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Complementary irrigation for sustainable production in olive groves in Palestine

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ABSTRACT

Prolonged drought stress in Palestine is one of the major limiting factors in the production and yield of the fruit of the olive tree, as this directly affects crop load, oil production per tree, oil quality and alternate bearing. The objective of the present study was to investigate the use of limited amounts of water as complementary irrigation to improve olive fruit growth and yield at harvest. Field-grown adult olive trees (*Olea europaea* L. cv. Nabali Baladi) were selected in three villages on the northern West Bank, and they were subjected to different complementary irrigation regimes from June to September, 2010. They were thus supplied with 1, 3, 6 m^3 water irrigation per tree over this entire period, corresponding to 2.4%, 7.1%, 14.2% of the whole seasonal water requirement per tree (42 m^3 water), respectively. Additional five rain-fed trees per site were used as controls. In one of the three villages, an additional treatment with 15 m^3 (35.6% of the total need) water irrigation per tree, was also applied. The results showed that the fruit size, pulp-to-pit ratio (on a fresh and dry weight basis) and 1-year-old mixed shoots were not affected by these water irrigation regimes. Total fruit yield per tree increased as the water irrigation increased, with the greatest effects for the highest water irrigation treatment, due to a higher number of fruits per tree (apparently due to lower fruit abscission). This study demonstrates that complementary water irrigation of olive trees to 35% of the whole seasonal water requirement can produce positive effects on olive fruit production in Palestine.

1. Introduction

Olive oil value-chain represents a pivotal sector in Palestine's economy and the primary source of income for more than 100 thousand families: olive tree cultivated areas account for about 93,000 ha (PCBS, 2009) and the average olive oil production is around 17,000 t per year (IOC, 2012).

However, olive trees in Palestine suffer for prolonged drought and high temperatures during the growing season. Under such conditions, the canopy and root vegetative development are negatively affected (Tognetti et al., 2006; Lodolini et al., 2011b). This aspect strongly affects the olive fruit production, and accentuates the natural tendency of the olive trees to alternate bearing bringing yield fluctuations up to 90% between year to year. Therefore, irrigation was considered the most effective tool to enhance olive fruit production and to maintain balanced vegetative growth, with the objective being to reduce the alternate bearing of these olive trees.

For water-irrigated olive groves, it has been shown that the olive yield can be increased by more than 100% in comparison with rain-fed olive trees (Goldhamer et al., 1994; Pastor et al., 1998; Patumi et al., 1999), depending on climate conditions, olive cultivar, and olive tree density and cultivation technique. Several studies have reported that particularly the fruit size, pulp-to-pit ratio, mesocarp cell size, and oil content can be positively affected by increasing the water supply to olive trees (Lodolini et al., 2011a,b; Gucci et al., 2009, 2011; Costagli et al., 2003; Inglese et al., 1996; Lavee et al., 1990; Proietti and Antognozzi, 1996). Moreover, recent studies have suggested that it is not necessary to irrigate olive trees with the whole yearly water amount that would be required by their calculated evapotranspiration. Indeed, in different environments, it was possible to reduce the amount of water applied during the growing season without negative effects on the olive fruit and oil yields (Moriana et al., 2003; Alegre et al., 2002).

Gucci et al. (2007) reported that water irrigation of olive trees can increase the number of fruits per tree, the fruit yield (on both a fresh weight [FW] and a dry weight [DW] basis), the single fruit FW, and the oil content in the mesocarp (on a DW basis) at harvest.

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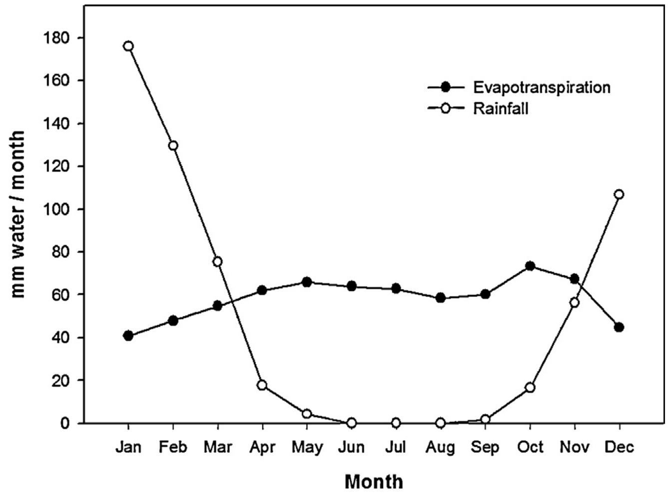

Fig. 1. Monthly olive evapotranspiration and rainfall trend during the year for northern Palestine, estimated as means from 11 years of data (1997–2008). The water deficit period runs from April to November (8 months).

Furthermore, no significant differences were shown between fully water-irrigated olive trees (i.e. 100% evapotranspiration requirement) and those receiving 46% of this total water requirement, using regulated deficit irrigation conditions (Servili et al., 2007). Indeed, this study showed a negative correlation between the total polyphenol content in the olive oil produced and the water status of the olive trees.

To investigate olive tree responses to complementary irrigation as a sustainable water management in a country where water availability is greatly limited, the present study aimed to identify the minimum water irrigation levels for induction of significant increases in the fruit yield in adult olive groves in Palestine (West Bank), as compared to rain-fed conditions.

2. Materials and methods

2.1. Evapotranspiration in Palestine

The total water requirement for olive trees under these Palestinian environmental conditions was estimated by standard methods based on 11 years (1997–2008) weather data for the Nablus and Tulkarem districts (northern West Bank). The calculation of the monthly reference evapotranspiration was carried out according to the Hargreaves equation. Crop evapotranspiration was calculated according to the method of the Food and Agriculture Organization of the United Nations (Doorenbos and Pruitt, 1974). This used the monthly crop coefficients, as reported by Orgaz and Pastor (2005) for similar environmental conditions (Jan: 0.82, Feb: 0.83, Mar: 0.59, Apr: 0.50, May: 0.42, Jun: 0.40, Jul: 0.37, Aug: 0.38, Sep: 0.48, Oct: 0.72, Nov: 0.97, Dec: 0.89), and a coefficient of ground cover of 1.0, determined from the mean diameter of the canopy-projected area of each tree at solar noon (Orgaz and Fereres, 1997). The estimations show that the total water requirement for the olive groves in Palestine is supplied by water irrigation of ca. 42 m^3 per tree through the water-deficit season.

Fig. 1 shows the monthly olive tree evapotranspiration and rainfall trends during the year in the study area, indicating that the water-deficit period can be from April to November (8 months) and rainfall are absent or negligible from May to September.

Table 1
Complementary water irrigation schedule.

Irrigation timing	Irrigation treatment (m^3/tree)			
Mid-June	–	1.0	1.0	2.0
End of June	–	–	1.5	2.2
Mid-July	0.5	1.0	1.5	2.2
End of July	–	–	–	2.2
Mid-August	0.5	1.0	1.0	2.2
End of August	–	–	–	2.2
Mid-September	–	–	1.0	2.0
Total (m^3/tree)	1	3	6	15
%Total evapotranspiration (100% = 42 m^3)	2.4	7.1	14.2	35.6

2.2. Experimental layout

The experimental work was carried out in three different olive groves with adult olive trees. These were selected in three villages in Palestine: Burin (latitude 32°10′41″N; longitude 35°14′54″E; altitude 545 m a.s.l.; Nablus district), Far'un (latitude 32°17′07″N; longitude 35°01′16″E; altitude 139 m a.s.l.; Tulkarem district) and Haja (latitude 32°11′49″N; longitude 35°07′25″E; altitude 324 m a.s.l.; Qalqilya district).

In the spring of 2010, 20 olive trees (cv Nabali Baladi) at similar growth stages were selected in both Burin and Far'un, and 25 olive trees in Haja, for a total of 65 trees. The mean (±standard error) trunk diameter, trunk cross-sectional area and canopy volume (assuming a cylindrical shape) were measured as 0.51 ± 0.02 m, 0.2805 ± 0.029 m^2 and 165.66 ± 11.2 m^3, respectively. The olive trees were spaced in 10 m × 10 m arrays (tree density, ca. 100 tree ha^{-1}).

In each olive grove, completely randomized blocks of 5 replications were subjected to different complementary water irrigation regimes, using several 220 l barrels (according to the water needed) that had holes drilled in the lower side and were located under the perimeter of the canopy projection on the ground. These barrels were refilled with water according to the scheme reported in Table 1 and water release on the ground was controlled during each irrigation date. The different water irrigation treatments were kept well separated to prevent water infiltration across the randomized blocks that could confound the applied water treatments.

2.3. Water irrigation

The complementary water irrigation was managed to supply 1, 3, 6 (and 15 only for Haja) m^3 of water per tree over the period from mid-June (8 weeks after full bloom) to mid-September (20 weeks after full bloom). These water amounts corresponded to 2.4%, 7.1%, 14.2% (and 35.6%), respectively, of the total water requirement for olive tree evapotranspiration in Palestine (i.e. 100% = 42 m^3). In each olive grove, a group of five rain-fed trees was used as the control. The irrigation schedule and supplied water are reported in Table 1.

Data loggers (Testo 175–H1, Testo SpA, Milano, Italy) were placed in each olive grove inside the canopy of a tree, to record air temperature and relative humidity at 60 min intervals throughout the experimental period. The sensors were shielded from direct sunlight. The precipitation records were obtained from the nearest weather station to each olive grove.

In the period from June 1 to October 20, 2010, no precipitation was recorded, and the mean air temperature was 27.1 °C.

2.4. Cultivation practices

Standard cultivation practices for olive groves in Palestine were used, with no fertilizers applied during the irrigation period. Olive fly was periodically monitored, but no spray applications were needed as there was no attack on the fruits through the whole experimental season.

2.5. Shoot measurements and olive sampling

Before the beginning of the experimental period, for each olive tree, eight 1-year-old mixed shoots (total 40 per treatment per olive grove) around the canopy at 1.5 m to 1.8 m from the ground were selected and labelled. Their seasonal vegetative growth was calculated as difference between the length measurements at the beginning of the experimentation and at the harvest time.

Ten non-injured fruits per experimental olive tree were randomly sampled every two weeks from 1.50 to 1.80 m from the ground, and their FW was recorded.

Immediately before the harvest, 100 fruits were sampled from around the canopy of each olive tree, to measure the mean fruit weight and for the calculation of the total number of fruits per olive tree, and to determine the maturation index according to standard methodologies (skin and pulp colors, on a scale from 0 to 7, according to Beltran et al., 2004).

From the same 100 fruits, 20 were selected to measure their FW. Once the pulp had been removed from each fruit, the FW and DW of the mesocarp + epicarp and endocarp were measured separately.

The total fruit production per tree was recorded at harvest (on October 11 for Burin, October 17 for Far'un, and October 5 for Haja at 23, 24 and 22 weeks after full bloom, respectively).

The oil content of the mesocarp was determined by extracting dry material with 40–60 °C petroleum ether using a Soxhlet apparatus (Donaire et al., 1977) and according to each water treatment of the olive trees in each olive grove, combining together the 20 olive fruit per tree previously sampled for FW and DW. The oil yield at harvest was calculated for individual trees according to the following equation:

$$\text{Oil yield} = (\text{MOC}) \times (\text{FFY}) \times \left(\frac{\text{M}}{\text{F}}\right) \times \left(\frac{\text{DW}}{\text{FW}}\right) \quad (1)$$

where MOC is the mesocarp oil content on a DW basis, FFY is the fruit fresh yield, M/F is the mesocarp/fruit ratio, and DW/FW is the ratio between the dry and fresh weights.

One oil sample per treatment (combining those of the three locations) was collected after the fruit processing, and subjected to chemical and sensorial analysis.

2.6. Statistical analysis

A multisite statistical design with olive groves as the site factor and irrigation as the treatment factor, by using the 4 irrigation treatments (rain-fed and 1, 3 and 6 m^3 of water per tree) applied on all the olive groves was used. The two-way ANOVA was performed to compare experimental groves and treatments interaction and the analysis of variance (ANOVA) and the post-hoc comparisons using the Newman–Keuls test ($P < 0.05$) were applied to identify significant differences among the water treatments (data given as the means from all of the olive trees in each of the three locations).

The regression analysis for the data of the olive grove located in Haja (highest number of irrigation treatments) was carried out to determine the quantitative effects of water irrigation regime.

3. Results

The fruit production (FW) per tree at harvest was increased by increasing the water irrigation regime (Figs. 2 and 3). In particular, with the addition of 15 m^3 water per tree over the period June–September in the olive grove in Haja, which corresponds to ca. 35% of the total water requirement according to the calculation of the olive tree evapotranspiration for this period in the study area, there was a significant fruit FW yield increase, in comparison with the control, rain-fed trees. This treatment more than doubled the mean FW olive fruit production per tree when compared to the rain-fed trees, and when compared to the 1 m^3 water irrigation (Fig. 3; mean of control and 1 m^3 water: 29.7 versus 62.7 kg fruit FW per tree; $P < 0.05$). No interaction between olive grove × irrigation treatment was found ($P = 0.06$) and no significant differences were seen between the control and the 1, 3 and 6 m^3 water irrigation regimes (Fig. 2). The regression analysis between the water supplied and the fruit produced as FW per tree canopy volume at harvest showed a positive and linear interaction (Fig. 3).

Similar results were seen for the number of fruits per tree at harvest (Figs. 4 and 5). Here the 15 m^3 water irrigation induced an increase to almost twice the control and the 1 m^3 water irrigation (mean of control and 1 m^3 water: 10,755 versus 21,495 fruits per tree ($P < 0.05$). Again, no interaction between olive grove × irrigation treatment was found ($P = 0.14$) and no significant differences were seen between the rain-fed trees and the 1, 3 and 6 m^3 water irrigation regimes, although there was a positive

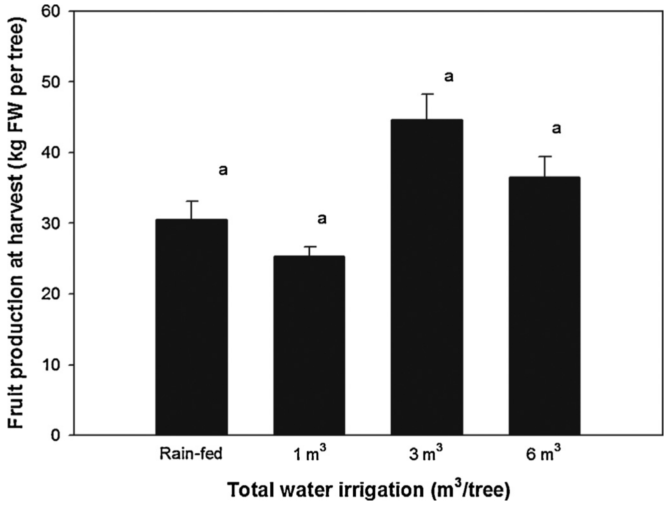

Fig. 2. Fruit production (FW) per tree at harvest according to increasing amounts of total water irrigation. Data are means + standard errors of 15 replicates for rain-fed, and 1, 3 and 6 m^3 water irrigation conditions. Different letters indicate significant differences between treatments (Newman–Keuls test; $P < 0.05$).

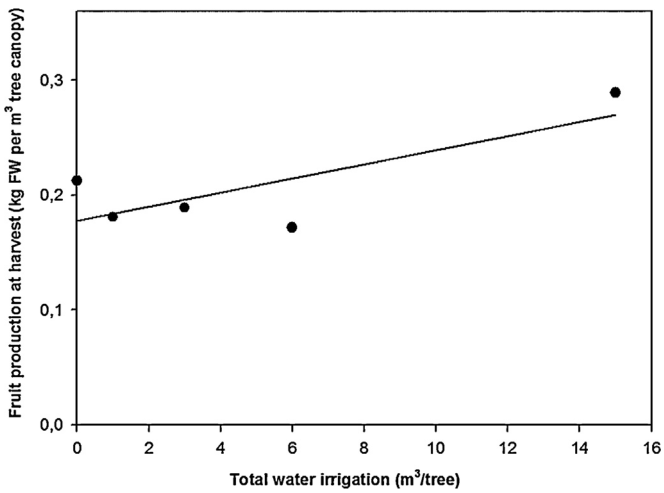

Fig. 3. Fruit production (FW) per canopy volume (m^3) at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 0.18 + 6.14x$; $R^2 = 0.61$).

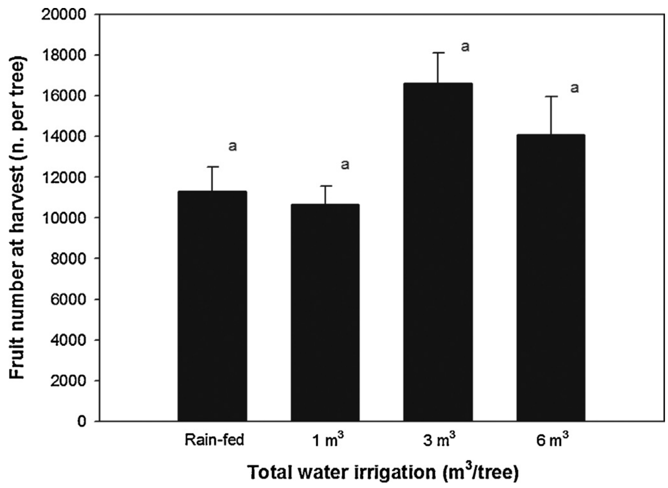

Fig. 4. Fruit number per tree at harvest according to increasing amounts of total water irrigation. Data are means + standard errors of 15 replicates for rain-fed, and 1, 3 and 6 m^3 water irrigation conditions. Different letters indicate significant differences between treatments (Newman–Keuls test; $P < 0.05$).

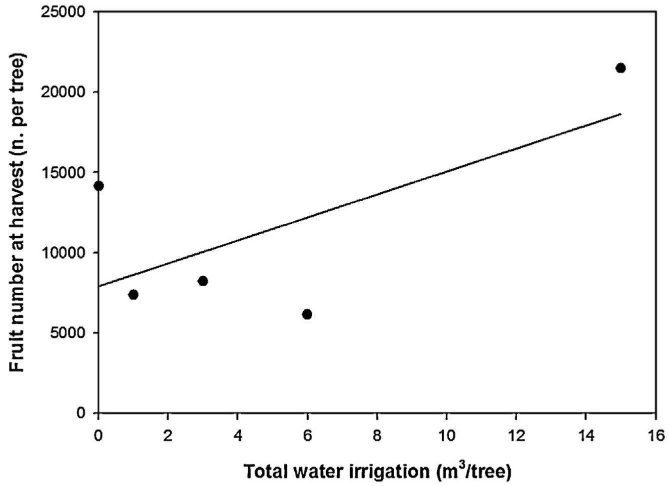

Fig. 5. Fruit number per tree at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 7890 + 715x$; $R^2 = 0.46$).

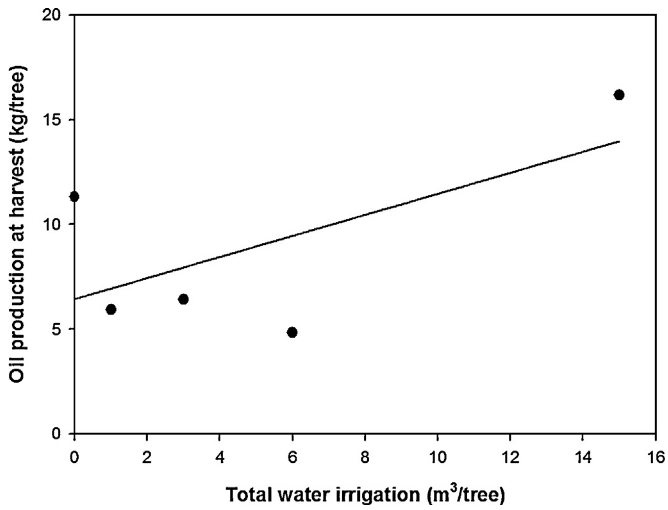

Fig. 6. Oil per tree at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 6.42 + 0.50x$; $R^2 = 0.41$).

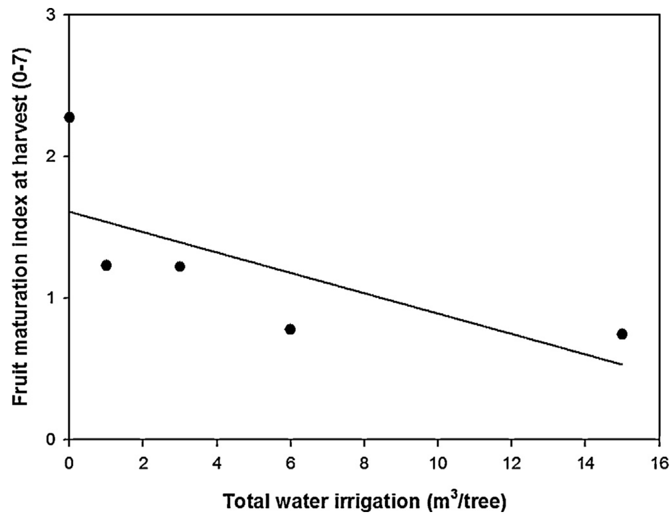

Fig. 7. Fruit maturation index at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 1.61 - 0.072x$; $R^2 = 0.49$).

and linear interaction between increasing water supplied and increasing fruit number per tree according to the regression analysis (Fig. 5).

The oil content in the fruit, expressed as percentage on DW basis, did not show a direct relationship with the irrigation water regime (average value: 60.5 ± 1.13%), while the olive oil production per tree at harvest was positively affected by increasing water irrigation (Fig. 6). In particular, the 15 m^3 water irrigation in the olive grove in Haja showed a significant increase when compared to the rain-fed trees, and to the lower water irrigation conditions ($P < 0.05$ for all). Indeed, again there was a doubling here when comparing the combined mean of the control oil production and that with 1, 3 and 6 m^3 water irrigation (mean, 7 kg per tree) with the 15 m^3 water irrigation (16 kg per tree; $P < 0.05$). As indicated here, there were again no significant differences in the oil production per tree between the control and the 1, 3 and 6 m^3 water irrigation regimes for the three olive groves.

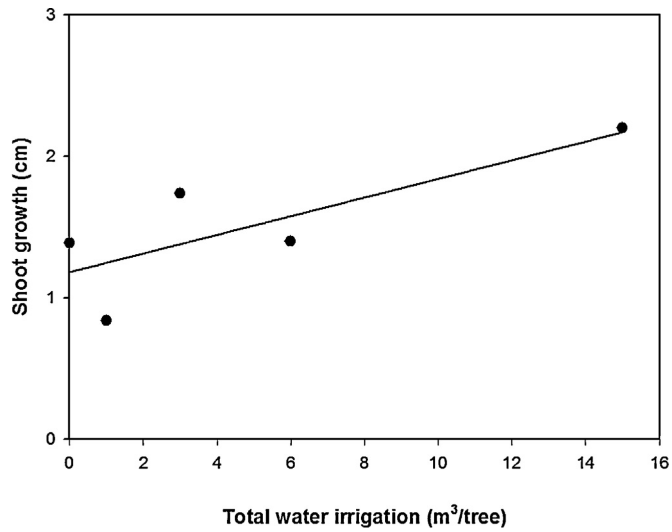

Fig. 8. One-year-old mixed shoot growth according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 1.18 - 0.062x$; $R^2 = 0.63$).

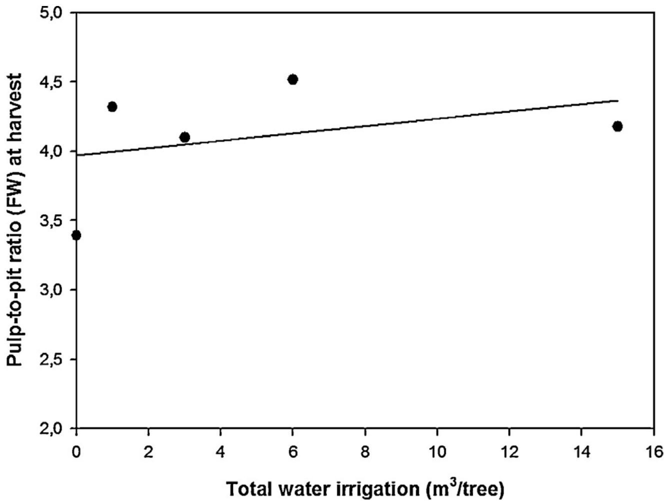

Fig. 9. Pulp-to-pit ratio at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are means of 5 replicates for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 3.97 + 0.026x$; $R^2 = 0.14$).

The fruit maturation index at harvest was decreased by increasing the water irrigation (Fig. 7). The rain-fed trees promoted higher values of fruit maturation (2.27), while the increasing water irrigation induced a decrease in the fruit maturation (regression analysis in the olive grove in Haja): 1.23, 1.22, 0.77 and 0.74 for 1, 3, 6 and 15 m^3 water irrigation regimes, respectively. This reached significance between the control and the 15 m^3 water irrigation ($P < 0.05$).

These water irrigation regimes did not, however, affect the vegetative growth of 1-year-old mixed shoots; indeed, for these shoots, there were no significant differences among any of the water irrigation conditions within each olive grove (data bit shown), but a positive and linear interaction between increasing water supplied and increasing shoot elongation was recorded in Haja according to the regression analysis (Fig. 8).

Similarly, the water irrigation did not affect the fruit seasonal growth trend (for both FW and DW) and the fruit, mesocarp and endocarp FWs or DWs at harvest (data not shown). However, a slightly positive relationship with increasing water irrigation regimes was recorded for all these parameters in Haja olive grove, as shown for the fruit pulp-to-pit ratio expressed on a FW basis (Fig. 9).

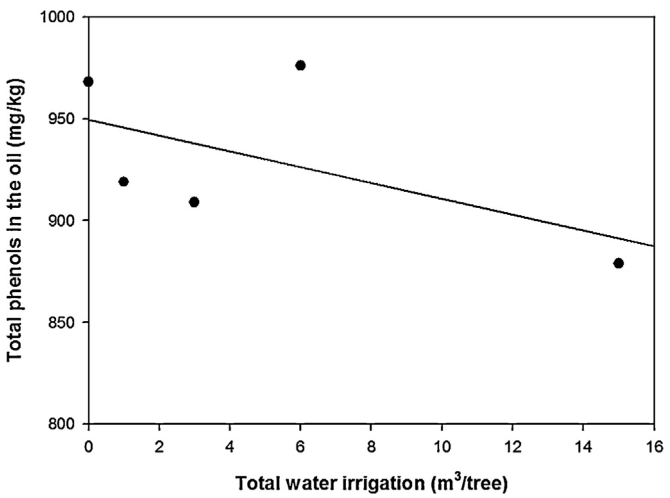

Fig. 10. Total polyphenols content in the oil at harvest according to increasing amounts of total water irrigation in Haja experimental grove. Data for linear regression are for 1 replicate for rain-fed, and 1, 3, 6 and 15 m^3 water irrigation treatments ($y = 949.65 - 3.89x$; $R^2 = 0.33$).

Finally, the oil chemical and sensorial characteristics were not affected by the water irrigation, with all of these values remaining within the normal range for each of the parameters for the extra virgin olive oils produced in these areas. The one exception here was for the total phenols content, where a slightly negative relationship was seen with increasing water irrigation regimes (Fig. 10).

4. Discussion

The present study shows that for the Palestinian environmental conditions (prolonged drought and high temperatures) the complementary water irrigation with 35% of the total seasonal water requirement does significantly increase the yield of these adult productive olive trees. When compared with the other treatments, the highest irrigation level tested here significantly increased the mean fruit production per tree (expressed both on FW and DW basis), as well as the mean oil production per tree. Indeed, as with the rain-fed (control) condition here, under the more severe of our water-deficit conditions (1, 3 and 6 m^3 water irrigation), this would have induced fruit abscission, as was reported by Inglese et al. (1996), although in the present study there was no (fruit drop) data collected to confirm this. Among the tested irrigation regimes, only 15 m^3 promoted a significant higher crop load as compared to rain-fed conditions.

The higher water irrigation level tested in the present study did not affect fruit growth during the season, or the fruit mesocarp, endocarp and pulp-to-pit ratio at harvest, on both a FW and DW basis, with no significant differences across the water irrigation treatments seen here. Similar results were seen for the mixed shoot growth, with no significant increases recorded even for the 15 m^3 water irrigation.

These results confirm that a drought stress during the early fruit development (included between fruit set and pit hardening), even followed by an irrigation until harvest, strongly affects the fruit and the mesocarp and endocarp growth, as reported by Gucci et al. (2002), and that beside the requirement for even higher amounts of water, start the irrigation earlier in the season would positively affect fruit and shoot growth under such environmental conditions.

Furthermore, not only the amounts of total water irrigation per tree and starting time, but also the complementary irrigation schedule was important in determining the reported results: biweekly irrigation treatments with 2.2 m^3 per tree showed to reduce drought stress and promote significant higher crop load.

Also, the complementary water irrigation did not affect the chemical or sensorial characteristics of the oil produced, which in the study areas, normally has an evident ripened tomato fruity aroma and dry-wood sensations. However, the 15 m^3 water irrigation appears to represent the threshold for a change in the total phenols content (perceived as bitter and pungent sensations), although without affecting the sensorial characteristics under these study conditions.

5. Conclusions

The data presented in this study show that complementary water irrigation carried out every two weeks through the summer period to supply 35% of the total calculated evapotranspiration needs (42 m^3 water) of the adult olive trees helps to increase their yield under the conditions in Palestine. Indeed, the amount of 15 m^3 water irrigation per tree through the season represents the threshold to obtain significant fruit and oil production increases, as compared to the rain-fed conditions. However, further investigations are necessary to identify the optimal complementary water irrigation and the timing to also affect the fruit size and stimulate the vegetative growth of the fruiting shoots.

The experimental approach used in the present study represents an innovation for the Palestinian territories (northern West Bank), and these data will be helpful to identify the minimum irrigation levels for the olive groves in this area. This will thus provide improvements to the olive oil yields and production, while overcoming the drought stress during fruit growth, to avoid sensorial defects (like an excessive dry-wood sensation) and to increase the quality of the olive oil while maintaining higher total polyphenols content.

However, the authors are well aware that the effective water irrigation regime indicated by the results of the present study is high, and that at present, reliance on groundwater cannot be considered as a feasible strategy that can be broadly diffuse in Palestine, due to restrained access and too high a cost. The development of non-conventional sources of water for agricultural reuse would partially overcome this limiting factor, as it might make available such no negligible quantities of water for this supplemental water irrigation.

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