Intelligent Irrigation Control in Olive Groves (*Olea europaea* L.): a Novel Approach for Water Resource Optimization

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Keywords: automatic controller, irrigation, moisture sensor, olive oil, quality

Abstract

In the last years, irrigation control in agricultural soils has been mainly focused on the optimization of the use of water resources, in order to overcome the difficulties imposed by a growing water demand and to reduce extraction costs. This work presents the field implementation of an automatic irrigation controller, as a novel approach for water resource optimization. The developed closed-loop irrigation control system includes the moisture measurement in roots zone and the control of the irrigation valves in order to maintain the moisture level around a set value. The controller determines when and how much to irrigate as a function of the current difference between soil moisture measurements and the reference values. The system is used in three irrigation treatments with different set-point moisture level: T1: soil moisture at field capacity; T2: water deficit level from pit hardening to harvest (40% of field capacity); and T3: water deficit level from fruit set to harvest (40% of field capacity). Experiences were carried out in a four-year-old experimental olive orchard grown 'Arbequina', located in San Juan, Argentina. Controller was able to maintain soil moisture values around the reference value, a fact that allows performing different irrigation strategies. Productive and qualitative parameters were affected by applying water deficit treatments in different phenological moments, the obtained oil quality being especially affected.

INTRODUCTION

Water is a limiting factor when augmenting the cultivation area and often affects directly the agriculture production in arid regions. In the olives production areas of Argentina, water is an insufficient resource, therefore it is of great importance to develop practices that rationalize its use.

In the last years, the advance irrigation controllers in agriculture have been focused on water use optimization, in order to overcome the difficulties imposed by a growing water demand and to reduce extraction costs. The irrigation controller is a system governing the solenoid valves opening and closing (control action) in order to irrigate predetermined crop areas. This process may be set up in two ways: (i) open-loop or, (ii) closed-loop (Kuo, 1995). In closed-loop configuration, also known as feed-back control, the irrigation controller has an internal algorithm that determines (on-line) the irrigation program based on the measurement or estimation of one or more variables involved in the soil-plant-atmosphere system. This information is acquired by the remote sensors, e.g., soil moisture, sun radiation, sap flow, etc. (Abraham et al., 2000; Capraro et al., 2008). The controller decides when to start and how long to irrigate, in order to bring the controlled variable up to the desired value (set-point). Although feed-back irrigation systems present major advantages over the open-loop systems, changes in the dynamics of the process are not always detected. Those problems are solved by the intelligent irrigation controller (Colin and Whitford, 1996; Capraro et al., 2008). This novel control method uses different mathematical models (formulated from first principles, identification processes and estimators) and measures the error between the steady-state sensed value and the desired value. If error exceeds some given tolerances, then the

Proc. VIth IS on Olive Growing
Eds.: E.M. Sampaio and A.C. Pinheiro
Acta Hort. 949, ISHS 2012

controller uses an adaptive algorithm that modifies model and control parameters (Iserman et al., 1992). The steady-state error can be reduced in future irrigation cycles with some adaptive characteristics.

An interesting irrigation strategy is a water supply under crop requirements, causing temporary water deficit in specific phenological periods. This strategy is known as regulated deficit irrigation (RDI) and has been object of numerous research works, such as those of Goldhamer et al. (1994), Alegre et al. (1999, 2002), Moriana et al. (2007), among others. RDI is a valid strategy for water use optimization and, even more, modifying final product characteristics (Gomez-Rico et al., 2007; Capraro et al., 2008).

MATERIALS AND METHODS

This work presents the development and field implementation of an intelligent irrigation controller. The software control includes the soil continued moisture measurements, data logging, monitoring parts and the irrigation control algorithm. The designed controller uses the moisture measurement in roots zone (30 cm deep) to control the irrigation solenoid valves (open/close). The controller calculates, every 15 min, the appropriate control actions for each irrigation zone. The main objective is maintaining the gravimetric moisture level (θ_g) around the moisture set point (θ_{sp}), optimizing the used water resource. The control algorithm consists of a mathematical model that understands the soil water dynamic together with identification and prediction strategies. Figure 1 shows a schematic of the complete system. The model was identified off-line and then automatically updated on-line according to the soil moisture variations.

The real time moisture measurement was achieved by capacitive-like sensors. This device uses two conductive plates inserted in the ground to make an ideal condenser with soil as dielectric (Bilskie, 1997). Changes in soil moisture are reflected as a change in the dielectric constant, thus changing the sensor condenser capacity. The condenser is part of a high frequency oscillator circuit, where the oscillation frequency (Fr) corresponds to the soil gravimetric moisture (θ_g) (Wang and Schmugge, 1980). Every sensor was calibrated in-situ to know real gravimetric moisture. Eight soil samples were taken from different moisture conditions and analyzed to determine θ_g, then adjusted to the value Fr. The field capacity (Fc) for each zone was obtained in the lab (Richards method) using the samples.

Irrigation Management Strategies

Three irrigation strategies were defined. In the first strategy, soil moisture was kept close to Fc during the whole season (treatment T1). Treatment 2 (T2) consisted in a RDI strategy from pit hardening to harvest (01/22/08 to 04/10/08). Finally, in treatment 3 (T3) the RDI strategy was applied from fruit set to harvest (11/30/07 to 04/10/08). In cases T2 and T3, water deficit meant 60% reduction of Fc soil moisture level.

The leaf water potential (Ψh) was determined at noon, following the technique described by Allegre et al. (1999). The Maturity Index (MI) was used to determine harvesting time which was performed when the MI reached values between 3.5 and 4. The oil content (%) and fruit moisture was determined by the Soxhlet method. Yield parameters, such as fruit number, volume and weight as well as the amount of supplied water was determined. Finally, oil was obtained with fruits from the three different treatments, using a discontinue process machine (Oinomio, Spremolive model).

The oxidative stability index, which is represented as the induction time in hours, was measured with a Metrohm 679 Rancimat apparatus (Metrohm, Herisau, Switzerland), at 110°C and 20 L/h airflow. Phenolic compounds were isolated by three extractions of oil in hexane solution with a 60% v/v water/methanol mixture. The content of phenolic compounds as mg/kg of caffeic acid was determined spectrophotometrically at 725 nm using Folin-Ciocalteau reagent. Tocopherols were evaluated by HPLC with fluorescence detector according to IUPAC (1992) 2.432 method. Fatty acids were determined as their methyl esters obtained by trans-esterification with a cold methanolic solution of potassium hydroxide following the IOOC standard method. Sterol contents were determined by CGC with IOOC analytical method. The analyses were carried out in triplicate. The differences in mean values between samples were assessed with Student's t test, being statistically different at a significance level of 5%.

RESULTS AND DISCUSSION

Moisture Control

The Fc values were 22, 21.3 and 21.5 g.% g^{-1} for treatments T1, T2 and T3 respectively. This information was necessary to found the set-point values, θ_{sp}, used into intelligent controller to perform the experiments.

Figure 2a, b and c show the gravimetric soil moisture variation (grey line), the reference value for (thick black line) and the control actions (thin black line) for each treatment. Figure 2a presents the evolution of treatment T1; at the beginning of the experience, the reference value was θ_{sp1}=2 g.% g^{-1}. On 18 February 2008, it was reduced to θ_{sp1}=21 g.% g^{-1}. Figure 2b shows results for treatment T2. In this case the initial reference value was θ_{sp2}=22 g.% g^{-1}. At the pit hardening (01/22/08), was modified to θ_{sp2}=7 g.% g^{-1}. On 13 February the reference was increased to 9 g.% g^{-1}, due to Ψ_h values less than -0.3 MPa (Fig. 3) were observed. Later, on 18 March θ_{sp2} was increased to 11 g.% g^{-1}. Figure 2c shows results of treatment T3. The experiment begins with a reference value θ_{sp3}=8.5 g.% g^{-1}. On 18 March, the set-point value is increased to 10 g.% g^{-1} due to Ψ_h values less than -0.3 MPa were observed (Fig. 3). Discontinuities in the figures are due to power cuts caused by storms.

The developed control algorithm kept the soil moisture above the reference value. Figures 2a, b and c also show some overlengths in the moisture level with values between 1 and 4%, after water is applied. This was mainly caused by two reasons: model disturbances and fixed sample time. The delay between the irrigation and the water sensing is variable and depend on the moisture level at the beginning of the irrigation and on unmeasured weather variables affecting the model. A solution to this problem could be to add to the prediction model some weather variables and measurement disturbances. On the other hand, control actions are kept constant between sample instants. In this sense, there is a hard restriction on the minimum water doses (15 min length); in several times is greater than necessary. The problem could be solved transforming the control action from discrete time to continue time (Saravia et al., 2007). By doing this, water irrigation amount could be applied at intervals less than the sample period. The intelligent controller, measures and evaluates predictions as a sole function of the soil moisture, so disturbances on crop are totally neglected. These affect the soil moisture with an important delay, usually greater than 4 h. However, disturbances that directly affect the soil, such as rain, were soon detected and taken into account by the controller. This is a feature absent in timed controller by being an open-loop system.

Water Relations

Figure 2d presents the amount of water applied during the treatments application cycle. As it can be seen, a water deficit treatment directly affects the total plant water consumption. In treatments T2 and T3 water supply was reduced 65 and 72% respectively from fruit set to harvest. Although T2 water deficit begun 51 days before T3 the reduction of water applied was not so evident, in spite of the greater plant consumption (December-January). Moriana (2007) observed that water deficit is more efficient when it is applied during a short time instead of the whole season. In the first case the root system grows faster without water deficit so when deficits appear the plant modifies its stomatal leaf conductance and, in consequence, its water uptake. Experiments made in partial rootzone drying suggest that the leaf is controlled by signals from the roots (Wahbi et al., 2005).

In Figure 3 changes in the leaf water potential at noon (Ψ_h) are shown. Treatment T3 do not show significant differences with T1 until 45 days after the water deficit was applied. From that moment to harvesting, both treatments differ statistically. Once the water deficit was applied, T2 Ψ_h level rapidly decreases showing differences with T1 and T3. These differences are maintained during the rest of the season. Recovery on water status observed at 01/22/08, in both water deficit treatments, can be explained by a strong rain occurred two days before that date. Minimum values of Ψ_h for T2 and T3 were around -3.3 MPa. Leaf water potential values resulted similar to those shown in Alegre et al. (1999) and Wahbi et al. (2005).

Oil Production and Water Use Efficiency

Table 1 shows that there were no significant differences in fruits and oil production between the treatments. However, differences in fruit weight and volume were observed. The differences in fruit weight do not affect the total yield because of the differences in fruit number per plant. Although, the fruit number does not show statistical differences, it could be explained because of the young heterogenic plants per plot observed. Treatments T2 and T3 presented smaller and lighter fruits, in coincidence with results presented by Lavee et al. (2007), where it is proven that the fruit growth is especially affected by water deficit treatments. This fact, however, does not justify the reduction in the number of fruit per plant, a factor that has also influence on fruit size and weight.

The oil contents (%) for treatments T1, T2 and T3 were 16.41, 14.55 and 15.81 respectively. Savings on water is reflected as a greater WUE in T2 and T3 (Table 1). Total applied water layer were 745, 532 and 573 mm for treatments T1, T2 and T3 respectively.

Oil Quality

Table 2 presents fatty-acid composition of oils from different treatments. Higher values for palmitoleic and linoleic acids and lower values for stearic and oleic acids were found in the fully irrigated sample (T1). As a consequence of these results, the OLLnRs were higher in water-stressed samples. Similar results were obtained by other authors (Salas et al., 1997; Gómez-Rico et al., 2007). The sample that shows the most severe stress condition (lower Ψ_h in the last period of maturation) (T2) presented the higher total sterol content (Table 3). An increase in campesterol and β-sitosterol and a decrease in Δ-5-avenasterol were observed with the severity augment of the treatment. These results are in accordance with those previously reported (Stefanoudaki et al., 2001). Highly significant differences in antioxidant components and OSI between irrigated and stressed samples (Table 4). Total tocopherol content decreased significantly as the amount of supplied water increased. However, polyphenol content and OSI were similar in T2 and T3 samples.

In brief, those samples with water stress showed the higher OSI in accordance with their higher OLLnR and antioxidant contents. Slight differences in OSI values between the level of stress may arise not only from fatty-acid composition, but also from the presence of minor components with anti- or pro-oxidant properties, some of them not quantified in this work such as carotenes, chlorophylls, and metals.

CONCLUSIONS

From a technological aspect, an intelligent controller capable of control a drip irrigation system function of the soil moisture is presented. Soil moisture is acquired by capacitive-like sensors. Controller was able to maintain soil moisture values around the reference value, fact that allow performing different irrigation strategies. Productive and qualitative parameters were affected by applying water deficit treatments in different phenological moments, the obtained oil quality being especially affected. General results of this experience show that is possible to apply technological tools to manage the irrigation process and improve its efficiency, especially in areas with lack of water resource.

ACKNOWLEDGEMENT

This work has been supported by Instituto Nacional de Tecnología Agropecuaria (INTA), Instituto de Automática (INAUT - UNSJ), Asociación Argentina de Grasas y

Aceites (ASAGA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), and Universidad Nacional del Sur, Argentina.

Literature Cited

Abraham, N., Hema, P.S., Saritha, E.K. and Subramannian, S. 2000. Irrigation automation based on soil electrical conductivity and leaf temperature. Agric. Water Manag. 45:145-157.

Alegre, S., Girona, J., Marsal, J., Arbones, A., Mata, M., Montagut, D., Teixido, F., Motilva, M.J. and Romero, M.P. 1999. Regulated deficit irrigation in olive trees. Acta Hort. 474:373-376.

Bilskie, J. 1997. Using dielectric properties to measure soil water content. Sensors Magazine 14:26-32.

Capraro, F., Schugurensky, C., Vita, F., Tosetti, S., Lage, A. and Patiño, D. 2008b. Intelligent irrigation in grapevines: a way to obtain different wine characteristics. 17th IFAC World Congress, Seoul, Korea.

Colin, A. and Whitford, D. 1996. Intelligent Irrigation. (Booklet) Cohort International Pty Ltd., Australia.

Goldhamer, D., Dunai, J., Ferguson, L., Lavee, S. and Klein, I. 1994. Irrigation requirements of olive trees and responses to sustained deficit irrigation. Acta Hort. 356:172-175.

Gómez-Rico, A., Salvador, M.D., Moriana, A., Pérez, D., Olemdilla, N., Ribas, F. and Fregapane, G. 2007. Influence of different irrigation strategies in a traditional Cornicabra cv. olive orchard on virgin olive oil composition and quality. Food Chem. 100:568-578.

Iserman, R., Lachmann, K. and Matko, D. 1992. Adaptive Control Systems. Ed. Prentice Hall.

IUPAC. 1992. Standard Methods for the Analysis of Oils, Fats and Derivates. 7th Ed., C. Paquot and A. Hautfenne (eds.), International Union of Pure and Applied Chemistry, Blackwell Scientific Publications Inc., Oxford.

Kuo, B.C. 1995. Automatic Control Systems. 7th Edition. Prentice Hall.

Lavee, S., Hanoch, C., Wodner, M. and Abramowitch, H. 2007. The effect of predetermined deficit irrigation on the perfomance on cv. Mohasan olives (*Olea europeae* L.) in the eastern coastal plane of Israel. Scientia Horticulturae 112:156-163.

Moriana, A., Pérez-López, D., Gómez Rico, A., Salvador, M., Olmedilla, N., Ribas, F. and Fregapane, G. 2007. Irrigation scheduling for tradicional, low-density olive orchads: water relations and influence on oil characteristics. Agr. Water Manag. 87:171-179.

Salas, J., Pastor, M., Castro, J. and Vega, V. 1997. Influencia del Riego sobre la Composición y Características del Aceite de Oliva. Grasas y Aceites 48:74-82.

Sarabia, D., Capraro, F., Larsen, L. and de Prada Moraga, C. 2007. Hybrid control of a supermarket refrigeration systems. 26th American Control Conference. NY, USA.

Stefanoudaki, E., Chartzoulakis, K., Koutsaftakis, A. and Kotsifaki, F. 2001. Effect of Drought Stress on Qualitative Characteristics of Olive Oil of cv Koroneiki. Grasas y Aceites 52:202-206.

Vita Serman, F., Schugurensky, C., Carrión, R. and Rodríguez, S. 2005. Evaluación del comportamiento de sensores de humedad de suelo de desarrollo local, en relación al contenido de agua y a la textura de suelo, CONAGUA 2005. Mendoza, Argentina.

Wahbi, S., Wakrim, R. Aganchich, B., Tahi, H. and Serraj, R. 2005. Effects of parcial rootzone drying (PRD) on adult olive tree (*Olea europeae*) in field conditions under arid climate. I Physiological and agronomic responses. Agr. Ecosyst. Environ. 106:289-301.

Wang, J.R. and Schmugge, T.J. 1980. An empirical model for the complex dielectric permittivity of soils as a function of water content. IEEE Transactions on Geoscience and Remote Sensing 18:288-295.

Tables

Table 1. Fruit and oil production and water use efficiency.

	Total yield (kg ha^{-1})	Fruit number	Fruit volume (cm^3)	Oil yield (kg ha^{-1})	WUE (oil yield kg mm^{-1})
T2	5820.8	4323	1.6b	920.0	10.94
T3	6572.5	4737	1.67b	1078.8	11.47
T1	6454.3	3089	2.42a	1035.72	8.66

Table 2. Fatty acid composition (methyl esters, % m/m).

Fatty Acid	**T1**	**T2**	**T3**
C14:0	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}
C16:0	18.75 ± 0.07^{a}	18.66 ± 0.05^{a}	18.77 ± 0.07^{a}
C16:1	2.91 ± 0.02^{b}	2.22 ± 0.00^{a}	2.22 ± 0.02^{a}
C17:0	0.11 ± 0.00^{c}	0.16 ± 0.00^{a}	0.15 ± 0.00^{b}
C17:1	0.26 ± 0.00^{b}	0.33 ± 0.01^{a}	0.33 ± 0.02^{a}
C18:0	1.70 ± 0.01^{c}	1.98 ± 0.00^{a}	1.86 ± 0.01^{b}
C18:1	56.31 ± 0.05^{c}	59.62 ± 0.04^{a}	60.13 ± 0.09^{b}
C18:2	18.52 ± 0.04^{c}	15.49 ± 0.01^{a}	15.11 ± 0.02^{b}
C20:0	0.35 ± 0.00^{c}	0.37 ± 0.01^{a}	0.35 ± 0.00^{b}
C18:3	0.69 ± 0.00^{c}	0.75 ± 0.00^{a}	0.67 ± 0.00^{b}
C20:1	0.22 ± 0.00^{b}	0.24 ± 0.00^{a}	0.24 ± 0.00^{a}
C22:0	0.10 ± 0.00^{c}	0.11 ± 0.00^{a}	0.10 ± 0.00^{b}
C24:0	0.06 ± 0.01^{a}	0.06 ± 0.00^{a}	0.06 ± 0.00^{a}
OLLnR	2.93 ± 0.01^{c}	3.67 ± 0.00^{a}	3.81 ± 0.00^{b}

Average values ±95% confidence intervals. The means with different letters in a same row are significantly different at the P=0.05 level.

Table 3. Methylsterols contents.

Sterol (%)	**T1**	**T2**	**T3**
Cholesterol	1.07	1.65	0.82
Brassicasterol	0.16	0.01	0.03
24-Methylene-cholesterol	0.10	0.10	0.18
Campesterol	3.72	4.19	4.03
Campestanol	0.17	0.19	0.24
Stigmasterol	0.83	0.94	1.01
Δ -7-Campesterol	0.29	0.35	0.29
Δ -5,23-Stigmastadienol	0.16	0.05	0.06
Clerosterol	1.79	1.09	1.09
β-Sitosterol	80.15	84.35	83.11
Sitostanol	0.98	0.49	0.55
Δ -5-Avenasterol	7.35	4.78	6.68
Δ -5,24-Stigmastadienol	1.97	1.04	1.13
Δ -7-Stigmastenol	0.23	0.30	0.27
Δ-7 Avenasterol	1.04	0.47	0.51
Total sterols* (mg/kg)	1680 ± 36^{b}	1891 ± 25^{a}	1657 ± 10^{b}

* The means with different letters in a same row are significantly different (P=0.05).

Table 4. Oxidative stability indexes and antioxidant compounds.

Sample	Polyphenols (mg kg^{-1})	Total tocopherols (mg kg^{-1})	OSI (h)
T1	64±5^b	181±4^c	7.45±0.14^c
T2	106±7^a	290±14^a	10.30±0.00^a
T3	111±8^a	229±15^b	9.89±0.00^b

Average values ±95% confidence intervals. The means with different letters in a same column are significantly different at the P=0.05 level.

Figures

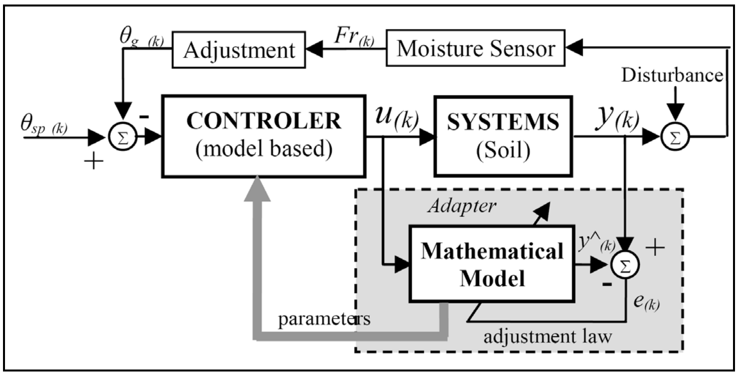

Fig. 1. Overall system block diagram.

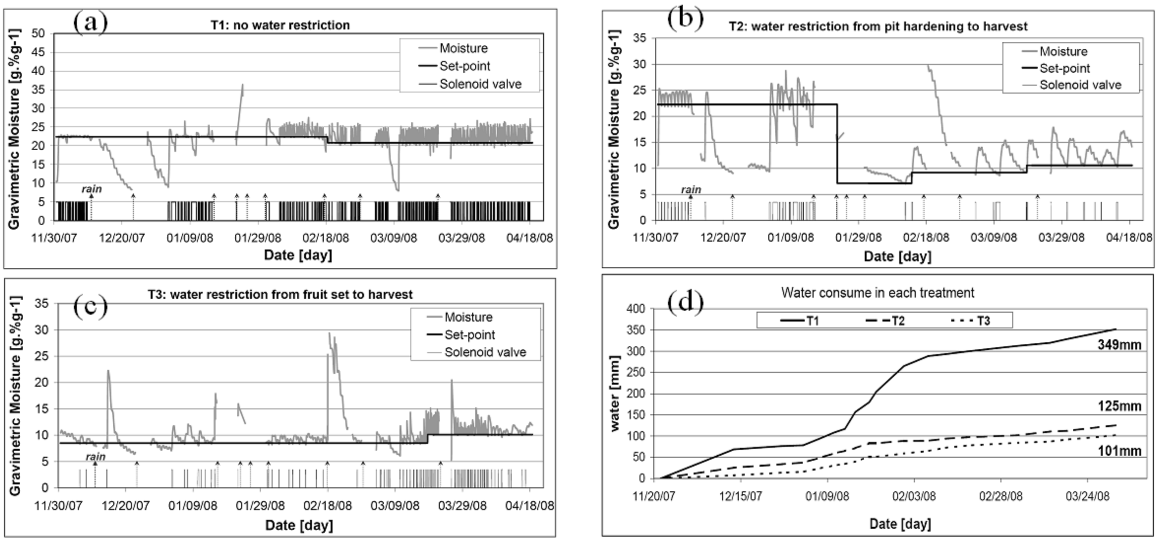

Fig. 2. Temporal evolution of soil moisture variation and water supplied in different treatments: T1 (no water deficit), T2 (water deficit from pit hardening to harvest) and T3 (water deficit from fruit set to harvest).

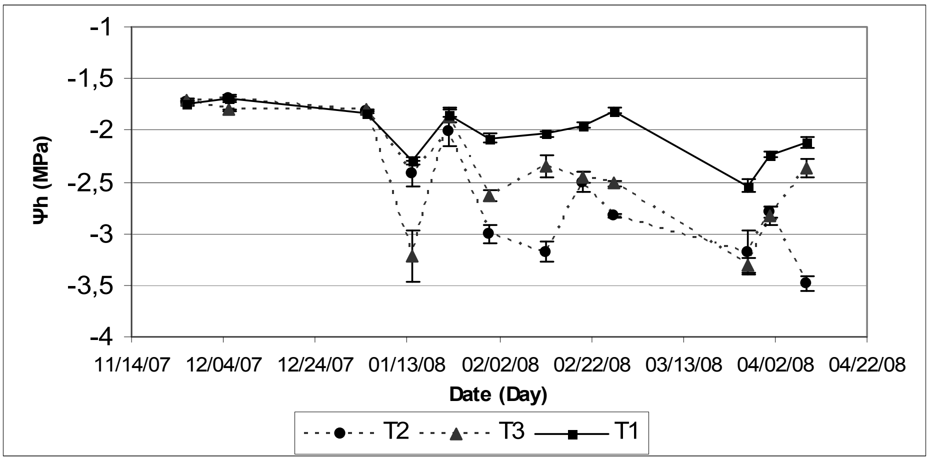

Fig. 3. Evolution of a midday leaf water potential in ‘Arbequina’ olive groves under three irrigation levels: T1 (no water deficit), T2 (water deficit from pit hardening to harvest) and T3 (water deficit from fruit set to harvest). Vertical bars represent the standard error.