Use of a plant microtensiometer to improve water productivity in deficit-irrigated sweet cherry trees under Mediterranean climate conditions

A. Calderón-Orellana[1,a], A. Olivos[2], M. Calderón-Orellana[2], P. Puentes[1] and N. Hermosilla[1]

[1]Departamento de Producción Vegetal, Facultad de Agronomía, Universidad de Concepción, Chile; [2]Olivos Innova, Olivos Riego SPA, Chile.

Abstract

Regulated deficit irrigation (RDI) is a sustainable practice that improves water use efficiency in fruit orchards. Although several studies have found consistent and positive effects of this practice, RDI requires frequent measurement of plant water stress (i.e., stem water potential). The pressure chamber (PC) has been the most reliable device for measuring stem water potential (SWP) for decades. However, the PC requires a well-trained operator and cannot provide continuous measurements of SWP. Recently, a plant microtensiometer (MT) has been successfully introduced in horticulture to estimate SWP continuously in several woody plants. Nevertheless, there is little information on the application of this device to manage RDI in commercial fruit orchards. A study was conducted in a commercial sweet cherry orchard for two consecutive years to determine stem water potential (SWP) thresholds for improving water productivity in deficit-irrigated plants using a plant microtensiometer (MT). MT SWP estimates are strongly correlated with PC SWP measurements (R^2=0.81, p-value<0.05) for a SWP range between -1.8 and -0.4 MPa. Moderate and severe RDI-induced reductions in stomatal conductance and Fv/Fm were observed, but these changes did not affect parameters indicative of early defoliation, such as intercepted solar radiation, leaf area index, and normalized difference vegetation index. Leaf stomatal conductance decreased by 50% when SWP estimates were close to -1.3 MPa, validating this SWP threshold as a physiological limit for moderate RDI. However, the most severe RDI was the only treatment that improved water productivity compared to the wet control (30%). These results confirm that the MT is a reliable tool for monitoring SWP in water-conserving irrigation practices aimed at improving water productivity.

Keywords: Regulated deficitirrigation (RDI), plant water stress, stem water potential (SWP), Leaf stomatalconductance, water-conserving irrigation practices

INTRODUCTION

Stem water potential readings are crucial for determining the optimal time to irrigate vegetable crops and defining an effective irrigation strategy (McCutchan and Shackel, 1992). For example, suppose the irrigation strategy is to keep plants free of water stress. In that case, irrigation should be applied when the SWP average represents optimum well-watered conditions for that particular fruit crop.

Regulated deficit irrigation (RDI) is a sustainable practice that improves water use efficiency in fruit orchards. If RDI is the chosen irrigation strategy, a period under water stress will be inevitable and even desirable if the goal is to improve the water productivity of the orchard. In any scenario, plants should not experience severe water stress during critical phenological stages to maintain high yields and optimal fruit quality.

In cherry trees (*Prunus avium* L.), SWP values close to -1.4 MPa have been associated with a decrease of more than 50% in stomatal conductance, limiting the gas exchange capacity of plants. However, the relationship between water stress and stomatal conductance varies

[a]E-mail: arcalderon@udec.cl

for different cultivars or rootstocks. ‘Santina’ is one of the most popular cultivars in Chile due to its early harvest, which enables it to achieve the best prices in international markets. In cherry trees, the application of RDI before harvest is not recommended for commercial orchards, as this is the period of the two most sensitive phenological stages to water stress. The maximum relative growth rate of the fruit (growth potential of each fruit) occurs in the fruit set phenological stage. If water stress is too severe, the fruit size will drop due to reduced cell division and elongation (Blanco et al., 2020). The phenological stage of flower induction occurs at the onset of veraison when fruit begins to synthesize the pigments responsible for the color change of the skin. This phenological stage is the second most sensitive to water stress, as prolonged severe water stress can alter the adequate transition from leaf to flower primordia and strongly reduce the fruit number for the following season. In addition, the drastic recovery of the orchard’s water status (due to rain or abundant irrigation) from a state of low soil moisture to saturation can induce high rates of fruit cracking, reducing the productivity of the plants (Correia et al., 2018).

The successful application of RDI under field conditions requires frequent measurement of plant water stress (i.e., stem water potential). The pressure chamber (PC) is one of the most accurate devices to measure midday stem water potential under field conditions. However, the PC has two relevant shortcomings: 1) it is a bulky device to carry and manipulate during the hottest hours of the day, and 2) the measurement procedure must be carried out by a well-trained person, hopefully with a high level of knowledge and experience. These factors have limited the use of PCs to estimate plant water status in fruit orchards, as fruit growers are more enthusiastic about automated and telemetric technologies. The microtensiometer (MT) is a sensor chip based on microelectromechanical systems (MEMS) that accurately measures SWP and allows continuous online monitoring of plant water status (Lakso et al., 2022). The accuracy and precision of the MT have been tested on field-grown apples, grapes, and almonds. However, the optimum performance of the MT depends on the quality of the installation and insulation methods, as each fruit species appears to exhibit different responses to the embedded MT sensor. Therefore, the ability to accurately monitor plant water stress in fruit trees and achieve good long-term results with the MT requires validation of this technology in more fruit crops and irrigation practices. A study was conducted in a commercial sweet cherry orchard for two consecutive years to determine SWP thresholds for improving water productivity in deficit-irrigated plants after harvest using a plant microtensiometer.

MATERIALS AND METHODS

A field experiment was conducted in a drip-irrigated cherry (*Prunus avium* L.) orchard, ‘Santina’, grafted on Colt, for two consecutive seasons, 2021-2022 and 2022-2023. The study site was located in Placilla (34°69’0.9”S 71°03’47.2”W), Libertador General Bernardo O’Higgins region, Chile. The orchard was conventionally managed, trained using the steep leader system with a density of 925 plants per hectare (plant spacing: 4.5×2.4 m). Three irrigation treatments were applied in the orchard from harvest to four weeks before the onset of leaf senescence (1st week of December to mid-April). The control treatment (WET) was irrigated to avoid water stress throughout the season, trying to maintain midday values of stem water potential (SWP) between -1.0 and -0.5 MPa. Two regulated irrigation treatments were applied: The moderate RDI treatment aimed to keep SWP values between -1.2 and -0.5 MPa. The severe RDI tried to maintain SWP values between -1.5 and -0.5 MPa. RDI was applied by completely cutting off irrigation after harvest. An irrigation event was applied to RDI plants when the SWP was lower than the SWP targets.

The experiment was arranged as a completely randomized block design with four replications. The experimental unit consisted of 12 plants distributed in three adjacent rows. Measurements of plant physiological responses to water deficit included midday stem water potential, stomatal conductance, PSII quantum yield (Fv/Fm), and intercepted photosynthetic photon flux density (PPFD). Yield estimates and fruit quality were determined at harvest, characterizing key quality parameters for the fresh and dry fruit markets (soluble solids concentration, skin color, and fruit weight).

RESULTS AND DISCUSSION

Deficit irrigation treatments caused no differences in intercepted photosynthetically active solar radiation (intercepted PPFD) (between 400 and 700 nm) for two consecutive seasons. Measured values of IPPFD were close to 90% from fruit set to the onset of leaf senescence (October to May) (Figure 1). These results suggest that the application of both moderate and severe postharvest water stress for two consecutive years may have no impact on the vegetative growth of plants during the current and the following seasons. However, this does not mean that RDI applied after harvest has no effect on plant size, as Blanco et al. (2019) reported a considerable reduction in pruning weights after severe water stress (SWP <-1.5 MPa).

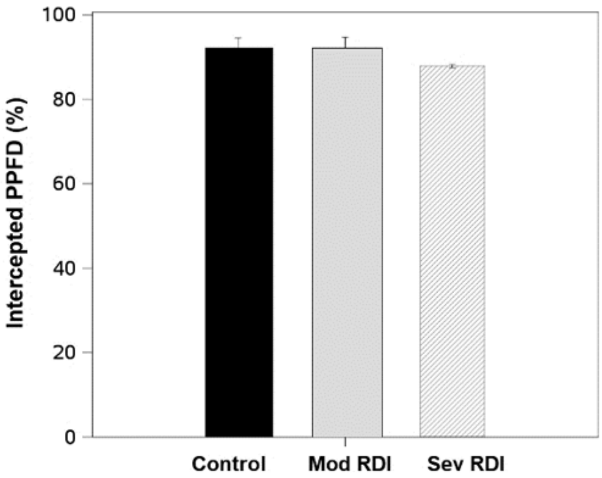

Figure 1. Intercepted PPFD at midday (12:00-15:30 h) in cherry plants (*Prunus avium* L.) subjected to different irrigation treatments (Control, moderate RDI, and severe RDI). n=4; error bars represent ±1 S.E.

During the 2022-2023 season, irrigation treatments maintained midday stem water potential (SWP) values close to -0.5 MPa between anthesis and harvest time (November). These SWP values represent cherry plants under optimum water conditions, with low atmospheric evaporative demand, characteristic of the spring months (November-December). Once RDI treatments were applied, significant differences in SWP were observed between irrigation treatments. In general, control plants exhibited SWP ±1.0 MPa, while plants subjected to moderate and severe RDI maintained SWP values between -1.3 and -1.0 MPa and between -1.6 and -1.0 MPa, respectively (Figure 2).

When analyzing water productivity (WP), which relates the yield obtained to the water provided by irrigation, the moderate RDI treatment maintained similar values to the control treatment. However, plants subjected to severe RDI showed a 9% higher WP than the control (Figure 3). These results agreed with those of Carrasco-Benavides et al. (2020), which showed that SWP values near -1.5 MPa after harvest had no impact on WP after two consecutive seasons. Nevertheless, the WP values found in the present study were lower than those reported by Blanco et al. (2021) for cherry trees 'Santina' grafted on 'Colt'. The discrepancy in WP values between the two studies is due to differences in the amount of irrigation water applied. In this study, the amount of irrigation water applied was equal to 100% ETc (7000 m^3 ha^{-1}), while in the abovementioned work, the amount of applied water was less than 3000 m^3 ha^{-1}.

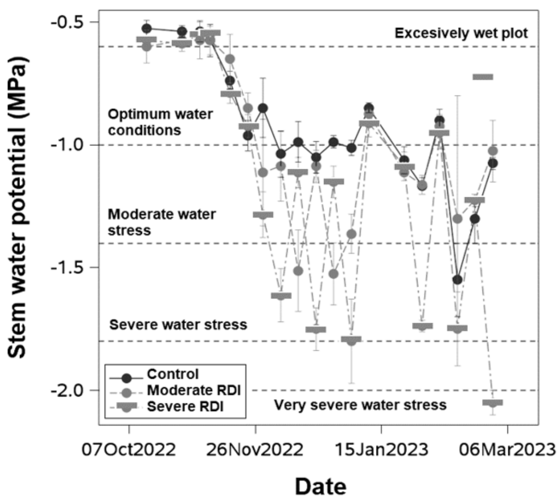

Figure 2. Stem water potential (SWP) at midday (12:00-15:30 h) in cherry plants (*Prunus avium* L.) subjected to different irrigation treatments (Control, moderate RDI, and severe RDI). *n*=4; error bars represent ±1 S.E.

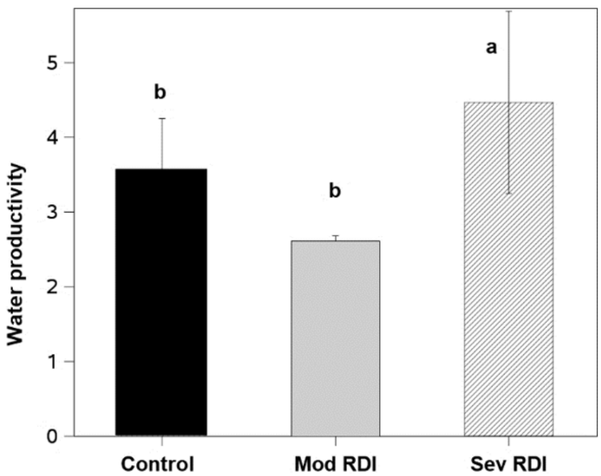

Figure 3. Water productivity in cherry plants (*Prunus avium* L.) subjected to different irrigation treatments (Control, moderate RDI, and severe RDI). *n*=4; error bars represent ±1 S.E. Different letters indicate significant differences at 95% confidence level (LSD).

Stomatal conductance (gs) of cherry trees responded rapidly to changes in plant water status. Midday values of gs decreased drastically by 50% when SWP reached -1.3 MPa. These results confirm that the SWP value of -1.3 MPa is the maximum physiological limit without adversely affecting photosynthetic processes (Figure 4A). Plants under moderate water deficits suffered a decrease of almost 25% in *Fv/Fm* (Figure 4B). Values of midday SWP <-1.3 MPa reduced the photosynthetic efficiency of PSII, which can be potentially harmful in cherry trees after a prolonged period under high amounts of solar radiation (PPFD >1500 mmol m^{-2} s^{-1}).

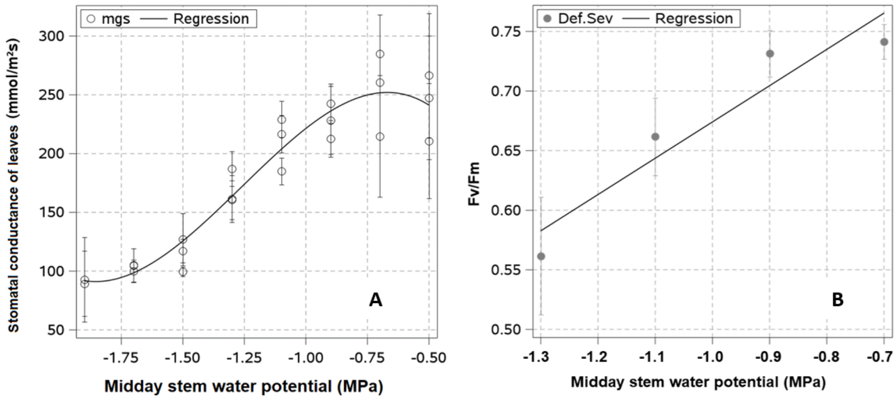

Figure 4. Relationship between mean values of stem water potential and stomatal conductance (A) and *Fv/Fm* (B) at midday (12:00-15:30 h) in cherry plants (*Prunus avium* L.) subjected to different irrigation treatments (Control and severe RDI). Error bars represent ±1 S.E. Each data point represents the average of 3 to 10 measurements.

The data obtained from continuous monitoring of plant water status using the microtensiometer (MT) showed a strong correlation with the SWP measurements obtained with the pressure chamber (CP). The regression analysis revealed a strong relationship between the two methods (R^2=0.81, y=0.78 + 0.099), using data from the most contrasting irrigation treatments (Figure 5). The determination coefficients in the second season were higher than those obtained in the previous season, resulting in an improvement in R^2 from 0.7 to 0.81. The better correlation detected in the second season was likely due to improvements in equipment installation, data reading, error filtering, and data processing. These results were similar to those reported by Conesa et al. (2023) for nectarine trees, where the coefficients of determination for the relationship of SWP readings between CP and MT were 0.86 for a wider range of water stress (between -2.0 and -0.7 MPa).

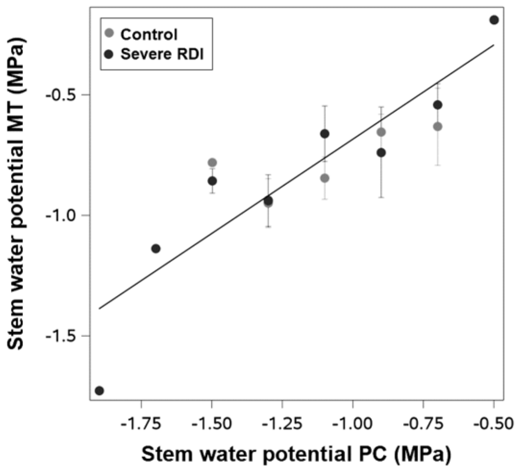

Figure 5. Relationship between mean values of midday stem water potential measured with the pressure chamber (PC) and the microtensiometer (MT) in cherry plants (*Prunus avium* L.) subjected to different irrigation treatments (Control and severe RDI). Error bars represent ±1 S.E. Each data point represents the average of 3 to 10 measurements.

The linear regression between stem water potential (SWP) and air vapor pressure deficit (VPD) shows a negative correlation between both parameters, indicating that plants under conventional irrigation (control) had SWP values between -1.3 and -0.5 MPa at midday and a VPD between 0.7 and 3.8 kPa (Figure 6). The water stress severity of well-irrigated plants increased as the season progressed due to higher water demand, reaching mild to moderate water stress levels for cherry trees (Blanco et al., 2019). From a practical perspective, SWP values of plants under efficient irrigation management should be between 0.1 and 0.2 MPa below the SWP baseline (i.e., more negative values). Therefore, the impact of the atmospheric evaporative demand on SWP readings must be considered when plant-based methods are used to determine irrigation frequency.

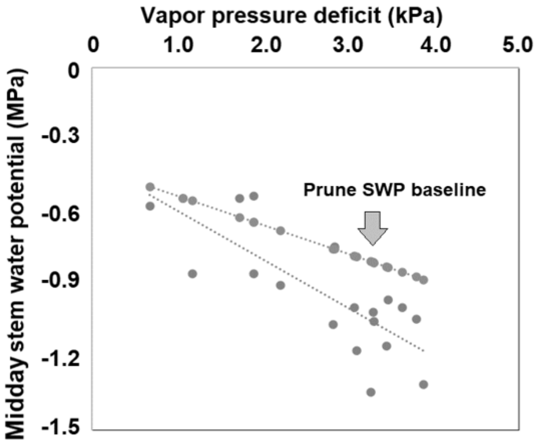

Figure 6. Relationship between air vapor pressure deficit and daily values of midday stem water potential measured with the pressure chamber (PC) in well-irrigated cherry plants (*Prunus avium* L.) Error bars represent ±1 S.E. Each data point represents the average of 3 to 10 measurements.

CONCLUSIONS

The MT provided continuous and accurate measurements of stem water potential that correlate strongly with pressure chamber measurements within the SWP range of -1.3 to -0.4 MPa. The accuracy of MT readings is essential for an effective application of moderate RDI. A moderate RDI resulted in a 50% reduction in leaf stomatal conductance, without affecting other early defoliation indicators. Water productivity values under moderate RDI were similar to those under the control treatment, indicating the feasibility of this practice in conserving water during the commercial production of cherries. These results validated the SWP threshold of -1.3 MPa as a physiological limit for moderate RDI during the postharvest period. The most severe RDI treatment improved water productivity compared to the control treatment, indicating that exposure of cherry trees to transient periods of severe water stress may be commercially tolerable for two consecutive years. This study confirms the reliability of MT as a tool for monitoring SWP and guiding water-saving irrigation practices aimed at improving water productivity in commercial orchards under Mediterranean climate conditions.

ACKNOWLEDGMENTS

We gratefully acknowledge the funding provided by the “FIA PYT-2021-0557: Desarrollo y determinación de la línea base de potencial hídrico del cultivo del cerezo, con uso de microtensiometro y riego deficitario controlado para desarrollar un nuevo y más eficiente servicio de monitoreo y programacion de riego”, Olivos Riego SPA, and Giddings Cerasus S.A

Literature cited

Blanco, V., Torres-Sánchez, R., Blaya-Ros, P.J., Pérez-Pastor, A., and Domingo, R. (2019). Vegetative and reproductive response of 'Prime Giant' sweet cherry trees to regulated deficit irrigation. Sci. Hortic. (Amsterdam) *249*, 478–489 https://doi.org/10.1016/j.scienta.2019.02.016.

Blanco, V., Blaya-Ros, P.J., Torres-Sánchez, R., and Domingo, R. (2020). Influence of regulated deficit irrigation and environmental conditions on reproductive response of sweet cherry trees. Plants *9* (*1*), 94 https://doi.org/10.3390/plants9010094. PubMed

Blanco, V., Zoffoli, J.P., and Ayala, M. (2021). Eco-physiological response, water productivity, and fruit quality of sweet cherry trees under high tunnels. Sci. Hortic. (Amsterdam) *286*, 110180 https://doi.org/10.1016/j.scienta.2021.110180.

Carrasco-Benavides, M., Espinoza Meza, S., Olguín-Cáceres, J., Muñoz-Concha, D., von Bennewitz, E., Ávila-Sánchez, C., and Ortega-Farías, S. (2020). Effects of regulated post-harvest irrigation strategies on yield, fruit quality, and water productivity in a drip-irrigated cherry orchard. N. Z. J. Crop Hortic. Sci. *48* (*2*), 97–116 https://doi.org/10.1080/01140671.2020.1721544.

Conesa, M.R., Conejero, W., Vera, J., and Ruiz-Sánchez, M.C. (2023). Assessment of trunk microtensiometer as a novel biosensor to continuously monitor plant water status in nectarine trees. Front. Plant Sci. *14*, 1123045 https://doi.org/10.3389/fpls.2023.1123045. PubMed

Correia, S., Schouten, R., Silva, A.P., and Gonçalves, B. (2018). Sweet cherry fruit cracking mechanisms and prevention strategies: A review. Sci. Hortic. (Amsterdam) *240*, 369–377 https://doi.org/10.1016/j.scienta.2018.06.042.

Lakso, A.N., Zhu, S., Santiago, M., Shackel, K., Volkov, V., and Stroock, A.D. (2022). A microtensiometer sensor to continuously monitor stem water potentials in woody plants, design and field testing. Acta Hortic. *1335*, 317–324 https://doi.org/10.17660/ActaHortic.2022.1335.39.

McCutchan, H., and Shackel, K.A. (1992). Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). J. Am. Soc. Hortic. Sci. *117* (*4*), 607–611 https://doi.org/10.21273/JASHS.117.4.607.