Smartphone as a tool for deficit irrigation management in *Vitis vinifera*

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Introduction

Vine water status is one of the most influential factors in grape vigor, yield, and quality (Ojeda et al., 2002; Guilpart et al., 2014). Severe water deficits during the first stage of crop development (bud break to fruit set) impact yield in the current year and the following year. While during grape ripening, water availability impacts berry size, grape composition, and health status. Therefore, a correct assessment of plant water status allows for proper water management with an impact on grape yield and composition (McClymont et al, 2012; Pereyra et al., 2022). Although there are direct or indirect techniques to assess the water status of a plot/plant, the reference technique remains foliar water potential (Carbonneau 1998). An alternative approach is to determine water status through the observation or evaluation of auxiliary variables related to water availability, such as the observation of growth apices. At this point, digital agriculture allows greater monitoring and predictability of crops, contributing to greater environmental sustainability. These digital tools become more necessary to adapt strategies to mitigate the effects of the climate change that is occurring and that intensely impacts grapevine cultivation (Venios et al., 2020). The climate outlook (2010-2070) for Uruguay and the region indicates an increase in rainfall (spring-summer) with longer periods of water deficits or excesses. In addition, they predict an increase of between 1.5 and 3.0ºC in the average temperature (PNA-AGRO, 2019) with a more significant number of heat waves. Heat waves are defined as more than three consecutive days with a maximum temperature higher than three times the standard deviation of the historical average expected for that date (PNA-AGRO, 2019). The evaluation of the growth apex or the determination of leaf area are input to characterize the water status within a vineyard during a given growth period and to adjust the water dosage to be applied.

Research Objectives

This study evaluated the productive response (yield and composition) to regulated deficit irrigation determined through the use of mobile applications installed on a smartphone. Two mobile applications were evaluated to determine when to irrigate and how much to irrigate easily. The use of mobile applications was corroborated with traditional determinations of water potential and vegetative growth.

Material and methods

Experimental site

The experiment was conducted in a 1.1 ha commercial vineyard located in Canelones, Uruguay (34°36'S,56°14W), during three consecutive seasons (2019-2020-2021). The vineyard was planted in 1998 with Vitis vinifera L. cv. Tannat, grafted on SO4 rootstock. The distance between vines was 2.5 m × 1.2 m (3333 vines ha-1). The vines were pruned with a double guyot system and the shoots were trained with a VSP (vertical shoot positioning) system. A high variability of yield and berry composition characterized the vineyard. Crop vigor was assessed at veraison using the Normalized Difference Vegetation Index (NDVI), calculated using aerial images, as described in Ferrer et al., 2020, defining three vigor zones, high (HV), medium (MV) and low vigor (LV). NDVI classes (high, medium and low) were systematically located in the same parts of the vineyard each year (Ferrer et al., 2020).

Treatments

Treatments were performed only in the low vigor zone to improve productive response and berry quality. Therefore, in the pre-established LV zone, treatments were arranged in a randomized block design with three replicates and 21 vines per replicate. A control treatment (C), without irrigation, was established. And a treatment with supplemental irrigation (I) followed the following criteria: 100% of the climatic demand (ETo) from bud break to flowering and 70% of the ETo from flowering to harvest.

Meteorological characterization

Meteorological characterization was carried out using a weather station owned by INIA (Instituto Nacional de Investigación Agraria; 34°40'S, 56°20'W; 10 km from the experimental site) and following World Meteorological Organization (WMO) standards. The following variables were evaluated: mean air temperature (Tm, °C), Penman-Monteithevapotranspiration evapotranspiration (ETo, mm), relative air humidity (RH, %) and rainfall (mm).

Irrigation adjustment

Predawn water potential (Ψp) was determined using a pressure chamber. Nine leaves were taken from each treatment. In addition, growth apices were observed using the smartphone application ApeX-Vigne (Brunel et al., 2019). For each replicate, 50 apices were evaluated on the 21 selected plants. Each apex was classified into three categories, full growth (FG); moderate growth (MG) and stopped growth (SG). Observations were made at key phenological moments for each treatment: flowering, fruit set, veraison and ripening. In 2019 and 2020, water potential determination and apex observation were carried out simultaneously, while in 2021 only water status was evaluated by apex observation.

The ETo adjustment using the Kc of the crop was used to determine the irrigation dose. Crop Kc was estimated using the equation proposed by Williams and Ayars (2005) that relates Kc to leaf area index (LAI). LAI was determined with the VitiCanopy application (De Bei et al., 2016). Six plants per replicate were evaluated and images were obtained using the front camera of a smatphone from under the plant at a distance of 80 cm between the plant and the device.

Plant measurement

Yield (Y, kg/vine), number of bunches (B/vine) and individual bunch weight (WB) were evaluated at harvest on the 21 plants per replicate. Individual berry weight at harvest was determined on 100 berries per replicate samples.

At harvest, two samples of 100 berries were taken from the central zone of the bunch (Deloire et al., 2019) for each treatment. The following were determined: total soluble solids (TSS) by refractometer (Atago, Japan); pH by pHmeter (Hanna Instruments, Italy); acidity by titration (gH2SO4/L) and total anthocyanins (A, mg/l) according to the methodology proposed by Glories and Agustin (1993) as modified by González-Neves et al. (2004). Measurements were duplicated with a spectrophotometer (Shimadzu UV-1240 Mini, Japan) using glass cuvettes (absorbance at 520 nm).

A Shimadzu HPLC with a diode array detector (DAD) and refractive index detector (RID) was used to determine organic acids, sugars and anthocyanins. The compounds were identified considering the retention time and their UV spectra. The quantification of each compound was carried out by means of the calibration curve using the corresponding standards.

Results

Climatic characteristics of the year

The three growing seasons differ in water availability. 2019 was a wet year (885 mm), 2020 a dry year (484 mm) and 2021 an intermediate year (539 mm). The years also differed in reference to evapotranspiration (ETo). The climatic water balance (cumulative rainfall - ETo) during the growing season was positive in 2019 (79 mm) and negative in 2020 (-419 mm) and 2021 (-300 mm).

Plant water status

The evolution of plant water status showed differences between years (Figure 1). In 2019 the Ψp was higher (> -0.46 MPa) compared to 2020 (> -0.85 MPa). In 2019, Ψp dynamics were similar for treatments C and I (absent to moderate at harvest). Whereas, in 2020, treatment C reached minimum Ψp values at harvest of -0.85 MPa while the irrigated treatment (I) allowed maintaining Ψp values above -0.35 MPa (moderate stress throughout the season). The interpretation of the growth apex observation results allowed generating 4 categories of water stress: 0- Absence of stress, 1- Moderate stress, 2- Severe stress and 3- Forte stress. For the two years evaluated (2019 and 2020), there is an almost exact similarity in the stress category provided by water potential and ApeX-Vigne. The results from both the water potential and apex observation indicate that for 2019 that no irrigation was required. In 2020 there were 24 irrigations and 135 mm were applied. While in 2021 it was 108 mm in 20 irrigations.

Plant response to water availability

The treatment with irrigation (I), increased leaf area in 2020 and 2021. And the Kc of the crop evolved from budbreak to veraison and then remained relatively constant. Yield per plant was higher in 2019 and 2020 compared to 2021 in the control situation. The treatment with irrigation allowed an increase in yield per vine (+80%) compared to the control (C) thanks to the greater weight of the bunch and the individual berries. In addition, berry weight was 40% higher in the treatment with supplemental irrigation.

Regarding primary metabolism, treatment I allowed a higher sugar concentration and pH compared to the control. An increase in glucose and fructose gave the increase in sugar concentration. Although total acidity did not show significant differences, there were differences in the concentration of each type of acid, with malic acid being the most concentrated in the berry of the irrigated plants. Treatment I had the highest anthocyanins in 2020 and 2021 compared to the control, with a higher percentage of glycosylated anthocyanins.

Conclusion

Irrigation monitoring was made possible through the use of mobile applications installed on a smartphone in a simple and fast way. These tools allow continuous and georeferenced monitoring of vegetative growth and water status, which provides growers with validated information for decision making. Supplemental irrigation (based on the use of apps) was decisive in obtaining higher yields with improved grape quality due to changes in the malic/tartaric ratio and a higher percentage of glycosylated anthocyanins.

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Tables and Figures

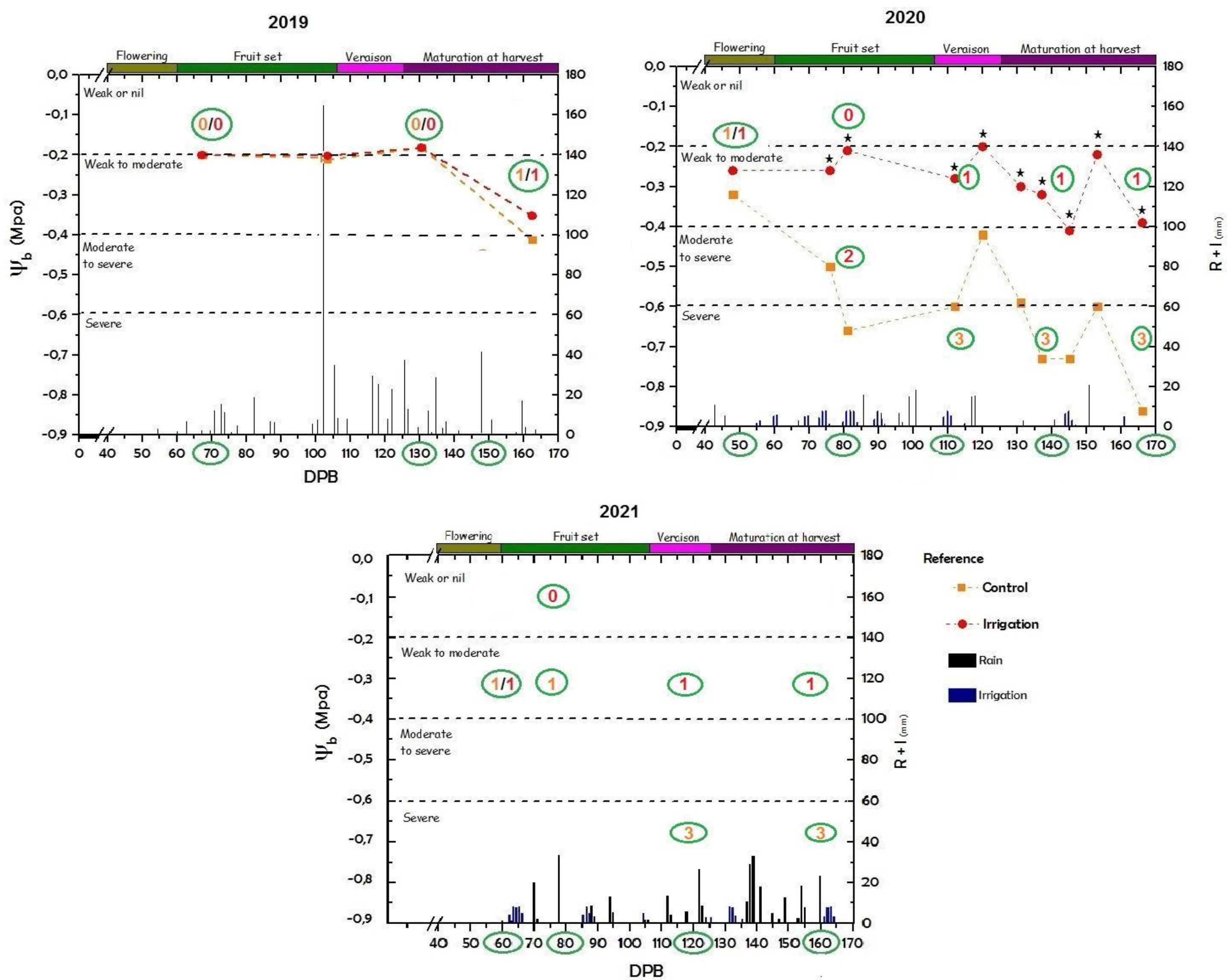
2019
2020
2021
Flowering
Fruit set
Veraison
Maturation at harvest
Weak or nil
Weak to moderate
Moderate to severe
Severe
Ψ_b (Mpa)
R + I (mm)
DPB
Reference
Control
Irrigation
Rain
Irrigation

Figure 1: Evolution of plant water status for the three seasons (2019-2021).
Dotted lines indicate the monitoring of water status by determining the baseline leaf potential. Orange squares indicate the control treatment. Red circles indicate irrigation treatment. Green circles indicate plant water status according to ApeX-Vigne. ApeX-Vigne water status categories: 0-Absent; 1-Moderate; 2-Strong and 3-Severe. The colors of the numbers in the green circle indicate treatment (orange: control; red: irrigation). DPB: Days post-brotacion. Columns on the X-axis indicate the volume of water applied in mm, black columns indicate precipitation (mm) and blue columns indicate irrigation.

Table. Average values of berry compositional traits according to treatments

Treatments	Soluble solids	Glucose	Fructose	Total acidity	Malic	Tartaric	Anthocyanins	Glycosylated	Acetylated	Cinnamylated
	g/l	mg/berry	mg/berry	g L-1 sulfuric	g/berry	g/berry	mg/l	%	%	%
2019										
Control	200	111.9	123.7	4.2	10.6	8.9	2110	45	27	26
Irrigation	209	n.d.	n.d.	4.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2020										
Control	203 *	93.3*	100.3*	4.5	3.3*	5.1	1692 *	44*	27	29
Irrigation	223 *	168.7*	150.5*	4.4	6.7*	5.3	2425 *	47*	26	27
2021										
Control	197*	177.5*	138.5*	4.1	6.8*	6.8	1694*	44*	27	25
Irrigation	212*	190.6*	167.7*	4.3	8.5*	7.5	2110*	48*	27	26

* Asterisks indicate significant differences according to the Fisher test (p-value< 0.05). n.d. No data available