse will exchange a unit on an as-needed basis. Each customer has their own account for following the input information that is available with an Internet connection. The subscription service covers the annual replacement of each sensor. Sensors are good for one season and then can be sent back and refurbished for the next season. When returned, a unit can either be installed in a different place on the same vine or on a different vine.

For some users that have special needs, units can be purchased individually. In such cases, a user may wish to test multiple plants for shorter periods of time where a subscription would not be as economical.

New Developments

The current FloraPulse MT is designed for trunks that are 2" in diameter. This size limits the number of grapevines that this system can accommodate. Fortunately, the company recognized that fact and is now completing final development of a smaller size unit that can be installed on a vine of about 1" (FIGURE 7). Much younger vines can be monitored by the new device, and earlier interventions will be easier to introduce for vine health.

Conclusion

FloraPulse MT will provide a wide range of data that will be important for vineyard personnel to learn how grapevines respond to the water potential in their vineyard. The optimization of water use will not only protect our water systems, in general, but has the great potential of maintaining a high-quality harvest in difficult climatic conditions. Knowing how leaf conductance is handling high VPD versus soil water can influence when and where irrigation can improve the opportunity for the season's success. There is much to learn about water management and crop quality. WBM

References

1. Pagay, V., M. Santiago, D. A. Sessoms, E. J. Huber, O. Vincent, A. Pharkya, T. N. Corso, A. N. Lakso and A. D. Stroock. (May 2014) "A Microtensiometer Capable of Measuring Water Potentials Below -10 MPa." *Royal Society of Chemistry*.
2. Black, II, W. L., M. Santiago, S. Zhu and A. D. Stroock. (July 2020) "Ex Situ and In Situ Measurement of Water Activity with a MEMS Tensiometer." *Analytical Chemistry* .2020, 92, 716-723.
3. Lakso, A. N., S Zhu, M. Santiago, K. Shackel, V. Volkov and A. D. Stroock. (2022) "A Microtensiometer Sensor to Continuously Monitor Stem Water Potenials in Woody Plants – Design and Field Testing." *Acta Hortic*. 1335. ISHS 2022. DOI 10.17660/ActaHortic.2022.1335.39.
4. Pagay, V.. (2021) "Evaluating a Novel Microtensiometer for Continuous Trunk Water Potential Measurements in Field-grown Irrigated Grapevines." *Irrigation Science* 2022, 40:45-54.
5. Blanco, V., L. Kalcsits (2021) "Microtensiometers Accurately Measure Stem Water Potential in Woody Perennials." *Plants* 2021, 10, 2780. *https://dpo/prg/10.3390/plants10122780*
6. Luo, Y., C-L. Ho, B. R. Helliker and E. Katifori. (2021) "Leaf Water Storage and Robustness to Intermittent Drought: A Spatially Explicit Capacitive Model for Leaf Hydraulics." *Frontiers in Plant Science* 12:725995, doi: 10.3389/fpls.2021.725995.
7. Jain, P., W. Liu, S. Zhu, C. Y-Y. Chang, J. Melkonian, F.E. Rockwell, M. A. Gore and A. D. Stroock. (2021) "A Minimally Disruptive Method for Measuring Water Potential in Plants Using Hydrogel Nanoreporters." *PNAS* 2021. 118, 23, e2008376118. *https://doi.org/10.1073/pnas.2008276118*