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Sap flow technique as a tool for irrigation schedule in grapevines: Control of the plant physiological status

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SUMMARY – The main goal of our research has been to obtain precise parameters based on sap flow techniques that allow to maintain grapevine water status under a sustained moderate water stress. Based on previous work of our group, we have used stomatal conductance (g_s) as a parameter that indicates the physiological status of the plant (Flexas and Medrano, 2002). A good correlation between stomatal conductance and the slope of the afternoon sap flow decline has been determined. This Sap Flow Afternoon Decline (SFAD) has been used to determine the irrigation schedule of grapevines (*Vitis vinifera* L. cv Tempranillo) based only on sap flow measurements but considering the physiological status of the plant. We propose that SFAD can be easily computerized and applied to grapevine irrigation.

Key words: sap flow, grapevine, water stress, stomatal conductance, irrigation.

Introduction

Grapevines (*Vitis vinifera* L.) have traditionally been cultivated without watering. Irrigation is becoming a frequent practice and a higher efficiency of water use by crops is necessary due to the scarcity of water in most grapevine lands and the important effects of water availability in crop yield and quality parameters.

There are several methods to estimate the water status of the plant. Among them, net photosynthesis (A_N) and specially stomatal conductance (g_s) have previously been shown to be very sensitive (Flexas and Medrano, 2002). From stomatal conductance measurements, three levels of physiological water status have been described which have a direct effect on photosynthesis.

Sap flow measurements have generally been used for determination of leaf morphology, plant's water consumption and for programming irrigation schedule (Lascano *et al.,* 1992; Eastham and Gray, 1998; Ginestar *et al.,* 1998; Braun and Schmid, 1999; Caló *et al.,* 1999), although none of them bases its determinations on the physiological status of the plant.

The main goal of this research was to find a parameter based on sap flow measurements that would allow the determination of the water status of the plant and generate an irrigation schedule according to it.

Material and methods

Six year old grapevines (*Vitis vinifera* L. cv Tempranillo) were grown in 60 l pots in organic material and perlite. Twelve plants were separated in three rows of 4 plants. Plants were irrigated at field capacity until the onset of the experiment. Plants were covered with a thermal blanket in order to avoid pot overheating and water evaporation.

Plants were watered by drop irrigation using a controlled program (Hunter EC 401i-E).

Photosynthesis and stomatal conductance were performed in six leaves per treatment at mid-morning with a LI-6400 open gas exchange system (LI-COR, Lincoln, Nebraska, USA) at 1500 μmol photons m^2/s of PAR light, a CO_2 concentration of 400 μmol/mol at ambient temperature.

Sap flow measurements were performed using the method described by Cermak *et al.* (2004): "The trunk heat balance method" (THB) (EMS, Brno). Sap flow was measured in three plants per treatment. The "Sap Flow Afternoon Decline" (SFAD) was measured with the sap flow measured between 15:30 and 19:00 (solar time). Sap flow measurements were measured every minute and integrated every 10 minutes. For SFAD calculation purposes, only full sunny days were taken.

Two experiments were performed in different years. The first experiment consisted of an evaluation of any possible correlation between stomatal conductance and sap flow parameters. Different water treatments were applied to each row of plants (100%, 50% and 30% ETP) and gas exchange and sap flow measurements were performed from July 11th to August 16th.

The second experiment performed in 2007, consisted in scheduling irrigation based on SFAD values, analyzing stomatal conductance as well as total water consumption. When SFAD values were below the threshold, irrigation to field capacity were applied.

Results

The slope of the sap flow afternoon decline (SFAD) showed the highest correlation with stomatal conductance (g_s) measured at mid-morning (Fig. 1), which is an indicator of the plant's water status (Flexas and Medrano, 2002). The SFAD was obtained from the sap flow day cycle. The afternoon slope was measured from 15:30 and 19:00 (solar time). Slopes with a $r^2 < 0.90$ were discarded as they mostly indicated cloudy or stormy afternoons. In grapevines, Flexas and Medrano (2002) described a critical level of water stress where water use efficiency was maximum and stress was still fully reversible. This level of moderate water stress was found at stomatal conductance between 0.05 and 0.1 mol H_2O m^2/s. As it can be observed in Fig. 1, this value of stomatal conductance was reached when the afternoon slope decline was between 0.2 and 0.3. Figure 1 shows a significant correlation between stomatal conductance (g_s), measured at mid-morning, and the slope of the sap flow afternoon decline (SFAD). These results were then used to plan a second experiment in which SFAD would be used as a signal for irrigation.

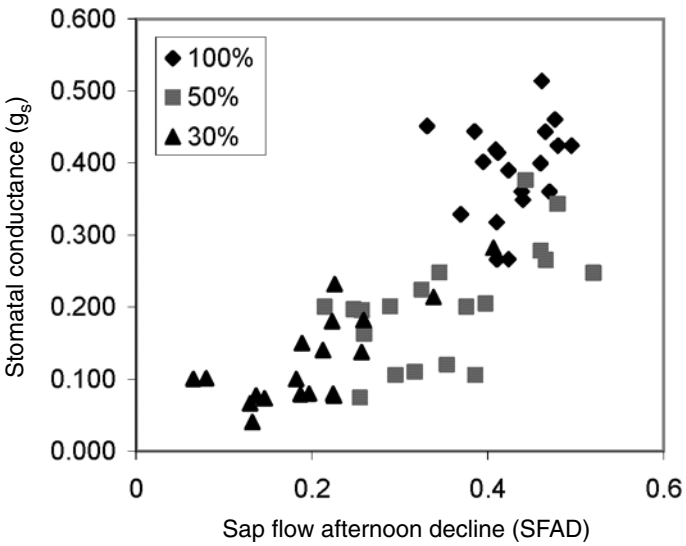

Fig. 1. Relationship between stomatal conductance and the afternoon slope decline (SFAD) of sapflow in grapevines under three different irrigation regimes (100% ETP: diamons; 50% ETP: squares; and 30% ETP: triangles).

The second experiment was developed in the same plants in a the following year. Based on the results of the first year, two treatments were developed. Full irrigated plants were watered daily to field capacity, while "control irrigation" were only irrigated when their SFAD value decreased below the threshold value of 0.25 (Fig. 2, top). As it can be observed in Fig. 2 bottom, SFAD values were in the range of 0.4 to 0.5 in full irrigated plants, corresponding perfectly with the 100% ETP irrigation from

the first experiment (Fig. 1). Plants under controlled irrigation presented a decrease in SFAD from 0.4 to values below 0.2 when irrigation was stopped (Fig. 2 bottom). When SFAD values decrease below 0.25, irrigation was triggered to field capacity. Under irrigation, SFAD values returned to values similar to fully irrigated plants.

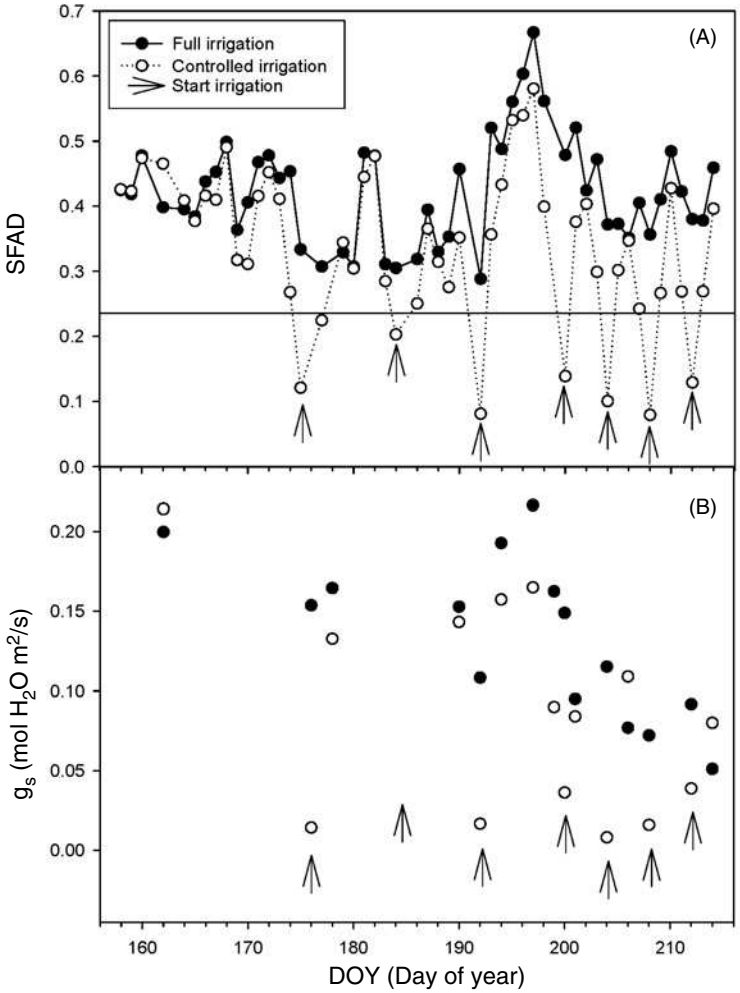

Fig. 2. A: Time-course of the irrigation schedule based on the value of SFAD, (top). Arrows indicate irrigation at field capacity. B: Time-course of stomatal conductance of grapevines. Fully irrigated (close symbols), Controlled irrigation (open symbols).

This "controlled irrigation" schedule was able to maintain stomatal conductance within the desired level of maximum water use efficiency as well as in the reversible control zone. Figure 2 bottom shows that under "controlled irrigation" stomatal conductance decreases to values near the threshold level described by Flexas and Medrano (2002) and that after irrigation stomatal conductance returned to values similar to those of fully irrigated plants, indicating that the effect was totally reversible. Moreover, under field conditions, it can be expected that the range of variations could be reduced due to the highest volume of the soil explored. Therefore, it can be concluded that SFAD could be used as a good indicator for irrigation scheduling.

Figure 3 shows the total water consumption during the experiment in the two treatments. Total water consumption of fully irrigated plants was 1320 l, while in controlled irrigation total water consumption was 1030 l. This represented a savings of water of 22%. It is important underlined that the goal of this experiment was to precisely set the irrigation timing more than total water saving. The total amount of water saved could even increase with an adequate irrigation program and also under field conditions.

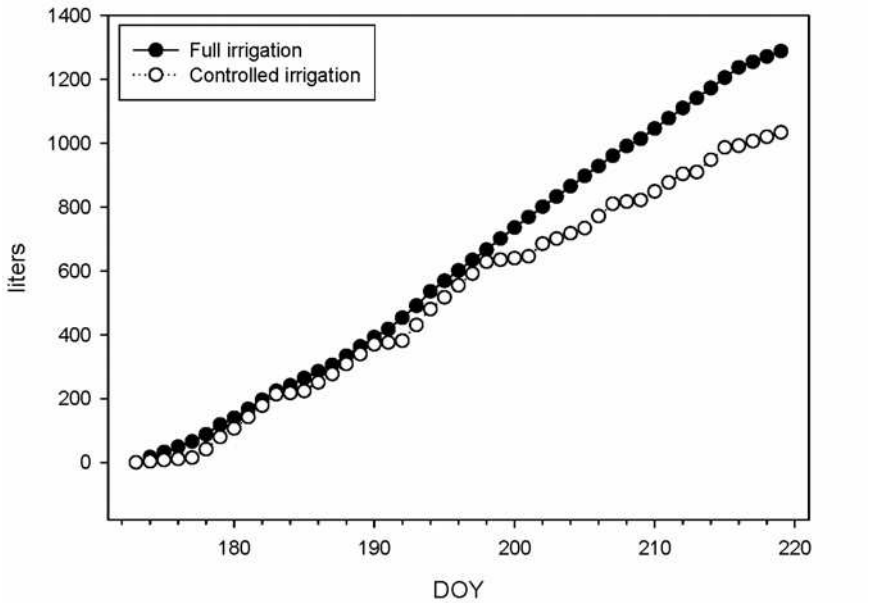

Fig. 3. Total water consumption in "Full Irrigation" schedule (closed symbols) and using the irrigation schedule based on SFAD described in Figure 2 (open symbols).

Conclusions

From these experiments it can be concluded that the Sap Flow Afternoon Decline (SFAD) measured as the slope of the afternoon sap flow rate is a very good indicator of the plant water status in grapevines. SFAD correlates very well with stomatal conductance (g_s) measured at mid-morning and it can be successfully used for irrigation scheduling.

Aknowledgments

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