Rev. FCA UNCUYO. 2018. 50(1): 73-83. ISSN impreso 0370-4661. ISSN (en línea) 1853-8665.

Physiological and production responses of olive (*Olea europaea* L.) cv. Frantoio under regulated deficit irrigation on a semiarid mediterranean weather condition (Cholqui, Maipo Valley, Chile)

Respuestas fisiológicas y productivas en olivo (*Olea europaea* L.) cv. Frantoio bajo riego deficitario controlado en condiciones de un clima mediterráneo semiárido (Cholqui, Valle del Maipo, Chile)

Cristián Kremer, Luis Reyes, Thomas Fichet, Víctor García de Cortázar, Julio Haberland

Originales: *Recepción:* 03/05/2016 - *Aceptación:* 11/04/2017 *Nota científica*

Abstract

The objective of the present study was to determine the Regulated Deficit Irrigation (RDI) effect on the cv. Frantoio olive tree, under semiarid mediterranean weather condtions (8 months dry period). The trial was established in the "El Oliveto" farm (33°48' S, 71°05' W) Cholqui, Melipilla, Metropolitan Region, Chile, and considered five irrigation treatments: 100% of crop evapotranspiration (ET_c) (T1), 85% ET_c (T2), 75% ET_c (T3), 70% ET_c (T4), and 65% ET_c (T5) applied between February (endocarp lignification) to May (harvest) of 2011. Periodic plant measurements were conducted, which included physiological parameters (midday stem water potential, photosynthesis and stomatal conductance) and production indices (mean fruit weight, maturity index and total production). The results obtained indicate that to a less irrigation water, the water potential, the stomatal conductance and the photosynthesis are decreased when compared to the 100% ET_c. As others have quoted, it was also noticed that the less irrigation water had no effect on yield and fruit oil content.

Keywords
olive oil • water stress • stem water potential

Universidad de Chile. Facultad de Ciencias Agronómicas. Casilla 1004. Santiago. Chile. cristiankremer@gmail.com

Resumen

El objetivo del presente estudio fue determinar el efecto del riego deficitario controlado (RDC) en el olivo cv. Frantoio, bajo condiciones de un clima mediterráneo semiárido (8 meses secos). El ensayo se estableció en el fundo "El Oliveto" (33°48' S 71°05' O) localidad de Cholqui, comuna de Melipilla, Región Metropolitana, Chile y consistió en 5 tratamientos de reposición hídrica equivalentes a: 100% evapotranspiración de cultivo (ET_c) (T1), 85% ET_c (T2), 75% ET_c (T3), 70% ET_c (T4), y 65% ET_c (T5) aplicados entre febrero (lignificacion del endocarpo) y mayo (cosecha) de 2011. Se realizaron mediciones periódicas a la planta, las que abarcaron variables fisiológicas (potencial hídrico xilemático, fotosíntesis y conductancia estomática) y de producción (peso promedio de fruto, índice de madurez y producción total). Los resultados obtenidos indican que a menor restitución hídrica, el potencial hídrico, la conductancia estomática y la fotosíntesis se ven disminuidos comparados con el 100% de ET_c. Tal como señalaron otros autores, se observó que la menor reposición hídrica no afectó ni la producción, ni el contenido de aceite en el fruto.

Palabras clave

aceite de oliva • estrés hídrico • potencial xilemático

Introduction

The greater demand for olive oil at a world level has led to an increase in planted areas (13) and has generated a competition for the available water resources. This competition has headed to the development of different irrigation strategies based on deficit irrigation, where reduction in yield is usually compatible with commercial goals; while water saving is substantial (3). A wide array of deficit irrigation alternatives exists, particularly regarding whether the application is constant (CDI), partial (partial root-zone drying, PRI) or regulated to specific periods (RDI). There is a considerable amount of information validating the use of these strategies (14). For example, Gucci *et al*. (2007) demostred that fruit and oil yield from olives cv. Leccino irrigated with a 50% of their water needs during the irrigation period (2.5 months) were 19% lower than those fully irrigated.

Instead, more reduction in fruit than in oil yield has been described in studies where different deficit irrigation strategies were used (3, 9, 10, 13). In these studies, the oil yield of deficit irrigated trees ranged from 75 to 86%. Other studies described non reduction in fruit load, fresh and dry fruit weight and fruit value under RDI strategies with a seasonal water reduction of 16 to 25 % during June and July (5). One of the possible harmful effects from RDI is causing stomata to partially close and, as a consequence, reducing the photosynthetic rate due to a lower water availability. In this regard, studies by Alegre *et al*. (1999) and Selles *et al*. (2006) in olives trees subject to RDI, shown significantly lower stomatal conductances (gs) when compared to the control group, which was irrigated in function of water demand.

Regarding the water status of olive trees under stress conditions, Grattan *et al*. (2006) found out that water replenishment treatment over a 71% ET_c, did not have any major difference on their xylematic water potential, which fluctuated from -0.2 MPa to -1 MPa.

Lower replenishment percentages led to reductions of xylematic water potential, reaching values of -4 MPa for replenishments between 15 and 25% ET_c. On the other hand, Alegre *et al*. (1999) found no significant differences in xylematic water potential between the control, 75 and 50% ET_c treatments. According to the research carried out by Grattan *et al*. (2006), it was also noticed that for water replenishment values below 70% ET_c, the weight of fresh fruits was negatively affected.

Nevertheless, this also brought a higher oil percentage in fruits, which was favorable in terms of oil production. Regarding the effects on the ripeness of fruits, olives under water stress conditions showed higher values on the ripeness index, which was related to a faster fruit ripening (2).

Despite this significant amount of information about the benefits of deficit irrigation strategies and in particular RDI for olive trees, several questions arise regarding the impact of such handling on productive farms in South America, where factors as soil, weather, and age of plants can be dramatically different from the original conditions of these research.

The latter is a major concern, specially in Chile, an emerging country in olive oil production, because research validating external results is scarce or not focused on the effects of these practices in oil production (15) or focused in periods where water for irrigation is not limited in the area of study (1). For these reasons, a field test was proposed for different levels of regulated water replenishment in "Frantoio" olives, with the aim of determining preliminary effects of RDI on physiological variables, production and oil content.

Materials and Methods

The experiment was carried out between February and May 2011 season in a commercial "Frantoio" olive orchard at the "El Oliveto" farm (33º48' latitude south, 71º05' longitude west, altitude 205 m a. s. l.), Cholqui, Melipilla, Metropolitan Region, Chile. The climate belongs to the temperate mesothermal stenothermic semiarid mediterranean type.

Temperatures range between an average maximum of 28.7ºC in January and an average minimum of 3.4ºC in July characterize the thermal regime. Annual average rainfall is 330 mm, with a water deficit of 1,030 mm and an 8 month dry period. During 2010 the annual rainfall was 290 mm concentrated between May and November, being the last precipitation event on November 2. No effective precipitation events occurred until June 2011.

Drip irrigated twelve year old "Frantoio" olive trees of similar vigor and fruit load were selected. The rows were N-S oriented and the spacing was 6x4 m with a total area of 1080 m^2. Irrigation design considered 4 L h^{-1} droppers with one line of droppers per row, each being 1 m apart (discharge equivalent to 0.66 mm h^{-1}). The soil was a deep well drained alluvial soil, with a sandy clay loam texture (1.5 Mg m^{-3} average bulk density).

The profile showed thin and middle roots up to 100 cm depth, with the highest percentage being concentrated between 20 and 70 cm. Soil water holding capacity (SWHC) was 0.13 cm^3 cm^{-3}, allowing an equivalent depth of water of 6.5 cm, considering the active root zone (20 to 70 cm).

Treatments

Five irrigation treatments (T) were established as a percentage restitution of the crop evapotranspiration (ET_c), (T1)100%, (T2)85%, (T3)75%, (T4)70%, and (T5)65%, which were monitored from the endocarp lignification stage (February 2, 2011) until the harvest (May 6, 2011). ET_c was estimated using the baseline evapotranspiration (ETo) based on the Penman-Monteith method and a crop coefficient (kc) of 0.7 (4).

Meteorological data was obtained hourly from a previously calibrated agrometeorological station (Campbell Scientific Inc.) which was located at 300 m from the study site. All treatments were irrigated every 3 to 5 days at the same moment with different irrigation times, estimated as the quotient of the ET_c fraction to be replenished and the equipment discharge (0.66 mm h^{-1}), considering a 90% irrigation efficiency.

To achieve the later, each treatment had an independent irrigation layout which was controlled with a programmable valve, set just before an irrigation event began. The accumulated ET_c estimated during the research period was 21.16 cm (from January 28 to May 6, 2011).

To offset the effect of soil water availability to delay the measurable impacts of the RDI in olives, the orchard was fully irrigated until January 28 and the differential irrigation started on February 1, 2011. The first measurement was made on February 8, before an irrigation event, with an accumulated ET_c of 3.94 cm between January 28 and February 8, and an estimated fraction of SWHC available ranging from 0.62 for T1 and 0.51 for T5.

Physiological variables

Photosynthesis and stomatal conductance were determined with an infrared gas analyzer (CIRAS-2, PP Systems). Two completely expanded and mature leaves were selected per plant in an average position on each tree, always maintaining the light exposure angles.

Each leaf was inserted into the assimilation chamber (2.5 cm^2 area) fed with air with a CO_2 concentration of 282 ± 20 ppm. The duration of the measurement varied between 40 and 60 seconds. Measurements were carried out between 12:30 and 14:30 local time, in days with clear skies: February 17, February 22 and March 3.

Xylematic water potential was measured at midday with a pressure chamber (PMS instrument, Oregon, U.S.A) using two branches exposed to the sun (one facing East and the other facing West) on three plants for each treatment. Before measuring, branches were covered with an aluminum and plastic sealed bag for at least one hour to permit xylem water potential and leaf water potential to equalize. Measurements were carried out every two weeks.

Production variables

The trees were harvest on May 6. The fruits per tree were counted, the average fruit weight was determined and the total kilograms (kg) per tree were weighed. The productivity and the crop load per tree were expressed by dividing the kg and fruits, respectively, by the trunk cross-sectional area (cm^{-2} TCSA) measured 40 cm up from the soil before the harvest, to take account of the possible differences in the size of the trees selected. Average fruit weight and ripeness index were determined on a subsample of 100 fruits with olives being separated by color into different categories and the ripeness index calculated with the formula proposed by Ferreira (Hermoso *et al.* 2004).

Oil content in fruits was determined by the Soxhlet extraction method in previously dried olive pulp and using petroleum ether as solvent. Results were expressed in oil percentage based on dry matter.

Experimental design

Corresponded to a completely randomized block design with 5 irrigation treatments distributed among 3 blocks, each block corresponding to a different orchard row. Each treatment per block was composed of 3 trees being the one in the center the experimental unit. Three pit hole (2 m depth, 6 m long, and 1.5 m wide) crossing the area between rows were described.

No roots were found between rows over 0.8 m from the center of the row, and the wet bulb had a similar radius. The latter description guarantee no border effects among neighboring rows since the distance between rows was 6 m. Results were subjected to an analysis of variance (ANOVA) with a 95% confidence level. Tukey´s multiple range comparison test was carried out at a 5% significance level, when the ANOVA showed significant differences.

Results

Xylematic water potential (Ψx)

Ψx did not show any significant differences between treatments for the first date of measurement, which would reflect a homogeneous soil water condition on plants a few days after the start of the RDI (figure 1a, page 78).

Nevertheless, starting from the third date of measurement, treatments with 75% or less ET_c replenishment tended to have lower *Ψx* values, which remained as such until harvest (figure 1a, page 78). This trend was significant for the last measurements, which showed significant differences between 100% and 65%.

The treatment with the highest water replenishment (100%), kept the highest *Ψx* values, with variations ranging from -1.6 to -2.9 MPa, while the treatment with the lowest water replenishment (65%), also showed the lowest values, with variations ranging from -1.9 to -3.8 MPa.

The values of *Ψx* varied also with the corresponding VPD (figure 1b, page 78), with lower values when VPD was high and higher values when VPD was low. Specifically, on the fourth date of measurement, when VPD was 1.5 kPa, the *Ψx* ranged between -2.3 and -3.5 MPa. Conversely, with a VPD of 0.6 kPa (sixth date of measurement) the *Ψx* ranged between -1.4 to -2.3 MPa.

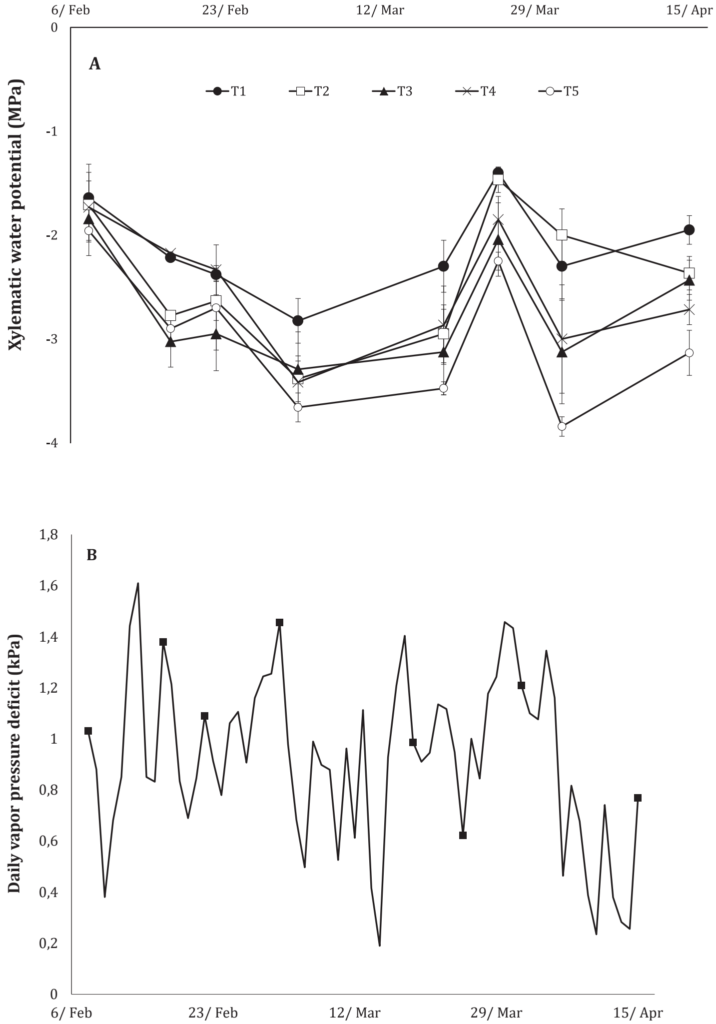
Relationships between physiological variables

Observations carried out at midday found out that for all the treatments when stomatal conductance increased (gs), photosynthesis (*A*), and transpiration (*E*) increased. An evaluation of the model parameters was made using a hypothesis test in order to verify if there are differences among the treatments slopes. No significant differerences were observed, therefore, the results were evaluated through a simple lineal regression (figure 2a and 2b, page 79), showing significant determination coefficients (R^2=0.77 and 0.86) for the regression between *A vs*. gs and *E vs*. gs respectively.

The regression between xylematic potential and stomatal conductance (figure 3a, page 80) or photosynthesis (figure 3b, page 80) showed that as xylematic potentials decreased, both stomatal conductance and photosynthesis were also diminished.

Production variables

There were no significant differences between treatments, which would indicate the RDI applied for this date and the established restrictions, would not affect the productive performance for "Frantoio" olive trees (table 1, page 81).



Bars indicate the standard error, the squares indicate the dates of xylematic potential measurement

Barras indican el error estándar, cuadrados indican los días de medición de potencial xilemático.

Figure 1. (A) Xylematic water potential measured at midday, (B) Average daily vapor pressure deficit (VPD).

Figura 1. (A) Potencial hídrico xilemático medido a mediodía, (B) Déficit de vapor promedio diario (VPD).

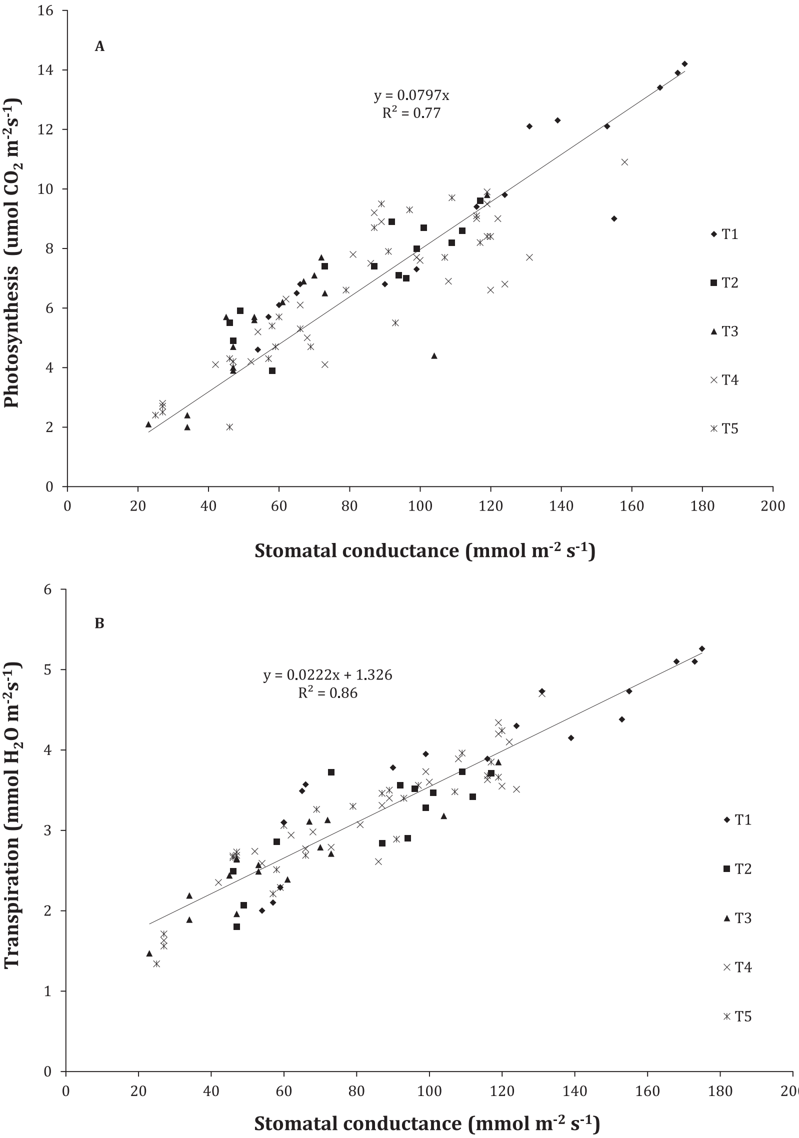
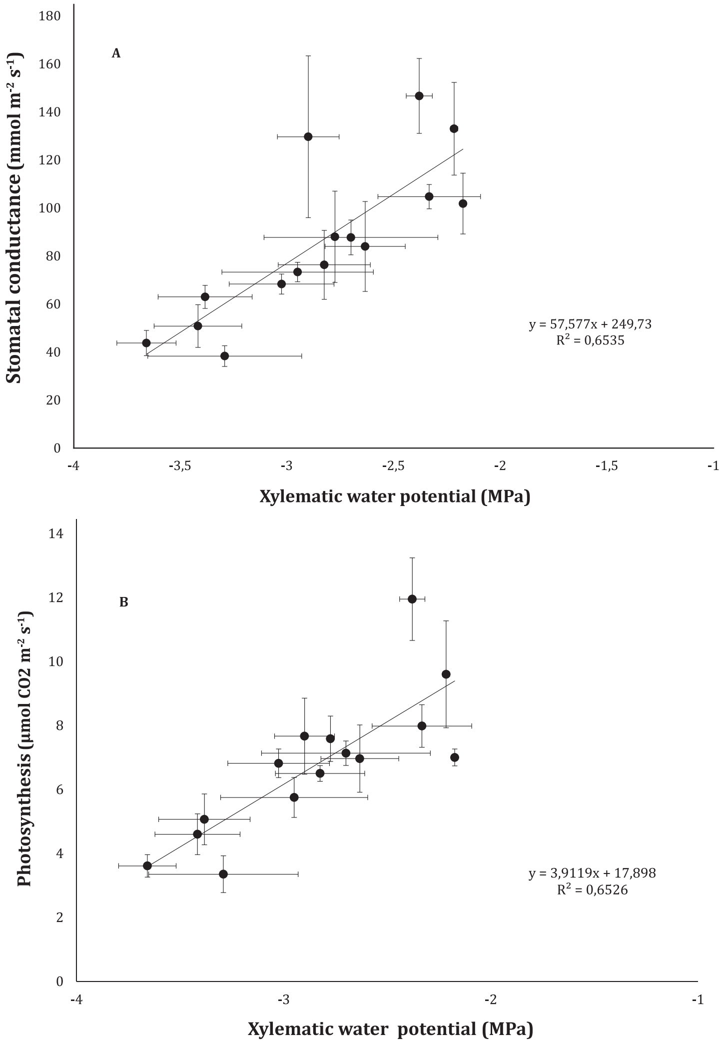


Figure 2. (A) Relation between photosynthesis and stomatal conductance for each observation, including the 5 treatments; the lineal regression which included the whole data is also shown, (B) Relation between transpiration and stomatal conductance for each observation, including the 5 treatments, the lineal regression which included the whole data is also shown.

Figura 2. (A) Relación entre fotosíntesis y conductancia estomática para cada observación incluyendo los 5 tratamientos, una regresión lineal incluye todos los datos, (B) Relación entre transpiración y conductancia estomática para cada observación incluyendo los 5 tratamientos, una regresión lineal incluye todos los datos.



The figures include data from the 5 treatments. / Las figuras incluyen datos de los 5 tratamientos.

Figure 3. (A) Relation between stomatal conductance (gs) and xylematic water potential, (bars indicate the standard error), the lineal regression for the data is also shown, (B) Relation between photosynthesis and xylematic water potential (bars indicate the standard error), the lineal regression for the data is also shown. Each dot represents the average of 3 replications for both parameters measured at midday.

Figura 3. (A) Relación entre conductancia estomática (gs) y potencial xilemático, (barras indican el error estándar), se presenta una regresión lineal para los datos, (B) Relación entre fotosíntesis y potencial xilemático (barras indican el error estándar), se presenta una regresión lineal para los datos. Cada punto representa el promedio de 3 mediciones para ambos parámetros medidos a mediodía.

Table 1. RDI effects on productive variables in "Frantoio" olive trees. Average value and its standard deviation per treatment are presented

Tabla 1. Efectos del RDC sobre variables productivas en olivos "Frantoio". Se presentan por tratamiento el valor promedio y su desviación estándar

Treatment	Ferreira ripeness index	Oil concentration dry weight basis (%)	Fruit yield (kg tree^{-1})	Fruit yield efficiency (g cm^{-2} TCSA)	Crop load (fruits cm^{-2} TCSA)	Fresh fruit weight (g)
100%	1.09 ± 0.12	45.91 ± 4.45	27.67 ± 15.41	54.41 ± 28.08	27.67 ± 17.38	2.17 ± 0.48
85%	1.54 ± 0.38	49.45 ± 2.42	28.30 ± 10.89	68.69 ± 15.25	34.55 ± 11.08	2.04 ± 0.33
75%	1.84 ± 0.16	50.87 ± 10.83	22.28 ± 4.86	49.41 ± 9.42	29.04 ± 9.93	1.77 ± 0.36
70%	1.41 ± 0.45	52.67 ± 5.35	17.73 ± 5.44	48.16 ± 12.31	23.75 ± 7.21	2.05 ± 0.10
65%	1.57 ± 0.34	53.17 ± 1.70	23.33 ± 9.62	58.11 ± 31.41	32.61 ± 19.40	1.84 ± 0.22
ANOVA p-value	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S.: not significant; ANOVA: analysis of variance.
N.S.: no significativo, ANOVA: análisis de varianza.

Either, Ferreira ripeness index (color fruit), oil content based on dry matter, fruit yield efficiency, crop load, and fresh fruit weight, presented no significant differences, suggesting that a moderate RDI (over 65% water replenishment) between endocarp lignification and harvest in "Frantoio" olive trees does not impact the variables analyzed for this study.

Discussion

Xylematic potential

Values obtained in this study which were higher than -3.8 Mpa for xylematic water potential (figure 1a, page 78), were similar to the ones obtained for other RDI tests on olive trees. There is the case of "Picual" olive trees, in which RDIs with contributions between 60 to 80% managed to induce xylematic water potential values over -3.8 MPa (12).

An analogous behavior was observed on "Frantoio" olive trees, which were subjected to irrigation between 66 and 100% of ET_c in the period between the start of endocarp lignification and start of harvest, achieving xylematic water potential values over -3.5 MPa, showing no significal differences (16), similarly Selles *et al*. (2006) found out with RDI treatments of 40% of ET_c applied on the III phase of the fruit growth Sevillana, values between -2 to -3.4 MPa.

Relation ships between physiological variables

The results for the relationship between *A* and *gs* were similar to the ones obtained by Moriana *et al*. (2002), in which "Picual" olive trees were subject to treatments of up to 75% water replenishment regarding ET_c. These authors found a regression ($y = 0.074\ x$; $R^2 = 0.92$), similar to the one obtained in this study (figure 2a, page 79), for plants with midday xylematic values higher than -4 MPa. There is a linear relationship between the decrease in potential and stomatal conductance.

Apparently, within the range of measured xylematic potentials, water stress protection includes stomatal closure and a decrease in potential as to preserve transpiration gradients.

The interesting part is that it is a linear reaction equally reflected in photosynthesis. Therefore, even though productive variables were not statistically altered (table 1, page 81), physiological ones were, a situation which should have an impact particularly on floral induction for the next season (11).

Production variables

The results obtained in this research suggest ET_c replenishment amounts applied on olive trees in this study from endocarp lignification until harvest do not affect oil level in fruits or other production variables as stated by other authors (5, 6, 16).

Conclusions

RDI practices do have an impact on olive trees. Xylematic potential measured at midday, showed a trend differentiating the various water amounts applied, even though this was a stastically significant indicator for the water stress conditions more at the end of this research. On the other hand, the correct interpretation of xylematic potential data as a characterization of water restrictions cannot be isolated or made independent from the VPD.

A linear relationship between the decrease in xylematic potential and its impact on physiological variables such as stomatal conductance and photosynthesis was found. This trend would reveal that a decrease in irrigation water causes a proportional decrease in assimilated production, a situation which must be kept in mind when the RDI practices overlaps with a process, such as floral induction. On the other hand, there were no effects on the most relevant productive variables such as fruit growth and oil buildup. These preliminary results are in concordance with results than others authors have quoted, with similar RDI practices, being an initial promissory result validating deficit irrigation from foreign research.

References

1. Agüero, A.; Rousseaux, M.; Searles, P. 2010. Respuestas fisiológicas y reproductivas al riego deficitario controlado de post-cosecha en olivo en una zona árida de Argentina. CRILAR CONICET. En: http://www.inta.gov.ar/mendoza/V_Jornadas/Ponencias/Aguero.pdf
2. Alegre, S.; Girona, J.; Marsal, J.; Arbonés, A.; Mata, M.; Montagut, D.; Teixidó, F.; Motilva, M. J.; Romero, M. P. 1999. Regulated deficit irrigation in olive trees. Acta Horticulturae (ISHS). 474: 373-376.
3. Caruso, G.; Rapoport, H. F.; Gucci, R. 2013. Long-term evaluation of yield components of young olive trees during the onset of fruit production under different irrigation regimes. Irrigation Sciences. 31: 37-47.
4. Girona, J.; Luna, M.; Arbonés, A.; Mata, M.; Rufat, J.; Marsal, J. 2002. Young olive trees responses (*Olea europea*, cv. "Arbequina") to different water supplies. Water function determination. Acta Horticulturae. 586: 277-280.
5. Goldhamer, D. A. 1999. Regulated deficit irrigation for Californian canning olives. Acta Horticulturae. 474(1): 369-372.
6. Grattan, S. R.; Berenguer, M. J.; Connell, J. H.; Polito, V. S.; Vossen, P. M. 2006. Olive oil production as influenced by different quantities of applied water. Agricultural Water Management. 85: 133-140.
7. Gucci, R.; Lodoloni, E.; Rapoport, H. F. 2007. Productivity of olive tree with different water status and crop load. Journal of Horticultural Science and Biotechnology. 82: 648-656.

8. Hermoso, M.; Beltrán, G.; Uceda, M. 2004 Maduración. Pp. 159-183. In: Barranco, D.; Fernández-Escobar, R.; Rallo, L. (Eds.). El cultivo del olivo, 5ta edición, ediciones Mundi- Prensa. España. 800 p.
9. Iniesta, F.; Testi, L.; Orgaz, F.; Villalobos, F. J. 2009. The effects of regulated and continuos deficit irrigation on the water use, growth and yield of olive trees. European Journal of Agronomy. 30: 258-265.
10. Lavee, S.; Hanoch, E.; Wodner, M.; Abromowitch, E. 2007. The effect of predetermined deficit irrigation on the performance of cv. Muhasan olives (*O. europea* L.) in the eastern coastal plain of Israel . Science Horticulturae. 99: 267-277.
11. Martín-Vertedor A. I.; Pérez, J. M.; Prieto, H.; Fereres, E. 2011. Interactive responses to water deficits and crop load in olive (*Olea europaea* L., cv. Morisca) I. Growth and water relations. Agricultural Water Management. 98: 941-949.
12. Moriana A.; Villalobos, F. L.; Fereres, E. 2002. Stomatal and photosynthetic responses of olive (*Olea europaea* L.) leaves to water deficits. Plant, Cell and Environment. 25: 395-405.
13. Moriana, A.; Orgaz, F.; Pastor, M.; Fereres, E. 2003. Yield responses of a mature olive orchard to water deficits. Journal of the American Society for Horticultural Science. 128: 425-431.
14. Podestá, L.; Vallone, R.; Sánchez, E.; Morábito, J. A. 2010. Efecto del riego deficitario controlado sobre el crecimiento vegetativo en plantaciones jóvenes de cerezo (*Prunus avium* L.). Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 42(1): 73-91.
15. Sellés, G.; Ferreira, R.; Sellés, I.; Lemus, G. 2006. Efecto de diferentes regímenes de riego sobre la carga frutal, tamaño de fruta, y rendimiento del olivo *cv.* Sevillana. Agricultura Técnica. 66(1): 48-56.
16. Tognetti, R.; d'Andria, R.; Sacchi, R.; Lavini, A.; Morelli, G.; Alvino, A. 2007. Deficit irrigation affects seasonal changes in leaf physiology and oil quality of *Olea europaea* (*cvs.* Frantoio and Leccino). Ann. Appl. Biol. 150: 169-186.