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Study of the within-plant spatial variability of stomatal conductance on a young 'Arbequina' olive orchard under drip-irrigated and semi-arid conditions

Estudio de la variabilidad espacial intraplanta de la conductancia estomática en un huerto joven de olivos cultivar 'Arbequina' regado por goteo creciendo bajo condiciones semiáridas

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ABSTRACT

For drip-irrigated olive orchards, plant water status monitoring is an important tool for irrigation management practices, as it determines final fruit and oil yield. However, plant water status monitoring using plant physiological measurements, such as plant water potential and stomatal conductance (g_s) imposes a challenge because the selection of the measurement site inside the canopy must be representative of the whole plant trend. Therefore, the objective of the present work was to study the spatial variability of stomatal conductance at the within-plant scale on a young drip-irrigated olive orchard under semi-arid growing conditions. A field study was carried out on a commercial drip-irrigated olive orchard (*Olea europea* L. 'Arbequina') located in Pencahue valley, Maule Region, Chile (35º 23' S; 71º 44' W; WGS 84; 96 m.a.s.l.). Measurements of g_s were done at four dates using an infrared gas analyzer (LI-COR, LI-6400, USA) during the 2011-2012 growing season. The results show that under mild to moderate water restriction (−1.5 to −2.2 MPa), intracanopy stomatal conductance variability was high and two sectors were identified, independent of the level of vegetative expression. In contrast, under moderate to strong water restriction (< −2.2 to −3.5 MPa), intra-canopy stomatal conductance variability was low for both high and low vegetative expression, with no sector detected. These considerations are relevant to select the more appropriate site within the canopy for plant water status and/or gas exchange measurements.

Key words: plant water status, sampling method, water restriction, intraplant variability.

RESUMEN

*Para olivos regados por goteo, el monitoreo del estado hídrico de la planta es una herramienta fundamental para la gestión del riego, ya que influencia directamente el rendimiento final de fruta y de aceite. Sin embargo, el monitoreo del estado hídrico de la planta utilizando mediciones fisiológicas tales como el potencial hídrico y la conductancia estomática (gs), implican un desafío técnico importante en la selección del sitio de medición dentro del dosel, el cual debe ser representativo de toda la planta. Por lo tanto, el objetivo de la presente investigación fue estudiar la variabilidad espacial de la conductancia estomática dentro de la planta, en un huerto joven de olivos regados por goteo creciendo en condiciones semi-áridas. Se realizó un ensayo de campo en un huerto comercial joven de olivos (*Olea europea *L. 'Arbequina') regado por goteo, ubicado en el valle de Pencahue, Región del Maule, Chile (35º 23' S; 71° 44' O; WGS 84; 96 m.s.n.m.). Las mediciones de gs se realizaron en cuatro fechas utilizando un analizador infrarrojo de gases (LI-COR, LI-6400, EE.UU.) durante la temporada de crecimiento 2011-2012. Los resultados mostraron que en condiciones de restricción hídrica de leve a moderada (–1,5 a –2,2 MPa), la variabilidad intraplanta de la conductancia estomática fue alta, permitiendo identificar dos zonas distintas dentro del follaje, las cuales fueron observadas en ambos niveles de expresión vegetativa. Por el contrario, en condiciones de restricción hídrica de moderada a fuerte (< –2,2 a –3,5 MPa), la variabilidad intraplanta de la conductancia estomática fue baja para ambos niveles de expresión vegetativa, sin detectar sectores distintos al interior de la planta. Los resultados anteriores son relevante para la selección del sitio más apropiado de muestreo dentro del dosel de la planta para las mediciones de potencial hídrico y/o intercambio gaseoso.*

Palabras clave: *estado hídrico de la planta, método de muestreo, restricción hídrica, variabilidad intraplanta.*

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Introduction

For drip-irrigated olive orchards, plant water status is an important variable as it determines the final fruit (Jara-Rojas *et al.*, 2009; Jara-Rojas *et al.*, 2015) and oil yield (Loyola-López *et al.*, 2008). The plant water status varies according to different factors, depending mainly on the weather conditions and the soil water content of the orchard. Thus, plant water status monitoring is a very important tool for irrigation management practices and it can be evaluated using plant physiological measurements, such as plant water potential (Ψs) and stomatal conductance (g_s) (Berenguer *et al.*, 2006; Naor *et al.*, 2001; Pérez-López, *et al.*, 2008). However, monitoring these variables impose a challenge because the selection of the measurement site inside the canopy must be representative of the whole plant trend. Little information is available in the literature on the representativeness of the standardized water status measurements, which are generally conducted in the middle zone of the canopy. Factors such as canopy management and trellising systems can modify the light interception of the leaves at different canopy levels and then modify gas exchange (Aasamaa and Sõber, 2011; Gucci *et al.*, 1999). The objective of the present work was to study the spatial variability of stomatal conductance within plants (intra-canopy) in a young drip-irrigated monocone trellised olive orchard growing under semi-arid conditions.

Materials and method

The field study was carried out on a commercial drip-irrigated olive orchard (*Olea europea* L. cv. Arbequina) located in the Pencahue valley, Maule Region, Chile (35º 23’ S; 71º 44’ W; WGS 84; 96 m.a.s.l.), during the 2011-2012 growing season. The olive orchard was planted in 2005 with a spacing of 1.5 m between plants and 5.0 m between rows, with rows orientated E-W. The plants were trained in a monocone trellis system with a total height above the ground of 3.2 m. The plants were drip-irrigated (2 drippers per tree with a discharge of 2.0 L h^{-1} each). The soil had a loam-clay texture with a bulk density of 1.34 g cm^{-3}, field capacity of 0.31 m^3 m^{-3} and wilting point of 0.16 m^3 m^{-3}. The experimental site has semi-arid climatic characteristics, with maximum and minimum average temperatures of 30 and 4.4 °C, respectively, and annual average rainfall of 700 mm most of it cumulated in the winter period (CIREN-CORFO, 1994). A climatic summary of the experimental season is presented in Table 1.

Eight trees with different vegetative expression were selected to perform the stomatal conductance measurements. Four trees were grouped as with *high vegetative expression* (HVE), which were 3.0-3.2 m height and had about 7 cm of trunk diameter, and four trees were classified as with *low vegetative expression* (LVE), plants 1.8-2.0 m height and with 5 cm of trunk diameter. Such differences in vegetative expression are present naturally in the experimental plot because of the important variability in soil depth.

The g_s measurements were done at midday (solar zenith) on four dates during the season, using an infrared gas analyzer (LI-COR, LI-6400, USA), on fully sunny days over healthy, fully expanded, sunlit leaves at each position selected inside the canopy.

To characterize the intraplant spatial variability of g_s, nine measurements were done in a grid distributed on the sunlit side of the plant canopy, as indicated in Figure 1. Data mapping was performed

Table 1. Summary of climatic variables present during the experimental period.

Variable	Season (Month/Year)					
	12/11	01/12	02/12	03/12	04/12	05/12
Maximum temperature (°C)	35.4	36.6	35.6	34.6	29.8	26.4
Minimum temperature (°C)	5.7	7.0	5.4	1.7	0	–2.4
VPD (kPa)	1.32	1.25	1.27	1.05	0.57	0.27
Precipitation (mm)	0	0	8.2	0.4	1.4	105.6
GDD_{10} (°Cd)	302	318	294	269	105	42

VPD: monthly average atmospheric vapour pressure deficit.

GDD_{10}: cumulative growing degree-days with base temperature 10 °C.

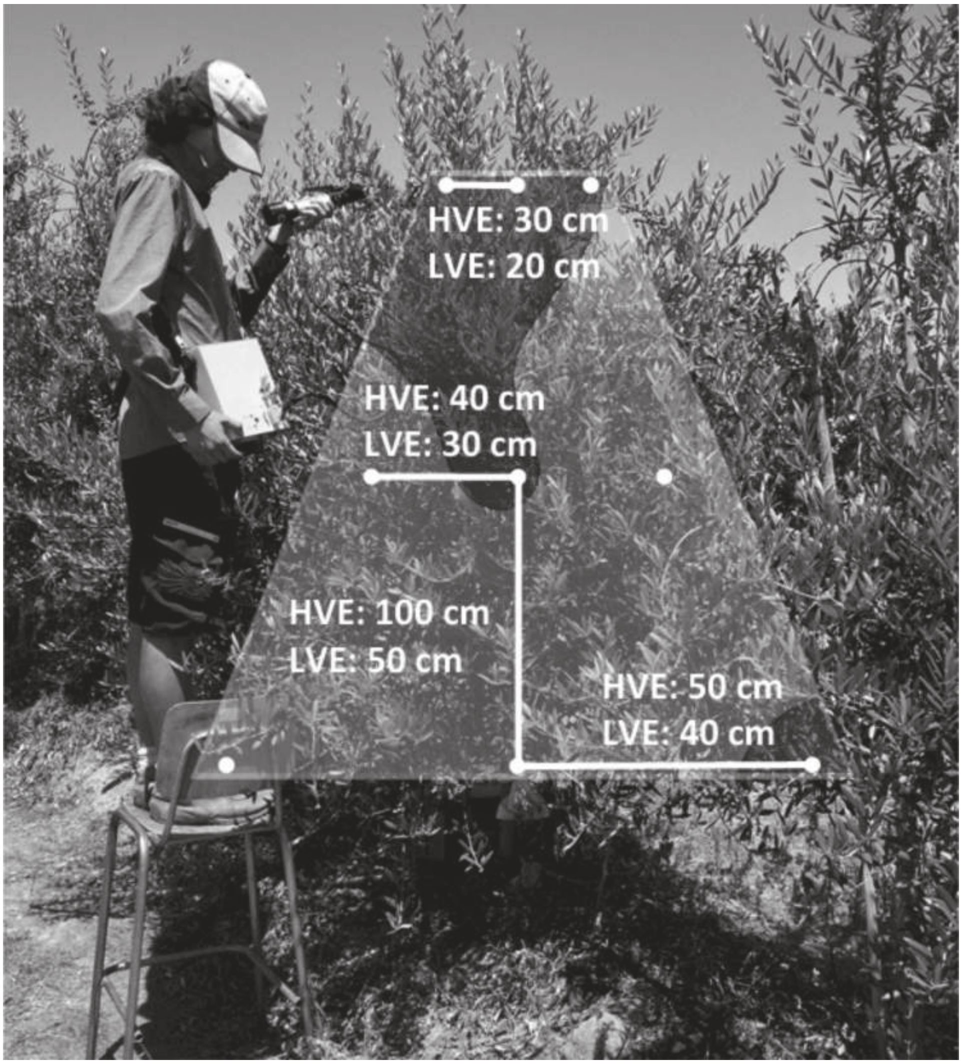

Figure 1. Representation of the intraplant grid on which stomatal conductance was measured. White circles indicate grid points and lines indicate the length among points. Dimensions of the grid differ between trees with high vegetative expression (HVE) from those of low vegetative expression (LVE). For all eight trees, the lower grid level is 80 cm above ground.

using the software 3D field (Version 2.9, Copyright 1998-2007, Vladimir Galouchko, Russia). Inverse distance weighting was used for interpolation due to the reduced number of data points inside the plant canopy.

Stem water potential was determined at midday (ψs) on the same days as the gas exchange measurements with a pressure chamber (PMS, model 1000, USA) [Scholander *et al.*, 1965; Begg and Turner, 1970]. Young shoots over the eight trees were selected and wrapped with plastic film and aluminium foil two hours before the measurements. The shoots were measured immediately after excision. To define the level of stress endured by the plants, the thresholds proposed by Ortega-Farías and López-Olivari (2012) were considered: (i) absent to mild (-2.2 MPa $\leq \psi s < -1.75$ MPa); (ii) mild to moderate (-3.6 MPa $\leq \psi s < -2.2$ MPa); (iii) moderate to severe (-5.1 MPa $\leq \psi s < -3.6$ MPa); (iv) severe (-6.2 MPa $< \psi s < -5.1$ MPa).

Results and Discussion

The climatic conditions of the experimental season are summarized in Table 1. The monthly maximum and minimum temperatures ranged between 26.4 and 36.6 °C and between –2.4 and 7.0 °C, respectively. The atmospheric vapour pressure deficit ranged between 0.27 and 1.32 kPa. There were precipitations during the growing season, but just May 2012 was important, with a total precipitation of 105.6 mm.

The work of Ortega-Farías and López-Olivari (2012) showed that a value of –2.2 MPa can be considered as a threshold to differentiate stressed and non-stressed trees from the standpoint of gas exchange. Considering this threshold, the olive orchard experienced mild to moderate water restriction (–2.2 to –3.6 MPa) at three dates, and absent to mild water restriction (–1.5 to –2.2 MPa) for the other two dates (Figure 2).

Under absent to mild water restriction (March 13th, Figures 3A and 3B), intracanopy stomatal conductance (g_s) variability was high (between 0.04 to 0.29 mol m^{-2} s^{-1}), where two sectors were identified for plants with both high and low vegetative expressions. In contrast, under mild to moderate water restriction (February 14th, Figures 3C and 3D), intracanopy stomatal conductance variability was lower (0.04 to 0.20 mol m^{-2} s^{-1}), for plants with both high and low vegetative expressions, and there were no sectors detected. These considerations are important and should be taken into account for selection of the most appropriate site for plant water status and/or leaf-level gas exchange measurements within the canopy. For mild to moderate water restriction, g_s measurements may be performed within the sunlit face of the canopy no matter the place selected. For absent to mild water restriction, g_s measurements may be performed within the sunlit face of the canopy considering two fix positions, taking care of sampling the upper most shoots of the plant were the higher rates of stomatal conductance occur. Hence, in order to perform a confortable and careful measurement, the operator would selection in most cases a mid-point, at mid-high in the canopy.

Conclusions

This work showed a significant variability in stomatal conductance within plants, which was dependent on the level of water restriction, but independent of the level of vegetative expression level. This result will help determine the appropriate site within the canopy to perform gas exchange measurements. For mild to moderate water restriction, that measurement may be performed anywhere within the sunlit face of the canopy, no matter how high

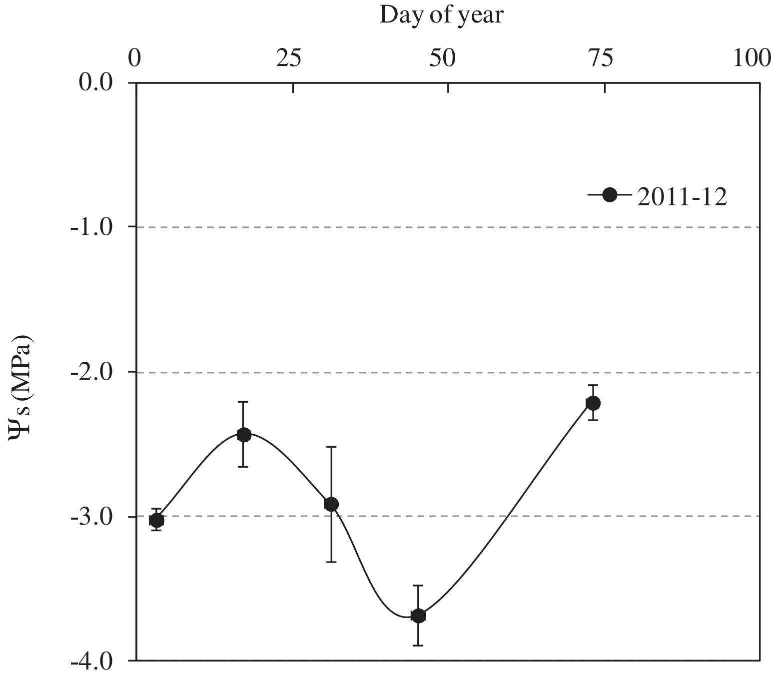

Figure 2. Mean values of midday stem water potential (ψs) of Arbequina trees growing under field conditions during 2011-12 growing season. Vertical lines represent standard deviation.

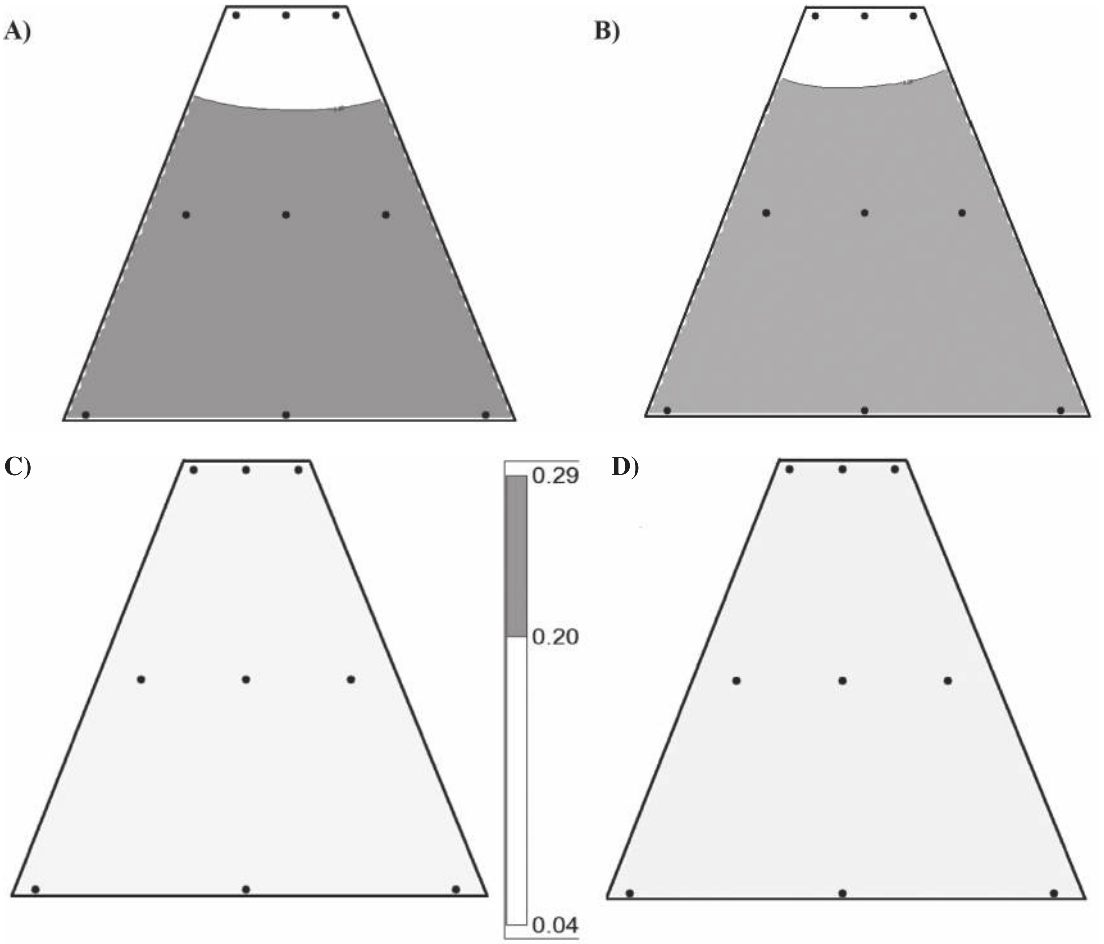

Figure 3. Maps of the intraplant spatial variability of the stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}) in 'Arbequina' olive trees. Two dates are depicted in the figure, March 13th, on which was measured the higher stem water potential of the season (absent to mild water restriction) (A and B), and February 14th, on which was measured the lower stem water potential of the season (mild to moderate water restriction level) (C and D). Figures on the left side (A and C) correspond to trees with high vegetative expression (HVE) and figures on the right side (B and D) correspond to trees with low vegetative expression (LVE). Dimensions of the grids are the same as in figure 1.

or low the place selected inside the predetermined grid. A recommendation is to select a mid-point, chest-high in the canopy, comfortable enough for the operator. On the other hand, under conditions of absent to mild water restriction, it is recommended to select two sites: one in the bottom half of the tree, and another in the upper part of the canopy.

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