Atti del XXVI Convegno Nazionale di Agrometeorologia

Approcci innovativi a supporto delle produzioni agrarie in un contesto climatico in evoluzione

L'AQUILA, 5 - 7 Giugno 2024

A cura di Francesca Ventura, Gabriele Cola, Francesca Di Cesare

Dipartimento di Scienze e Tecnologie Agro-Alimentari
Università di Bologna

COUPLING STEM WATER POTENTIAL AND SOIL WATER POTENTIAL ON IRRIGATED AND NOT IRRIGATED VINES. PRELIMINARY RESULTS FOR *Vitis Vinifera L. cv. Teroldego*

MISURAZIONE AFFIANCATA DEL POTENZIALE IDRICO DEL FUSTO SU VITE IN REGIME IRRIGATO E NON. RISULTATI PRELIMINARI SU TEROLDEGO

Cecilia Mattedi[1*], Fabio Zottele[1], Francesco Centurioni[1], Amelia Caffarra[2], Corradini Stefano[1]

[1] Fondazione Edmund Mach - Centro di Trasferimento Tecnologico - Agrometeorologia e Irrigazione, San Michele all'Adige, Italy
[2] ITK, Clapiers, France
* cecilia.mattedi@fmach.it

Abstract
Improving wine quality necessitates precise control over plant water stress, which requires accurate scheduling of irrigation based on the plant's water status and the soil's water availability. The aim of this experiment is to monitor the water status of grapevines and soil in both irrigated and not-irrigated conditions to quantify differences in the plant's physiological response and yield. In addition, novel microtensiometer probes for measuring continuously the Stem Water Potential were tested for efficacy. These probes were coupled with a handcrafted tensiometer to monitor the Soil Water status and at the end of the season all the yield was analyzed to determine the main oenological parameters driving the final quality of the musts. Initial findings indicate that the microtensiometers gave effective estimates of the vines' water status, revealing rapid plant responses to water inputs and atmospheric changes. Notably for the experiment, soil moisture exceeded field capacity under irrigated vines before irrigation, suggesting potential water loss through deep percolation, and both the irrigated and not-irrigated vines were in water comfort for all the vegetative season without any detriment both in production and quality.

Parole chiave
Agricoltura di precisione; irrigazione; potenziale idrico del fusto; potenziale idrico del suolo; microtensiometri
Keywords
Precision agriculture; irrigation; stem water potential; soil water potential; microtensiometers

Introduction

Wine quality can be improved by moderate plant water stress during maturation (Van Leeuwen et al., 2009; Gambetta, 2016; Mirás-Avalos and Araujo, 2021). In irrigated vineyards, the level of water stress can be regulated by optimizing irrigation timing and quantity. However, to do so, a precise knowledge of plant and soil water status is needed at each moment. This can be complicated, as many factors come into play affecting the soil-plant-atmosphere continuum. Soil water content depends on atmospheric variables which determine water inputs and evaporation, on its water holding capacity and the presence of plant cover. Plant water status depends on soil available water and evapotranspiration.

The standard method for plant water status monitoring in research is the measurement of the leaf water potential, usually performed with pressure chambers (Deloire et al., 2020). However, appropriate sampling relies on the operator itself, which is responsible to ensure proper sampling technique (Levin, 2019). Microtensiometers are a viable alternative to perform non-invasive and remote monitoring of stem water potential, which is considered an equally viable method to assess the water status of grapevine (Choné, 2001; Williams and Araujo, 2002; Lakso et al., 2022). Furthermore, the high sampling rate of these sensors allows the continuous measurement of the plant parameters (Lakso et al., 2022). The primary objectives of this study are to investigate the effects of irrigated and non-irrigated conditions on the dynamics of plant water status, as well as on grape quality and yield. To achieve this, we monitored stem water potential using microtensiometer probes and simultaneously measured soil water content using tensiometers.

Materials and Methods

Experimental site

The study area is located in Novali, close to Mezzolombardo, in the Trentino-Alto Adige region (Italy) (46°12′35.172″N 11°6′36.187″E) at about 215 m above sea level. Placed at the bottom part of a valley in the central part of the Alps, the landscape morphology ranges from sub-flat to flat. The soil's parent material is made up of gravels and sands of mixed lithology, mainly calcium carbonate. The cultivated variety is Teroldego, an autochthonous grape variety, grafted onto Teleki 5C rootstock to maintain the vigor, and managed using the "pergola doppia" training system. Row and vine spacing are 5 m x 0.5 m. The vineyard is oriented from North-East to South-West.

Following the USDA classification, the soil is loamy, rich in rock fragments, cobbles, gravel, and shallow (about 80 cm deep). The anthropic horizon is rich in organic carbon (1.3 %) with a depth of 30 cm. The growth of the vines' root system is limited to 50 cm of soil depth due to alluvial rocks and pebbles, so sensibly reducing the average root depth reported by the literature (Allen, 2000).

The irrigation setup consists in a single drip line and the output of the emitters is 2.2 l h^{-1}. The irrigation is managed by the local irrigation association. The irrigation schedule consists in 4 h of irrigation given to the vine from 11 A.M. to 3 P.M. on 24^{th} and 28^{th} June 2023 and on 1^{st}, 5^{th} and 8^{th} July 2023 so that the total amount of water declared by the Irrigation Association is 8.8 l d^{-1} except for July 1^{st}, when an amount of 7.7 l d^{-1} of water per emitter was provided.

Climatic framework

Meteorological measurements were provided by the nearest meteorological station by Fondazione Edmund Mach (name: Mezzocorona Novali, station ID: 45). It is located approximately 700 m South of the experimental site at a similar elevation (216 m a.s.l.) with data recorded since 1999.

The climate of the site can be described as Oceanic type (Do) following the Köppen–Trewartha climate classification (Trewartha and Horn, 1980). The average air temperature during the vegetative season of 2023 is equal to 20.18 °C and identifies a particularly warm growing season with respect to the climatological mean (19.6 ± 0.8°C). The cumulative precipitation occurred during the growing season is equal to 729.6mm and is far above the median of cumulative precipitation over the series (535.0 ± 123.0 mm). However, between April and June 2023, 270.6 mm of precipitation were recorded, which is very close to the median of the previous years for the same time period (241.8 ± 43.1 mm).

Vapor Pressure Deficit (*VPD*) was calculated with the formulas from Monteith and Unsworth (2008):

$$e_s = 0.61078\, exp[17.27\, T(T + 237.3)^{-1}]$$

$$\mathrm{VPD} = e_s (1 - 0.01\, \mathrm{RH})$$

being T and RH the air temperature and the relative humidity of the air respectively.

Vines' water status measurements

For this study, two mature and healthy representative vines were chosen. One of them was treated as usual, and the other one was kept without irrigation.

The vines' water status was measured with FloraPulse microtensiometers (Lakso et al., 2022), which allowed continuous monitoring of stem water potential (Ψ_{stem}). On 2023, May 25^{th}, a total of 4 probes were installed, two on the irrigated vine and two on the not irrigated one. On each vine, one probe was installed in the lower part of the stem (40 cm from the ground) and one on the higher part (80 cm from the ground). Each microtensiometer was embedded into the trunk, within the xylem tissue, and it equilibrated with the vine within 2 days of installation. Stem Water Potential values of the not-irrigated vine ($\Psi_{stem,not\ irr}$) were recorded every 20 min, wirelessly transmitted via telemetry and displayed on the FloraPulse user interface. Instead, the two probes on the irrigated vine were connected to a CR1000 datalogger (Campbell Scientific Inc.), and values ($\Psi_{stem,irr}$) were recorded every 15 min.

For this study, due to the malfunctioning of one of the probes on the not-irrigated vine and of the data logger on the irrigated one, only the measures of Ψ_{stem} from the 1^{st} to 15^{th} of July are used.

Soil moisture measurements

To monitor the matric tension (Ψ_{soil}), two tensiometers were installed on June, 20^{th}. Each tensiometer was crafted following the procedure explained by Thalheimer (2013). One of them was installed next to the irrigated vine and the other one next to the not-irrigated vine. Both tensiometers were connected to the same CR1000 data logger used to measure the stem water potential of the irrigated vines. The values of Ψ_{soil} were recorded with a time interval of 15 min. Given the limiting depth for the root zone, in order to determine the soil moisture the installation depth of tensiometers was around 30 cm. Furthermore, each tensiometer was installed under the drip line and between two drippers.

Grape quality and vine balance

No canopy regulation was applied to the two selected vines after the late-winter pruning in order to maintain all the new biomass produced during the vegetative season. The vines were harvested on September 25th and all the grapes were weighed (W_g), bagged and refrigerated. During the same day, the following oenological properties of the must were analyzed: sugar content, pH, total acidity, malic acid, tartaric acid, Yeast Assimilable Nitrogen (*YAN*) and Potassium (K^+). To estimate the vine balance, the Ravaz index (Ravaz and Sicard, 1903) was calculated for each vine using the following formula:

$$I_{rav} = W_g \cdot W_b^{-1}$$

where W_b is the weight of the biomass grown during the vegetative season, collected and weighed on 2024 January, 11th.

Results and discussion

Stem water potential and soil moisture

The graphs in Fig.1 show plant and soil water status, with the blue lines representing the irrigated regime ($\Psi_{stem,irr.}$, $\Psi_{soil,irr.}$) and the red lines the not-irrigated regime ($\Psi_{stem,not\ irr}$ and $\Psi_{soil,not\ irr}$).

Above is plotted the time-series of the FloraPulse microtensiometers installed in the upper part of the vines' trunk: for the data analysis, the values of lower microtensiometers were discarded due to the malfunctioning of one of the probes and only the values recorded for the higher probes have been used for consistency. In the graph below is plotted the evolution of the signal of the two tensiometers, together with the amount of precipitation (black bars). The blue vertical stripes mark the time intervals in which the irrigation was on.

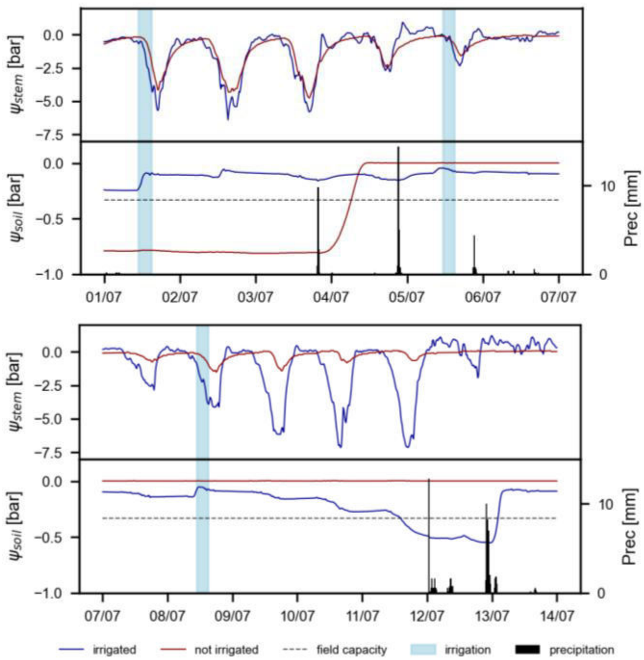

Fig.1 - Time series of Ψ_{stem}, and Ψ_{soil} of irrigated (blue) and not irrigated (red) vines for the first week (above) and the second week (below). Field capacity of the soil is reported with the dashed line, precipitation denoted with the dark bars. Blue vertical stripes mark the periods when irrigation is applied.

Fig.1 - Andamento di Ψ_{stem}, e Ψ_{soil} della vite irrigata (in blu) e di quella non irrigata (in rosso) durante la prima settimana (grafico in alto) e durante la seconda settimana (grafico in basso). La linea tratteggiata indica la capacità di campo del terreno, la precipitazione è rappresentata dalle barre nere mentre le strisce blu indicano i periodi di irrigazione.

During the first week (from July 1st to July 7th) the two microtensiometers have similar qualitative trends. At pre-dawn Ψ_{stem} is in equilibrium with the tension state of the soil (Ψ_{soil}) (Williams and Araujo, 2002), with values close to 0 bars. The gradual increase of air temperature and the decrease of RH in the morning caused the gradual fall of Ψ_{stem} in both vines. This corresponds to an increase of $\Delta\Psi_{stem}$ along the soil-plant-atmosphere continuum (Bonan, 2019) and is associated to a stronger water flow and higher leaf transpiration rate (Choné, 2001). The lower peaks of $\Psi_{stem,irr}$

range between −5.5 bar and −7.5 bar, but after the occurrence of precipitation and irrigation they do not fall below −2.5 bar. After a consistent precipitation event occurred on July 13th the values recorded by the probes oscillate around 0 bar.

During the first week, the values of $\Psi_{stem,not\ irr}$ follow $\Psi_{stem,irr}$, but the daily minimum value of $\Psi_{stem,not\ irr}$ is slightly lower in magnitude. The signal weakens starting from July 7th, and it approaches 0 bar after July 12th. This does not imply that the water flow in the stem ceases, since a negative $\Delta\Psi_{stem}$ is however observed. This could be the effect of stomatal closure, which is one of the mechanisms that plants activate in order not to lose significant amounts of water vapor through transpiration and to reduce the risk of cavitation into the xylem (Tombesi et al., 2016; Buckley, 2019).

The tensiometer of the irrigated vine records $\Psi_{soil,irr}$ value around −0.25 bar on the first day of the analysis, and its signal clearly reacts to the water inputs: it increases rapidly when irrigation is applied and when precipitation occurs. The line pattern on July 2nd suggests that some irrigation was applied, although no communication was given by the Irrigation Association. $\Psi_{soil,irr}$ gradually falls below the -33 kPa threshold during the dry period after the irrigation of July 8th. It is important to notice that, during the first week, irrigation was applied even though $\Psi_{soil,irr}$ was above field capacity. An excess of water input in the soil enhances the probability of gravitational water flowing through percolation and if the water exceeds the root zone it becomes no longer available for root uptake and so is basically wasted.

Looking at the tensiometer of the non irrigated vine, a low value of $\Psi_{soil,not\ irr.}$ is recorded on July 1st ($\Psi_{stem,not\ irr.}$= -0.79 bar): the soil was dry as no precipitation occurred since the installation day (June 20th). It kept almost a constant value until the occurrence of the first precipitation on July 4th, then it rapidly increased and stabilized at a value around 0 bars. This is probably due to a malfunctioning of the probe.

Even in the periods with no irrigation and no precipitation, neither $\Psi_{stem,irr}$ nor $\Psi_{stem,not\ irr.}$ reached values that could be associated with severe stress for the vines (Deloire et al., 2020). However, two microtensiometers per vine could have allowed the calculation of the gradient of Ψ_{stem} in each plant, so providing a more complete overview of the magnitude of the water fluxes in the plant.

Exploratory analysis of the measures of Ψ_{stem} for both the irrigated and not irrigated vines show that for some hours during the day $\Psi_{stem,irr} > \Psi_{stem,\ n.irr}$ and vice versa. One hypothesis is that an environmental threshold exists to activate this switching behavior. A preliminary analysis identifies VPD, air temperature and the global solar radiation (R_S, MJ m^{-2}) as the main driver of this threshold-triggered behavior, but for a statistical confirmation more data should be collected.

Only thanks to the continuous measurement of the microtensiometers, correlations were found between Ψ_{stem} and the variation of these atmospheric variables, with different lag times dependent on the considered atmospheric variable (1:00 h lag time for air temperature and VPD, and about 4:00 h for global solar radiation).

Oenological analysis and vine balance

The results of the oenological analysis of the harvested grapes show no substantial differences between the irrigated and not-irrigated vines in terms of sugar content, pH and potassium (Tab.1). The irrigated vines show lower values for all the components of the acidity and the Yeast Assimilable Nitrogen (*YAN*). The yield of the irrigated vine, W_g= 12.99 kg is 29% higher than the yield of the not-irrigated one, with a higher weight of the dry biomass (W_b= 1.98 kg, +17%) with respect to the not-irrigated vine. For the irrigated vine the I_{rav} resulted 6.5 while for the not-irrigated vine it was equal to 5.7; in both irrigation regimes values were in the range of an optimal productive-vegetative balance (Howell, 2001). However, with only one replication for the experimental treatment (irrigated vs. not-irrigated) these values should be taken with extreme caution.

Conclusions

In order to optimize the water resource, the soil-plant-atmosphere continuum should be considered in irrigation scheduling: coupling the microtensiometers embedded in the vines with the tensiometers in the soil greatly assists in this regard.

The preliminary results of this vegetative season show that the microtensiometer probes are a promising technology to continuously track Ψ_{stem} shedding new light on how both soil and plants rapidly react to water inputs and changes in the atmospheric conditions, with easier tasks to perform with respect to measurements taken with the pressure chamber (Deloire et al., 2020) and widening new perspectives on how to interpret the coupled measures of Ψ_{stem} and Ψ_{soil} (Williams and Araujo, 2002).

Tab.1 - Oenological characterization of the grapes in both irrigated and not irrigated musts. YAN stands for Yeast Assimilable Nitrogen.
Tab.1 - Risultati delle analisi enologiche dei mosti della vite irrigata e non-irrigata. YAN rappresenta l'azoto prontamente assimilabile (APA).

	Irrigated	**Not irrigated**
Sugar content	230.82 ± 12.61 $g\ l^{-1}$	240.44 ± 3.93 $g\ l^{-1}$
pH	3.22 ± 0.01	3.37 ± 0.15
Total acidity	8.11 ± 0.61 $g\ l^{-1}$	9.80 ± 1.53 $g\ l^{-1}$
Malic acid	3.28 ± 0.37 $g\ l^{-1}$	4.46 ± 0.10 $g\ l^{-1}$
Tartaric acid	6.08 ± 0.15 $g\ l^{-1}$	6.43 ± 0,37 $g\ l^{-1}$
YAN	115.67 ± 7.23 $mg\ l^{-1}$	188.33 ± 20.21 $mg\ l^{-1}$
K^+	2.15 ± 0.05 $g\ l^{-1}$	2.95 ± 0.17 $g\ l^{-1}$

The microtensiometer probes showed that both the irrigated and not-irrigated vine never reached values of Stem Water Potential associated to water stress levels (Deloire et al., 2020), being in water comfort for all the vegetative season despite the differences in irrigation water input.
In some cases, the tensiometers showed that the soil below the irrigated vine was steadily above the threshold of -33 kPa, an estimation of the field capacity (Nemes et al., 2011), even before being irrigated. For higher values of this pressure head, a gravity-driven flux of water could onset and water potentially could be lost through deep percolation if it infiltrates beyond the root zone and so, wasted.
Exploratory analyses show a lagged correlation between Ψ_{stem} and the meteorological variables, while the relation between $\Psi_{stem,irr.}$ and $\Psi_{stem,not\ irr.}$ seem to show a time-to-event behavior linked to a "stimulus" driven by VPD and R_S.
Oenological analysis of the harvested grapes show an increase of the total acidity and higher Yeast Assimilable Nitrogen for the vine that received less water during the vegetative season. A reduction of the yield has been observed for the not-irrigated vine (9.39 kg, -29%). However, the calculation of the Ravaz Indexes confirmed that both vines were in optimal productive-vegetative balance.

Although these preliminary results are not generalizable due to the lack of experimental replicates, we are considering expanding the experiment to include more vines to gather a more comprehensive vegetative and productive dataset by the end of the next growing season.

Acknowledgements

We extend our deepest gratitude to Danilo Caset who generously provided the grapevines for our experiment, adapting agricultural practices to accommodate our research needs. His contributions have been invaluable in constructing the tensiometers, executing the wiring and also helping us in installing the microtensiometers. His dedication to monitoring the development throughout the growing season and his insights into data interpretation have been pivotal to the success of our study.
We also thank Michael Santiago, Terrence Jones and Maryrose Lund of the Florapulse Co. staff for all their technical support.

References

Allen R.G. (Ed), 2000. Crop evapotranspiration: guidelines for computing crop water requirements, repr. Food and Agriculture Organization of the United Nations, Rome.
Bonan G.B., 2019. Climate change and terrestrial ecosystem modeling. Cambridge University Press, Cambridge, United Kingdom ; New York, NY.
Buckley T.N., 2019. How do stomata respond to water status? New Phytologist, 224 (1): 21–36.
Choné X., 2001. Stem Water Potential is a Sensitive Indicator of Grapevine Water Status. Annals Of Botany, 87 (4): 477–83.
Deloire A., Pellegrino A., Rogiers S., 2020. A few words on grapevine leaf water potential. IVES Technical Reviews, Vine And Wine,
Gambetta G.A., 2016. Water Stress and Grape Physiology in the Context of Global Climate Change. Journal Of Wine Economics, 11 (1): 168–80.
Howell G.S., 2001. Sustainable Grape Productivity and the Growth-Yield Relationship: A Review. American Journal Of Enology And Viticulture, 52 (3): 165–74.
Lakso A.N., Santiago M., Stroock A.D., 2022. Monitoring Stem Water Potential with an Embedded Microtensiometer to Inform Irrigation Scheduling in Fruit

Crops. Horticulturae, 8 (12): 1207–22.
Levin A.D., 2019. Re-evaluating pressure chamber methods of water status determination in field-grown grapevine (Vitis spp.). Agricultural Water Management, 221: 422–9.
Mirás-Avalos J., Araujo E., 2021. Optimization of Vineyard Water Management: Challenges, Strategies, and Perspectives. Water, 13 (6): 746–78.
Monteith J.L., Unsworth M.H., 2008. Principles of environmental physics, 3rd ed. Elsevier, Amsterdam Paris.
Nemes A., Pachepsky Y.A., Timlin D.J., 2011. Toward Improving Global Estimates of Field Soil Water Capacity. Soil Science Society Of America Journal, 75 (3): 807–12.
Ravaz L., Sicard L., 1903. Sur la brunissure de la vigne. Les Comptes Rendus De L'Academie Des Sciences, 136: 1276–8.
Thalheimer M., 2013. A low-cost electronic tensiometer system for continuous monitoring of soil water potential. Journal Of Agricultural Engineering, 44 (3): 114–9.
Tombesi S., Poni S., Palliotti A., 2016. Stress idrico in Vitis vinifera: variabilità delle risposte fisiologiche intraspecifiche e loro potenziale sfruttamento nella mitigazione degli effetti dei cambiamenti climatici. Italus Hortus, 23 (1): 45–53.
Trewartha G.T., Horn L.H., 1980. An introduction to climate, 5th ed. McGraw-Hill, New York.
Van Leeuwen C., Trégoat O., Choné X., Bois B., Pernet D., 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? OENO One, 43 (3): 121–34.
Williams L.E., Araujo F.J., 2002. Correlations among Predawn Leaf, Midday Leaf, and Midday Stem Water Potential and their Correlations with other Measures of Soil and Plant Water Status in Vitis vinifera. Journal Of The American Society For Horticultural Science, 127 (3): 448–54.