

Interactive responses to water deficits and crop load in olive (*olea europaea* L., cv. Morisca) I. – Growth and water relations

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ABSTRACT

To characterize the interactions between variable water supply and crop load on vegetative growth and water relations of an olive orchard (cv. *Morisca*) planted in 1998 at 417 trees ha⁻¹, two different experiments were conducted over a six-year period (2002–2007) in Badajoz, Southwest of Spain. Experiment 1, assessed the responses during the early years of the orchard (2002–2004) using four irrigation treatments that applied fractions of the estimated crop evapotranspiration (ET_c) (125%, 100%, 75% and 0%) and three crop load levels (100%, 50% and 0% of fruit removal, termed off, medium and on treatments). Experiment 2, assessed the response of more mature trees (2005–2007) to three irrigation treatments (115%, 100%, and 60% of ET_c) and the natural crop load which were off, on, and medium in 2005, 2006 and 2007, respectively. Although vegetative growth was mainly affected by the level of water supply, crop load also influenced vegetative parameters, especially the interaction between high loads and water deficit. Trunk growth was more sensitive to water deficits than ground cover, and at the branch scale, water deficits reduced branch length and node numbers but only reduced internode length in on trees. Water relations were more affected by the level of water supply than by crop load. Nevertheless, the presence of fruits affected olive tree water status and, particularly, increased the stomatal conductance of on trees during late summer and early fall under all levels of water supply. Interactions between water stress and crop load levels were not very strong, and were more evident in mature than in young olive trees.

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1. Introduction

Olive (*Olea europaea* L.) has been grown traditionally for centuries in countries of the Mediterranean basin. The increase in olive oil consumption related to the perception of health-related benefits (Waterman and Lockwood, 2007) has led in the last two decades to the intensification and expansion of olive cultivation, inside and outside of the Mediterranean countries. At present, there are 7.6 million hectares of olive orchards in the world, of which 66% are located in the Mediterranean basin (FAO, 2010). Spain is first in acreage and in production of table olives and olive oil with 2.5 million hectares (MARM, 2010). In addition to the expansion of olive cultivation, there have been efforts in production intensification, notably by increasing tree density and by shifting from rain fed to irrigated conditions.

Outside table olive production, irrigation was seldom practiced for the production of olive oil until recently, even though it had been observed that very low volumes of applied water raised crop productivity substantially (Orgaz and Fereres, 2007). The introduction

of drip irrigation has transformed the industry; not only practically all of the newly irrigated plantations are under drip but also, a significant proportion of the old, rain fed plantations, are being transformed to irrigation with this method. The expansion of irrigation has been significant (Pastor et al., 2007); starting at around 10% in 1990, olive irrigated orchards in Spain now represent over 25% of the whole cultivated area in the country. The increase in irrigation water demand for this expansion cannot always be met, given the scarcity of water in many of these regions. The water supply restrictions have led to various forms of deficit irrigation (Fereres and Soriano, 2007) where water deficits are imposed, either continuously throughout the season or during specific developmental stages (Iniesta et al., 2009; Moriana et al., 2003). Deficit irrigation experiments have been carried out with different olive varieties; notably, *Arbequina* (Grattan et al., 2006; Iniesta et al., 2009); *Picual* (Moriana et al., 2003); *Muhasan* (Lavee et al., 2007); *Cornicabra* (Perez-Lopez et al., 2007) and *Frantoio* and *Leccino* (d'Andria et al., 2009; Tognetti et al., 2004). Concomitant with the investigations on deficit irrigation management, there has been renewed interest in characterizing the responses of the olive to water deficits (Tognetti et al., 2005, 2006, 2007, 2008) and the capacity of the tree to adapt to water stress conditions (Fernandez et al., 2006). Olive trees have the reputation of being drought resistant and knowl-

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edge of its responses to water stress would be important to design optimal deficit irrigation strategies.

The olive, as many other fruit trees, has an alternate bearing pattern by which fruit production fluctuates from high to low yields in two consecutive years (Monselise et al., 1983), often called on and off years; in fact, periodicity of the olive is very high (Lavee, 1996). Fruit production in olive depends directly on the vegetative growth of the preceding season because fruits develop from buds located in shoots of the previous year (Rapoport, 2007). The carbon demand from fruits in a year of high crop load limits vegetative growth, thus restricting the potential yield of the following year. Thus, it is the competition between vegetative and reproductive growth that is at the root of the alternate bearing behaviour (Berman and DeJong, 2003). In the olive, the yield ratio between on and off years may oscillate between 5 and 10 without management interventions (Lavee et al., 2007). It is therefore important to understand how olive trees respond to crop load and, given that vegetative growth is very sensitive to water deficits (Hsiao, 1973), how crop load and water status interact in determining the growth and ultimately the yield of olive trees. The effects of high crop loads on vegetative growth suppression and on tree water relations have been documented in other tree species such as peach (Berman and DeJong, 1996), plum (Intrigliolo and Castel, 2007), pear (Naor, 2001), and apple (Naor et al., 2008). However, there is little understanding of the effect of the combined effect of water stress and crop load on the vegetative growth and water relations of olive trees.

The olive cultivar *Morisca* is one of the most important cultivars in Southwest Spain (Extremadura) and in Portugal. This cultivar has a markedly alternate bearing pattern, even more than other cultivars in the same environment, but it is not known whether such behaviour is genetically determined or related to specific environmental factors. It has been observed that this cultivar is very vigorous, and that it produces excessive vegetative growth which is normally controlled by pruning. Hence, the use of deficit irrigation should be an ideal tool to manage tree size. Maintaining more compact canopies with deficit irrigation rather than by pruning would not only reduce production costs, but also lessen the amount of wood requiring disposal, as suggested by Goldhamer et al. (2006).

To investigate the interactions between crop load and the responses to water deficits, two field experiments have been conducted with the cv. *Morisca* which are reported in this and in a companion paper (Martín-Vertedor et al., 2011). The objectives of this paper were aimed at characterizing the vegetative growth of *Morisca* as affected by crop load under variable water supply, and at determining the effects of crop load on the water relations of this cultivar when subjected to water deficits.

2. Materials and methods

Two experiments were conducted; the first one (Experiment 1) investigated the interaction between different levels of applied water and crop loads on young olive trees, while the second (Experiment 2) studied the effect of different irrigation depths within annual variations in the natural crop load on older trees of the cultivar *Morisca*. This cultivar is known for having a marked alternate bearing behaviour, and is used for both oil and table olive production due to its high oil concentration and large fruit size.

2.1. Experimental orchard and climatic conditions

This work was performed during six years (2002–2007) in an olive (*O. europaea* L.) orchard cv. *Morisca* located at Vegas Bajas del Guadiana, Extremadura, Southwest of Spain (38°51'N, 6°40'S, altitude 200 m).

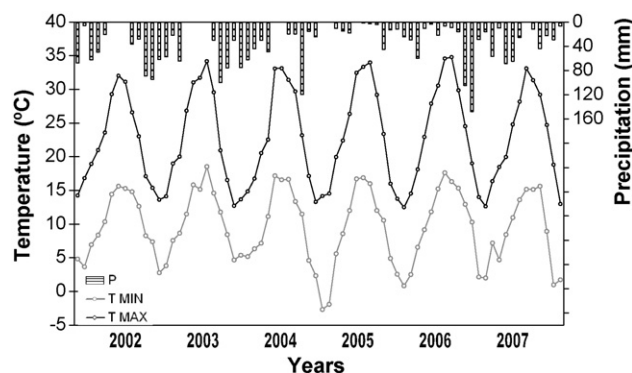


Fig. 1. Monthly records of maximum daily air temperature ($T_{\max}$, °C), minimum daily air temperature ($T_{\min}$, °C) and monthly rainfall (P , mm), during the six experimental years.

The climate of the area is Continental Mediterranean with Atlantic influence, dry and hot summers, and cold winters with irregular precipitations. The average rainfall for the six experimental years was 404 mm (Fig. 1 and Table 1). Only 2005 was particularly dry (260 mm; Table 1) whereas the rest of the years had around average precipitation. Reference evapotranspiration (ET_0) ranged between 1145 mm in 2002 and 1420 mm in 2005 (Fig. 1 and Table 1). Meteorological data were collected at an automated weather station located 800 m from the olive orchard which recorded half-hourly averages of global radiation, air temperature, relative humidity, wind speed and rainfall.

The soil is an Alfisol, suborder Xeralfs, group Haploxeralfs (USDA), and the profile shows a weak structure and light colors at the surface with low content of N, P and K. The soil is of sandy-loam texture with about 1% organic matter and 1.5 m depth. Drained soil water upper limit was $0.21 \text{ cm}^3 \text{ cm}^{-3}$ while the lower limit was $0.09 \text{ cm}^3 \text{ cm}^{-3}$. The soil was kept under no tillage using herbicides during all experimental years.

Olive trees were planted in 1998 at $6 \times 4 \text{ m}$ ($417 \text{ trees ha}^{-1}$) and were irrigated (every one to three days) with a drip system with four emitters (4 l h^{-1}) per tree, located on a single dripline. Water meters measured the amount of applied water in each plot. At the beginning of the experiments, the average tree canopy volume was around 12 m^3 . Standard cultivation practices of the area were used except for the irrigation schedule for both experiments and the fruit thinning in Experiment 1.

2.2. Experimental design

Experiment 1 was designed as a split-plot factorial, with four irrigation levels as main plots and three crop load levels as subplots (Fig. 2A). The irrigation treatments were replicated four times for every crop load level and each main plot consisted of three adjacent rows with three trees each. The central tree was used as experimental tree and the rest as guard trees. Experiment 2 consisted

Table 1

Annual ET_0 and rainfall (R , mm) for the six experimental years, and irrigation season period (ISP, day of year) and seasonal water applications for the irrigated treatments of Experiment 1 (E, C, and MD during 2002–2004) and for the three treatments of Experiment 2 (E, C, and SD during 2005–2007).

	2002	2003	2004	2005	2006	2007
ET_0	1145	1169	1290	1420	1315	1263
R	447	441	460	260	465	356
ISP	126–291	138–287	132–292	109–283	115–289	131–291
E	340	414	558	553	702	350
C	272	331	447	428	388	305
MD	204	248	335	–	–	–
SD	–	–	–	161	180	193

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