BIO Web of Conferences **235**, 02003 (2026) https://doi.org/10.1051/bioconf/202623502003
CONAVI 2024

A/Ci curves in response to water limitation in Glera cultivar: preliminary results

Monica Canton[1*], *Luca* Tezza[1], *Franco* Meggio[1,2] and *Andrea* Pitacco[1,2]

[1]Department of Agronomy, Food, Natural resources, Animals and Environment—DAFNAE, University of Padova, Agripolis, Viale dell'università 16, Legnaro, 35020 Padova, Italy

[2]Interdepartmental Research Centre for Viticulture and Enology—CIRVE, University of Padova, Via XXVIII Aprile 14, Conegliano, 31015 Treviso, Italy

Abstract. Photosynthetic CO_2 responses are studied to understand how photosynthesis adapts to changing environmental conditions and to predict plant carbon uptake under future climate scenarios. The aim of the present work was to gain understanding photosynthesis response to drought stress and plant water status in grapevines. The open field experiment focused on *Vitis vinifera* cv. 'Glera' and applied two treatments: irrigated and not irrigated. A/Ci curves were measured using a Li-6400XT portable photosynthesis system. Measurements were conducted at 30°C and 400 ppm CO_2, followed by 300, 200, 100, 50, 400, 600, and 800 ppm CO_2 under 1500 µmol m^2 s^{-1} of photosynthetic photon flux density (PPFD). The Farquhar, von Caemmerer, and Berry photosynthesis model ('FvCB model') was used to estimate the maximum carboxylation (V_{cmax}) and maximum electron transport (J_{max}) rates. Plant water status was assessed by stem and leaf water potential (Ψleaf, MPa). A parallel measure of leaf dark respiration was done at different temperatures. Despite regular precipitation during fruit growth, some differences in photosynthetic capacity highlighted variations between irrigated and not irrigated plants. For irrigated plants, A/Ci curves were grouped together compared to not irrigated ones and presented higher photosynthetic rates. Leaf water potential showed similarity between treatments, differing for some specific days but not causing excessive stress to the plants. Irrigated plants exhibited higher correlation between V_{cmax} and J_{max} rates. Leaf dark respiration increased linearly with rising temperatures. The study revealed the resilience of grapevines to challenging weather conditions and highlighted the positive impact of irrigation on physiological processes, photosynthesis, and water status.

Key words: Grapevine, *Vitis vinifera* L., Leaf gas exchange, Water deficit, A/Ci curve analysis.

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*Corresponding author: monica.canton@unipd.it

1 Introduction

The analysis of A/Ci curves, which depicts the net CO_2 assimilation rate (A_n) in relation to the calculated internal CO_2 concentrations (C_i), has emerged as a powerful tool for the analysis and interpretation of leaf photosynthesis across a broad spectrum of experimental conditions [1-2]. This response function, which describes the relationship between net CO_2 assimilation rate (A_n) and internal CO_2 concentrations (C_i), also serves as the foundational framework for numerous mechanistic plant physiology models [3]. The photosynthesis model proposed by Farquhar, von Caemmerer, and Berry [1], commonly referred to as the 'FvCB model', is widely used for the interpretation and modelling of leaf gas exchange of C_3 plants. It facilitates the derivation of consistent metrics for photosynthetic capacity and the prediction of photosynthetic responses to variations in the internal CO_2 concentration within the spongy mesophyll airspace [4]. The model considers the more constraining of two essential processes: Rubisco activity and electron transport. Empirical investigations aimed at determining the critical parameters for these processes, specifically the maximum rate of carboxylation (V_{cmax}) and the maximum electron transport rate (J_{max}), are imperative [5].

The effects of global warming are evident in viticulture everywhere [6]. The frequency and intensity of drought events are projected to rise in the near future due to reduced regional precipitation and heightened evapotranspiration resulting from global warming [7]. Water deficits will have a significant impact on different aspects of plant development, including vegetative growth, inflorescence development, berry set, and berry development. The extent of these effects depends on factors such as the phenological stage of the plant, the severity of the water deficit, and the duration of the water deficit [8]. Mild deficits may result in temporary stomatal limitations, but more severe ones will result in non-stomatal limitations, deeply affecting photosynthesis and productivity [9].

The aim of the present work was to gain insights photosynthesis responses to drought stress and plant water potential in Glera cultivar.

2 Materials and methods

2.1 Plant material and experimental conditions

Experiments were conducted in field conditions in summer 2023 from July to beginning of September on *Vitis vinifera* L. cv. Glera (clone 19) vines grafted onto Kober 5BB (K5BB) rootstock and VSP trained with Sylvoz pruning system. The vineyard was located in the Veneto region of Northern Italy (45°24' N, 11°33' E). Within this experimental setup, two treatment groups were established, consisting of 25 plants each: one group was kept at well-watered conditions (irrigated), while the other group was subjected to water stress conditions (not irrigated). For the irrigated treatment group, irrigation was applied using a drip system, with a weekly water supply of 12.5 mm.

The weather conditions such as temperature, relative humidity and precipitation were monitored by a weather station situated inside the field.

2.2 Gas exchange and leaf water potential

Gas exchanges were measured with an open-system apparatus (LI-COR-6400, LI-COR Inc., Lincoln, NE, USA) during fruit growth, from July to September. Measurements were conducted using a 6 cm^2 leaf cuvette. Before A/Ci curves measurements, leaves were dark-adapted for 20-min to measure the dark respiration rates (R_d). After that, leaves were subjected to at least 20-min of acclimation at a constant saturating photosynthetic photon flux density (PPFD) of 1500 μmol of photons m^{-2} s^{-1} before starting the measurements at CO_2 concentration at 400 μmol CO_2 mol^{-1} (followed by 300, 200, 100, 50, 400, 600, 800 μmol CO_2 mol^{-1}). Leaf temperature was maintained at 30 °C. Relative humidity (RH) was ranging between 50 and 70 % allowing ∼1.5 kPa of vapor pressure deficit (VPD) inside the chamber. Measurements were performed on fully expanded leaves, between 9.00 and 14.00 solar time. Additionally, leaf R_d was measured randomly on irrigated vines at different temperatures (20, 25, 30, 35 and 40 °C). V_{cmax}, J_{max} and the intercellular CO_2 concentration at which the transition from Rubisco to RuBP regeneration limitation occurs were calculated for the A/Ci curves by fitting the FvCB model using the 'Plantecophys' R package 'fitaci' function [4]. The leaf water potential (Ψ_{leaf}, MPa) was measured at pre-dawn and midday, as well as stem water potential (SWP) using a Scholander-type pressure chamber (model PMS-600, PMS Instruments, Corvallis, OR, USA). For SWP six randomly chosen sun-exposed, and fully expanded leaves per treatment, which had been enclosed in an opaque plastic bag for more than 1 h to prevent transpiration and allow them to reach equilibrium with the water potential in the stems, were measured from solar noon until the early afternoon. Each leaf was excised from the shoot with a scalpel blade and placed in the pressure chamber with the petiole protruding from the chamber lid. The chamber was pressurized using an air pressure tank, and SWP was recorded as soon as the xylem sap was observed emerging from the cut end of the petiole.

3 Results and discussion

3.1 Vine water status and gas exchange

During the summer of 2023, weather conditions were characterized by frequent precipitation events, which had a significant impact on the experiment (Fig. 1A). Despite this, significant differences were observed between irrigated and not irrigated (rainfed) plants. The irrigation started in the middle of June until the end of August. Minimum, maximum and mean temperatures were calculated from February to harvest (Fig. 1A). Figure 1B displays the changes in pre-dawn and midday Ψ_{leaf} as well as SWP. For pre-dawn and midday, there were no statistical differences among the two treatments. However, notably, differences in SWP became more pronounced, particularly in the middle of July. According to Choné [10] SWP is a better estimator of plant water status than Ψ_{leaf}. SWP differentiates better than Ψ_{leaf} due to the small variability between bagged leaves on different shoots of the same vine. Ψ_{leaf} is much more variable, depending on the local climate.

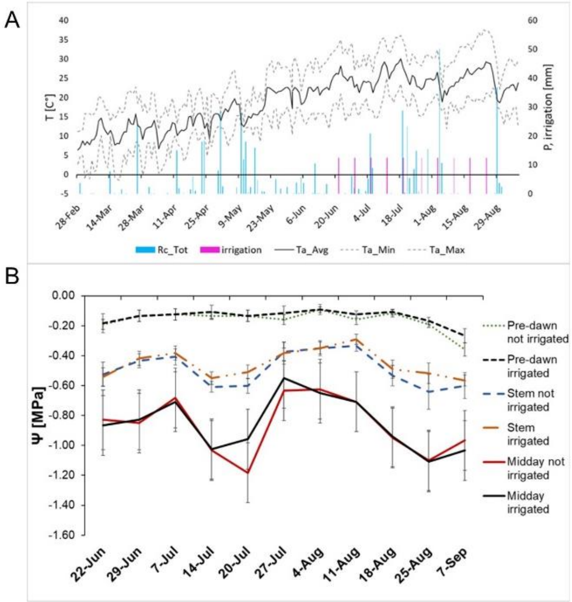

Fig. 1. Climate data presenting maximum (Ta_Max), median (Ta_Avg), and minimum (Ta_Min) temperatures, as well as precipitation and irrigation levels (A). Diurnal pre-dawn and midday leaf water potential (Ψ_{leaf}, MPa) and stem water potential (SWP) values from June to September (B).

CO_2 response curves were fitted with the FvCB model with R_d as an input (Fig. 2A). J_{max}, V_{cmax} and TPU (triose phosphate utilization) (when possible) were obtained from the fitting. Frequently, TPU is not a limitation at any C_i and so only two phases may be seen [11]. Irrigated vines presented higher photosynthetic rates compared to not irrigated ones (Fig. 2A) and shows that under well-watered conditions the photosynthesis is limited mainly by RuBP-regeneration. On the other hand, under water stress photosynthesis is limited by all three phases, such as Rubisco activity, the capacity for RuBP regeneration, and TPU limitation. A decrease in C_i below ambient will lower A_n rates and the pools of Calvin cycle intermediates, which can affect the activity of Rubisco and other enzymes. These changes may, in turn, alter in vivo Rubisco activity and the capacity for RuBP regeneration [11]. Irrigated plants exhibited higher correlation between V_{cmax} and J_{max} rates (Fig. 2B). Both parameters are vital for assessing the photosynthesis capability under varying conditions and environmental changes. Stomatal conductance (g_s) was lower in not-irrigated vines compared to irrigated ones and increased with the rise in C_i only on irrigated vines (Fig. 2C). In general, grapevine is considered a drought avoiding species, and it is capable of efficiently control g_s and transpiration rates [12].

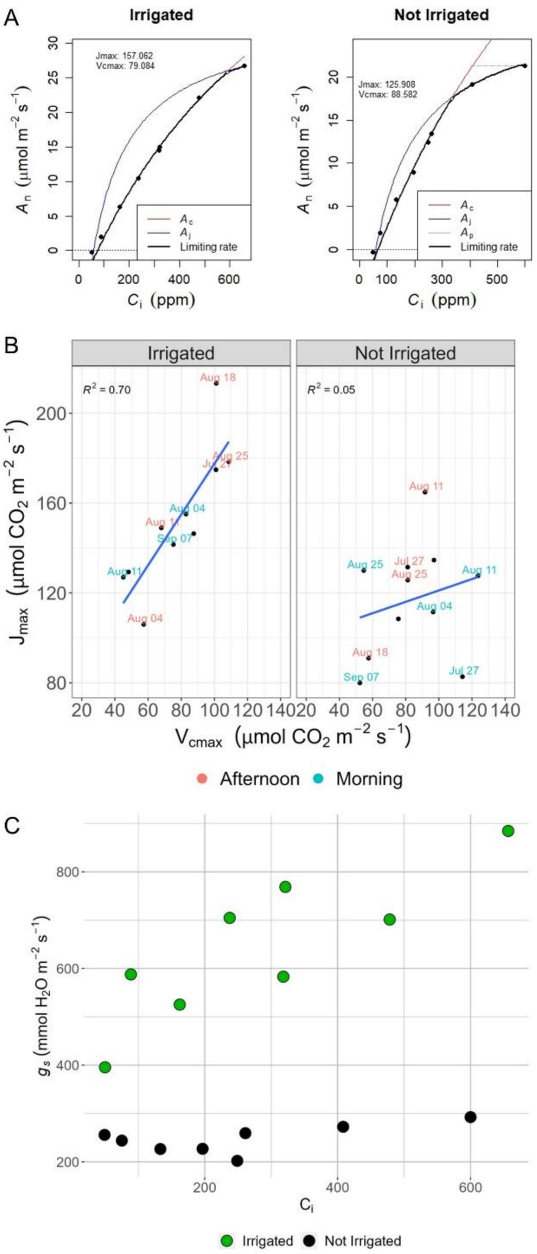

Fig 2. Leaf photosynthesis-CO_2 response curve as modelled with the FvCB model in irrigated and Not Irrigated (A) plants, relationship of the ratio of J_{max}/V_{cmax} in irrigated and not irrigated vines (B) and stomatal conductance (g_s) in response to C_i (C).

Leaf dark respiration linearly increased with the rise of the temperature (Fig. 3). Tombesi et al. [13] found similar results in grapes from cv. 'Montepulciano' measuring temperatures from 10 to 35 °C. Respiratory activities assume significant importance in the determination of net primary production. The energy required for growth processes and the maintenance of already formed tissues, such as ion uptake, protein turnover, pigment production, and other cellular activities, is contingent upon respiration activity. The total respiration of a plant, which can account for up to 70 % of the daily CO_2 fixed through photosynthesis [14], remains insufficiently characterized in grapevines. This lack of definition may be attributed to the dynamic nature of specific respiration rates per unit weight or other relevant measures, which can vary across different stages of the growing season and are influenced by the specific vine organ, growth phase, and environmental factors. Notably, temperature stands out as one of the foremost factors exerting a substantial influence on respiration activity. Temperature can indirectly modulate the development of various vine organs [15] by altering assimilate availability and sink strength, thereby affecting the overall plant metabolic activity.

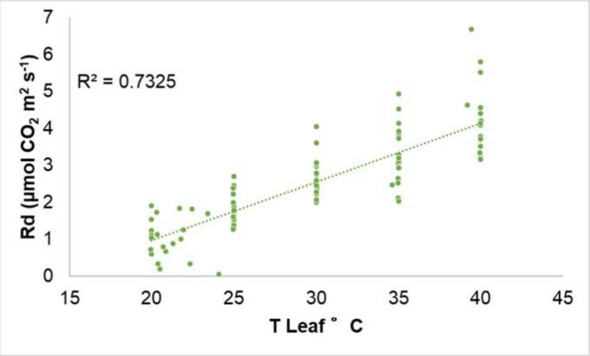

Fig 3. Leaf dark respiration response to different leaf temperatures.

4 Conclusion

The correlation between V_{cmax} and J_{max} rates in irrigated plants highlighted their vital role in assessing photosynthetic capability under varying environmental conditions. Leaf dark respiration rates demonstrated a linear increase with rising temperatures, with temperature being a significant factor influencing respiratory activities in grapevines. The importance of respiration in determining net primary production and its variability across different growth stages and environmental factors were discussed. Stomatal conductance was lower in not-irrigated vines compared to irrigated ones, emphasizing the grapevine's efficient stomatal control as a drought-avoiding species. In summary, the study revealed the resilience of grapevines to challenging weather conditions and highlighted the positive impact of irrigation on physiological processes, photosynthesis, and water status. The findings contribute valuable insights into the complex interactions between environmental factors and grapevine physiology, essential for understanding and managing vineyard conditions for optimal grape production.

This study was carried out within the Agritech National Research Center and received funding from the European Union Next-GenerationEU (Piano Nazionale di Ripresa e Resilienza (PNRR) – missione 4 componente 2, investimento 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

References

1. G. D. Farquhar, S. Von Caemmerer, & J. A. Berry, A Biochemical Model of Photosynthetic CO_2 Assimilation in Leaves of C_3 Species. Planta, **149** (1980) 78–90.

2. C. J. Bernacchi, E. L. Singsaas, C. Pimentel, A. R. Portis, & S. P. Long, Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell & Environment, **24** (2001) 253–259. https://doi.org/10.1111/J.1365-3040.2001.00668.X

3. S. D. Wullschleger, Biochemical Limitations to Carbon Assimilation in C3 Plants—A Retrospective Analysis of the *A/Ci* Curves from 109 Species. Journal of Experimental Botany, **44** (1993) 907–920. https://doi.org/10.1093/JXB/44.5.907

4. R. A. Duursma, Plantecophys - An R package for analysing and modelling leaf gas exchange data. PLoS ONE, **10** (2015) 1–13. https://doi.org/10.1371/journal.pone.0143346.

5. B. E. Medlyn, E. Dreyer, D. Ellsworth, M. Forstreuter, P. C. Harley, M. U. F. Kirschbaum, X. Le Roux, P. Montpied, J. Strassemeyer, A. Walcroft, K. Wang, & D. Loustau, Temperature response of parameters of a biochemically based model of photosynthesis. II. A review of experimental data. Plant, Cell and Environment, **25** (2002) 1167–1179. https://doi.org/10.1046/J.1365-3040.2002.00891.X.

6. M. Sodini, T. Callesen, M. Canton, L. Tezza, F. B. Campos, D. Zanotelli, P. Tarolli, P. Sivilotti, A. Pitacco, & M. Tagliavini, Major threats caused by climate change to grapevine. Italus Hortus, **30** (2023) 1–24. https://doi.org/10.26353/J.ITAHORT/2023.2.0124.

7. S. Tombesi, T. Frioni, S. Poni, & A. Palliotti, Effect of water stress "memory" on plant behavior during subsequent drought stress. Environmental and Experimental Botany, **150** (2018) 106–114. https://doi.org/10.1016/J.ENVEXPBOT.2018.03.009.

8. W. J. Hardie & J. A. Considine, Response of Grapes to Water-Deficit Stress in Particular Stages of Development. American Journal of Enology and Viticulture, **27** (1976) 55–61. https://doi.org/10.5344/AJEV.1976.27.2.55.

9. C. Lovisolo, I. Perrone, A. Carra, A. Ferrandino, J. Flexas, H. Medrano, & A. Schubert, Drought-induced changes in development and function of grapevine (*Vitis* spp.) organs and in their hydraulic and non-hydraulic interactions at the whole-plant level: a physiological and molecular update. Functional Plant Biology, **37** (2010) 98–116. https://doi.org/10.1071/FP09191.

10. X. Choné, C. Van Leeuwen, D. Dubourdieu, & J. P. Gaudillère, Stem Water Potential is a Sensitive Indicator of Grapevine Water Status. Annals of Botany, **87** (2001) 477–483. https://doi.org/10.1006/ANBO.2000.1361.

11. S. P. Long & C. J. Bernacchi, Gas exchange measurements, what can they tell us about the underlying limitations to photosynthesis? Procedures and sources of error. Journal of Experimental Botany, **54** (2003) 2393–2401. https://doi.org/10.1093/JXB/ERG262.

12. M. M. Chaves, O. Zarrouk, R. Francisco, J. M. Costa, T. Santos, A. P. Regalado, M. L. Rodrigues, & C. M. Lopes, Grapevine under deficit irrigation: hints from physiological and molecular data. Annals of Botany, (2010) 661–676. https://doi.org/10.1093/aob/mcq030.

13. S. Tombesi, I. Cincera, T. Frioni, V. Ughini, M. Gatti, A. Palliotti, & S. Poni, Relationship among night temperature, carbohydrate translocation and inhibition of grapevine leaf photosynthesis. Environmental and Experimental Botany, **157** (2019) 293–298. https://doi.org/10.1016/j.envexpbot.2018.10.023.

14. H. Lambers & L. H. W. van der Plas, Molecular, biochemical and physiological aspects of plant respiration. SPB Academic (1992).

15. K. Gashu, N. Sikron Persi, E. Drori, E. Harcavi, N. Agam, A. Bustan, & A. Fait, Temperature Shift Between Vineyards Modulates Berry Phenology and Primary Metabolism in a Varietal Collection of Wine Grapevine. Frontiers in Plant Science, **11** (2020). https://doi.org/10.3389/FPLS.2020.588739/FULL.