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Olive oil production as influenced by different quantities of applied water

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ABSTRACT

Irrigation management can have a profound influence on olive oil production. We initiated a 2-year study in the spring of 2002 to identify the optimal level of applied water on a super high tree-density (spacing 1.5 m × 3.9 m) olive (*Olea europaea* L.'Arbequina I-18') orchard. Irrigation water was applied by drip irrigation to produce different water-application treatments of 15, 25, 40, 57, 71, 89, and 107% ET of non-stressed trees in 2002 and 28, 33, 55, 74, 93, 117, and 140% ET in 2003. Tree growth was monitored by changes in trunk diameter and branch length and their increases over the season were very responsive to irrigation treatments. Mid-day stem water potentials (SWP) were measured periodically throughout the season and values ranged between −0.2 and −4.1 MPa. Differences in stem water potential were consistent with the irrigation treatments and decreased with reduced water applications after stored soil water was depleted. Stable isotope discrimination was an effective indicator of seasonal tree-stress experience and increased in a second order function to the applied water. Fruits were harvested at two different times at the end of each season to evaluate treatment effect in relation to harvest date. At each harvest, fruit production (kg/ha) followed a second order relationship ($r^2 = 0.79$–0.99) with applied water. Olive oil was extracted using the Abencor method and the percentage of oil extracted from the fruit decreased linearly ($r^2 = 0.91$–0.93) with increased applied water for three out of the four harvests. The overall quantity of oil extracted per area followed a second order function ($r^2 = 0.71$–0.94) in three of the four harvests. In 2003, there was a poorer correlation ($r^2 = 0.56$) between oil yields and irrigation treatment for the earlier harvest. However, for the second harvest, total oil yield per tree increased with applied water reaching a maximum at 408 mm (75% ET). Data from both harvests in 2002, on the other hand, indicate that an optimum oil extraction is achieved over a wide range of treatments (i.e. 196–491 mm (ET_c 40–89%)). Therefore, our data indicate that oil yields can be maximized over a rather broad range of applied water because increases in fruit yield with increased applied water can be off-set to a large extent by the reduction in the percentage of oil extracted. Oil quality must also be considered when optimizing the amount of applied water.

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1. Introduction

Olive oil production has a long history in Mediterranean countries. Historically, olives were produced under dry-land conditions where trees were spaced widely to take full advantage of the stored soil water from winter rains for spring and summer growth. More recently, new orchards are irrigated by low-pressure systems and are planted at higher densities achieving greater yields and resulting in less alternate-bearing behavior (Beede and Goldhamer, 1994). In California, olive oil has increased in popularity and there is a growing interest among certain growers for producing an oil of high quality.

Studies have shown that irrigation can increase olive production (Samish and Spiegel, 1961; Lavee et al., 1990; Girona, 1996; Moriana et al., 2003) thereby increasing total oil production per tree. However, studies differ regarding their overall performance to applied water. For example, Patumi et al. (1999) found that irrigation of olives increased yields substantially over those that were rain-fed, but that applying 24–75 mm of water made no difference. Pastor et al. (1999) also showed that irrigation in southern Spain had a dramatic effect on yield but found no difference in treatments that applied between 150 and 320 mm. Therefore, these studies showed that irrigation increased yields even though there was no statistical difference between applied amounts.

Moriana et al. (2003) found that oil yields from a mature orchard in southern Spain increased dramatically with increasing applied water achieving a maximum crop evapotranspiration (ET_c) between 700 and 800 mm. They found that yields followed a second order function rather than a simple linear response. Baratta et al. (1986) found optimal yields for olives in Sicily to be achieved with slightly higher application rates 800–1000 mm). Despite these important findings in the literature, little irrigation-management research has been conducted on super-high-density plantings of olives to optimize olive oil production and quality.

The super-high-density system (1500–2500 trees per/ha) was developed within the past decade to use over-the-row mechanical harvesters to reduce the costs of hand harvesting and to bring orchards into production within only a few years after planting. In order to limit tree size within this system and accommodate the harvester, vegetative vigor of the tree must also be managed. Many questions arise as to the effects of different irrigation levels on shoot growth, flowering, fruit set, fruit size, fruit maturity, oil extraction, oil chemical attributes and oil sensory characteristics.

Therefore, we conducted a 2-year study to determine the effects of different quantities of applied water on the growth and water relations of ‘Arbequina’ olive in a super high-density orchard near Oroville, California. Specific objectives were to quantify the impacts of irrigation treatments on oil production, fruit yield, fruit set, and fruit size. Irrigation effects on the oil quality, both chemical and sensorial, are documented in another paper (Berenguer et al., 2006). Therefore, the overall objective of this two-component oil quantity/oil quality study was to find an optimal range of irrigation treatments that provided both high oil production and high quality oil.

2. Materials and methods

The 2-year experiment began in the spring of 2002 at a large ranch in California’s Sacramento Valley near Oroville with 30 month-old olive trees that were drip irrigated. The summer temperature in this area often exceeds 35 °C and the reference evapotranspiration (ET_o) was 1370 mm in 2002 and 1290 in 2003. Most of the rain occurs in non-summer months and rainfall amounts during the 2001–2002, 2002–2003, and 2003–2004 seasons were 545, 595, and 460 mm, respectively. The soil type at the site is a gravely sandy loam with a hard pan at 0.75–1.0 m depth. The orchard is planted with the variety ‘Arbequina I-18’ at a high density (1.5 m × 3.9 m) equalling nearly 1700 trees/ha.

Seven irrigation treatments were imposed on 24 April 2002 that applied different amounts of water throughout the season. The various treatments received cumulative seasonal water applications of 58, 101, 202, 303, 404, 505, and 606 mm, corresponding to 15, 25, 40, 57, 71, 89, and 107% ET_c, respectively. The experiment was designed as a randomized block with three replications. Each of the 21 plots consisted of eight trees within each of three adjacent rows. The center four trees were selected for all measurements and harvest and surrounding trees were considered “guard tree” borders. All trees were drip irrigated with different combinations of 2 and 4 L/h pressure-compensating emitters (1–3 emitters/tree) to achieve the various treatments. Regardless of differences in emitter spacing among treatments, the soil surface was wet more or less a continuous strip after each irrigation, with exception of the two driest treatments. The lowest water-application treatment differed from the other treatments in that initially it was without irrigation until 22 July 2002 when trees showed considerable stress. At this time a single emitter per tree was added which applied the same rate as the second-lowest water application treatment. Irrigations continued through October 9 resulting in a total of 32 irrigations.

In 2003, the experiment was repeated using the same plots and trees but the orchard managers wanted to increase the seasonal applied water to increase the vegetative growth of the young trees. This was done primarily by increasing the irrigation frequency from 5 to 6 times per month in 2002 to 12 to 14 times per month in 2003. In this later year, each of the seven irrigation treatments received 28% (112 mm), 33% (136 mm), 55% (272 mm), 75% (408 mm), 93% (544 mm), 117% (680 mm), or 140% (816 mm) of non-stressed tree ET_c. Irrigation treatments began on May 29 and continued until October 19 resulting in 68 irrigations.

Pruning, fertilizer, weed control, and pest management practices were done according to normal grower practices. Leaf petiole samples were collected each year and analyzed for N, P, and K to verify that plant nutrition was adequate.

Olive evapotranspiration (ET_c) was determined using the daily reference evapotranspiration (ET_o) provided by a nearby CIMIS (California Irrigation Management Information System) weather station, a crop coefficient (K_c) of 0.75 for olive obtained experimentally in California (Beede and Goldhamer, 1994) and a reduction coefficient (K_r) (Fereres and Castel, 1981) to account for orchard maturity (i.e. total canopy coverage). The K_r applies to canopies less than 50% ground cover and is described as $K_r = 2C/100$ where C is percent canopy cover. Therefore, the water use of olive trees (ET_c) was calculated as $ET_c = ET_o \times K_c \times K_r$.

Canopy coverage was measured each year at the initiation of irrigation treatments and again after fruit harvest. Initially, trees across all treatments were very uniform and K_r values for all treatments were 0.53, before treatments were imposed in 2002. K_r values increased at different rates depending upon treatment. The K_r values at the end of the experiment in November 2003 were 0.72, 0.74, 0.85, 0.94, 1.0, 1.0, and 1.0 for the seven treatments listed in order of increasing water application.

The ET_o varied from 26 (December) to 210 (July) mm in 2002 and 20 to 206 mm for respective months in 2003.

Tree measurements were made at monthly intervals during each season to characterize growth, fruit set, and water relations. Five branches on each of the four center trees were tagged to measure changes in branch length (i.e shoot growth). Trunk diameters were also measured about 30 cm above the soil surface with callipers at the same marked point on the trunk and oriented in the same position at each measurement.

Water relations and stress response in trees were evaluated physically by measuring stem water potentials and biochemically using carbon isotopic discrimination. Stem water potential was measured using pressure chambers on leaves that were covered with foil-faced bags after at least 15 min prior to measurement to allow equilibration. Field evaluations indicated that two leaves per tree were sufficient for quantifying stem water potential in any particular tree (Shackel and Mameli, personal communication). Some branches in each plot were also tagged at the beginning of each season for delta ^{13}C determination to be used as an indicator of cumulative tree-water-stress over the season. Carbon isotopic discrimination reflects changes in leaf diffusive resistance among treatments and therefore is indirectly related to water stress. A marker was used to indicate the meristematic point at the beginning of the season and at the end of the season, all new growth beyond this point was sampled, dried, and ground into fine powder for delta ^{13}C analysis. Carbon isotopic discrimination is defined $\Delta = (\delta_a - \delta_p)/(1 + \delta_p)$ where δ_a and δ_p are the isotopic compositions of air and plant material, respectively (Farquhar et al., 1989). This index describes the tree's ability to selectively fix $^{12}CO_2$ over $^{13}CO_2$. This ability to discriminate is inversely related to tree stress (Poss et al., 2000).

Soil matric potential was also measured in the center block on four treatments (wettest, third wettest, third driest, and driest). At each of these four stations, nine WaterMark sensors[1] were monitored. Three sensors were placed in the tree row, below the drip line at 30, 60, and between 75 and 90 cm depths. The depth of the deepest sensor varied representing the maximum root depth and the top of the hard pan. An additional three sensors were installed at equivalent depths directly in the center between tree rows and the third set of three were installed at equivalent depths midway between the tree-row station and the center-row station. The sensor positions provided us with a nine-point grid allowing us to observe root-water extraction patterns, two-dimensionally over each season.

Measurements were also made on flowers to estimate fruit density (number of fruit per length of branch), fruit retention (percentage of the initial fruits that remained at the end of the season), and fruit set (percentage of initial flowers with fruit at harvest). These measurements were made on each of the tagged branches used to characterize growth. Just prior to bloom, 10 consecutive inflorescence pairs were marked and the number of flowers on each inflorescence was counted. Fruits that remained at each of the positions during the season were later counted and recorded. Fruit set was only measured on node 5 in 2002 and nodes 4, 5, and 6 in 2003 since previous studies have shown that these middle nodes provide a good assessment of fruit set (Martin et al., 1993).

At the end of the season, two separate harvests were made to determine effects of irrigation treatments on oil content/extraction and quality in relation to early and late harvests. We found that harvesting at two different times was useful particularly since irrigation affects fruit maturity. Therefore, data spanning over two time periods can provide insight regarding the rate of fruit maturity among treatments. In 2002, the first harvest was 31 October and the second was the 18 November. In 2003, harvests were 28 October and 25 November. Trees within the experimental plots were individually harvested by hand while the rest of the ranch continued with over-the-top mechanical harvesters. At each harvest, fruit weight, fruit water content, and the total oil content were determined on each individual tree that was harvested for that particular date. Fresh-fruit samples were taken to the laboratory and stored in a cold room at 4 °C. The individual fruit size was determined by weighing a random sample of 100 fruits. Olive oil was extracted using the Abencor method (Martínez et al., 1975) and oil percentages (v/v) were determined. Maturity index and oil quality were also determined and results are reported in a separate paper.

In 2004, all experimental treatments were returned to normal grower's practices. Nevertheless, measurements were made on the same trees monitored the previous 2 years to characterize return bloom, fruit yield, and fruit size. Trees were harvested on 22 October.

3. Results and discussion

3.1. Tree growth

The volume of applied water had a profound influence on branch growth. During the first year, differences in growth rates were detected as early as the end of May (Fig. 1). By the end of the season, no significant difference was found among the higher irrigation treatments (i.e. ET_c 71–107%) however, marked differences were found when trees were given less water. Branch length of trees from the lowest water application treatments was only about half of those from higher water application treatments. As water application treatments increased from 40 to 56% ET, branch length increased from 68 to 86% of those from the highest water-application treatments.

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[1] Mention of company names or products is for the benefit of the reader and does not imply endorsement, guarantee or preferential treatment by the University of California.

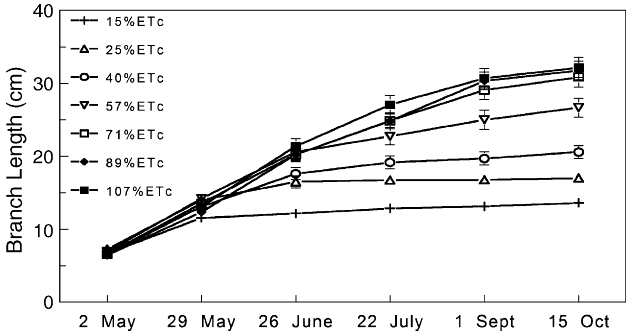

Fig. 1 – Branch growth throughout the 2002 season in relation to different irrigation treatments. Vertical bars represent standard error.

In 2003, branch-length curves followed the same patterns as they did in 2002. The only difference is that it took an additional month in the irrigation season before significant differences were detected among treatments. At the end of the season, cumulative lengths of branches treated at 74% ET were half those irrigated at 93% or above. There was no difference in cumulative growth at the end of the season between treatments with water applications of 93% and above but those treated with only 28 and 33% ET were less than one quarter of those at the highest application treatments. Not surprising, branch lengths from those treated with 55% ET were intermediate between 74% and the lowest application treatments.

Similar effects were also found based on trunk diameter measurements. Interestingly the highest water application treatment resulted in the largest gain (63%) in trunk diameter over the 2-year period despite insignificant differences in branch length in trees between the top water application treatments. The three next highest water application treatments resulted in a 53% increase with no significant differences among those treatments. The treatment that represented 40 and 55% ET (2002 and 2003, respectively) resulted in a modest 43% increase while the two most water-deprived treatments gained only 18–20% in trunk diameter over the 2-year period.

3.2. *Plant water relations*

Plant water relations, characterized by mid-day stem water potential, indicated that water potential varied throughout the 2002 and 2003 seasons between −0.2 and −4.1 MPa, but relative differences among stems from different treatments on a particular sampling day were very consistent. In 2003, there was no difference in SWP among treatments up through the 17 June sampling even though the water potential dropped from −0.2 MPa in May to about −1.0 MPa in mid June (Fig. 2). Stem water potentials decreased across treatments as the season progressed. Stem water potential was not different among the three highest water application treatments at the late season sampling but thereafter deceased steadily with decreased applied water dropping below −4 MPa for the driest treatment. This same relationship among treatments and time was also observed in 2002.

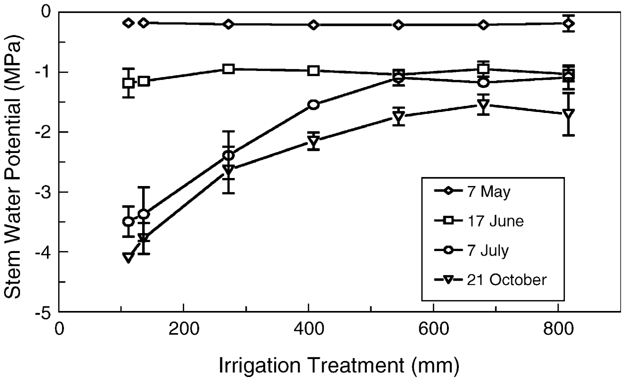

Fig. 2 – Stem water potential (SWP) measured at four different times in the 2003 season for each of the irrigation treatments. Values are the means of eight trees. Vertical bars represent standard error.

The main difference between the 2 years is that stem water potential differences among treatments were detected at an earlier time (i.e. June 6) in 2002, particularly with the two driest treatments relative to the others. There was also one sampling date late in the season (September 6) where the decrease in stem water potential with decreasing water application was less (i.e. reaching only −1.4 MPa) than those of other sampling days presumably due in part to the abnormally cool day (25 °C) for that time of year.

Characteristic changes in soil water potential were synchronized with those changes in stem water potential and root water extraction patterns were relatively the same both years. For example, in early May, 2003, soil water potential was greater than −0.02 MPa at all soil water measurement points regardless of water application treatment (data not presented). By the third week in July, soil water potentials at the 30 cm depth in the least-watered plots already approached their seasonal minimum (<−0.18 MPa), regardless of sensor position between rows. The third driest plot showed reading from −0.08 to −0.12 MPa, regardless of position and continued to steadily decrease until the end of the season. The plot with the highest applied water maintained a high soil-water potential (>−0.02 MPa) until September where it began to decrease steadily for the rest of the season. In contrast to sensors placed at 30 cm, those placed at lower depths tended to take longer to reach the low water potentials that were observed at the shallower depths. Those sensors placed at 75–90 cm in the center between rows indicated that the soil remained wetter, longer than other portions of the profile suggesting that root activity was much less at this location than other parts of the soil profile. It is not surprising that in the more heavily irrigated plots, large soil water changes occurred much closer to the tree and closer to the soil surface. Those plots that received less water, on the other hand, showed more modest soil water changes in a larger volume of soil.

Cumulative or seasonal plant water stress was also characterized by carbon isotope discrimination (Δ). In 2003, we found a second order relationship ($r^2 = 0.86$) in Δ with increasing applied water (Fig. 3), reaching a maximum at the three highest water application rates. The lack of difference

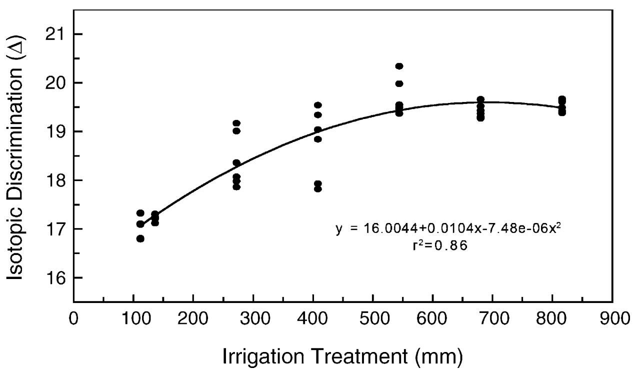

Fig. 3 – Carbon isotopic discrimination in young olive shoots in relation to applied irrigation water.

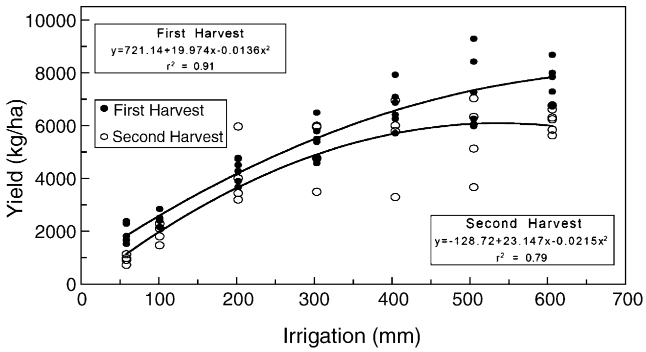

Fig. 4 – Olive fruit yield (kg/ha) in 2002 in relation to applied irrigation water.

among the three highest treatments is consistent with the lack of difference found in stem water potential among these same treatments. In 2002, the same second order relationship was found ($r^2 = 0.71$) but Δ did not reach a maximum until the two highest water application treatments, which again is consistent with the stem water potential data collected that year. These data indicate that stable carbon isotope discrimination was an effective indicator of cumulative tree stress. The advantage with this technique is that the seasonal cumulative tree stress is biochemically recorded in the carbon fractionation of the new growth. Water potential in the plant only describes the plant's water- relation response at that particular point in time and provides no indicators of environmental stresses the tree may have endured before then. However, we found that characterization of stress by carbon isotopic discrimination was a bit more variable in plants treated with intermediate levels of water than were those measured by pressure chamber.

3.3. *Fruit set*

Different water-application treatments affected fruit set in 2002 but not 2003. Fruit set was measured several times during both seasons but only data from the late measurement taken in 2002 is shown in Table 1. The number of fruit per branch, the number of fruit per inflorescence, fruit density (number of fruit per cm branch) and resulting fruit set all increased with an increase in applied water up to 71–89% ET. As irrigation increased to 107%, all these parameters decreased even though the decrease was not significant regarding fruit density. Fruit retention, on the other hand, was not affected by irrigation treatment.

In 2003, fruit set and retention were not significantly different among any of the irrigation treatments.

3.4. *Fruit yields*

Fruits were harvested at two times at the end of each season, however sufficient yield from the second harvest in 2003 was not available for measurement. Olive weights (kg/ha) increased in 2002 following a second order function with increased % ET (Fig. 4) just as what was described by Moriana et al. (2003). Fruit yields were no different at the later (November 18) harvest than they were for the earlier harvest. Fruit yields approach a maximum at the upper water application treatments. Fruit yields, per quantity of applied water, were actually higher in 2002 than in 2003. In 2003, yields of fresh olives from the first harvest were related to the following function; $Y\,(\text{kg/tree}) = -7\text{E}-06x^2 + 0.012x + 0.24$ ($r^2 = 0.996$); where 'x' is the applied water in millimeter.

3.5. *Individual fruit size*

Some of the difference in yield among treatments can be accounted for by reduced fruit size (Fig. 5). Individual fruit size increased with increased applied water ($r^2 = 0.77$ and 0.83 for

Table 1 – Influence of irrigation treatments on fruit density and fruit set

Treatment (% ET)	Number of fruit/branch	Number of fruit/inflorescence	Fruit density (number/cm)	Fruit retention (%)	Fruit set (%)
15	10.04 a[a]	0.53 a	0.52 a	92.5 ab	1.94 a
25	12.05 b	0.62 ab	0.62 b	0.2 ab	2.65 a
40	13.39 bc	0.70 bc	0.70 bc	93.3 ab	2.82 a
57	13.98 bc	0.73 bc	0.73 cd	90.3 ab	2.85 a
71	16.37 de	0.86 de	0.80 de	93.4 b	4.34 b
89	17.31 e	0.90 e	0.88 e	93.7 ab	4.14 b
107	15.24 cd	0.79 cd	0.80 cde	88.2 a	2.71 a

Data from 21 October 2002.

[a] Means with same letters are not significantly different. Duncan's multiple range test, $\alpha = 0.05$.

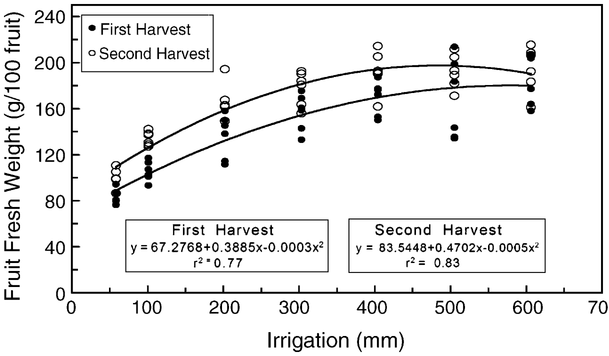

Fig. 5 – Influence of different irrigation treatments in 2002 on individual fruit weight.

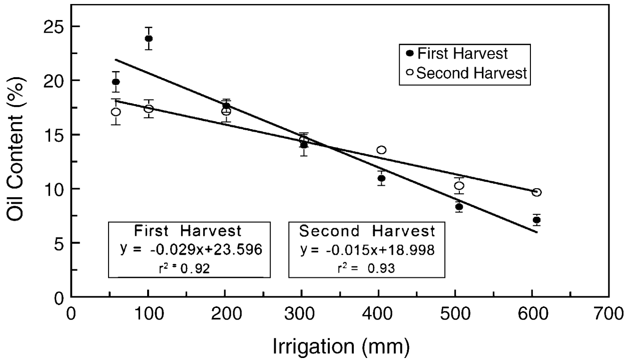

Fig. 6 – Oil extraction (%) in relation to different applied water at two harvests in 2002. Vertical bars represent standard errors.

first and second harvests, respectively) reaching a maximum at about 71% ET_C. The weight of individual fruits from trees in plots that received the least water in 2002 were only half those in the highest irrigation treatments. In 2003, the effect of irrigation treatment on fruit size was not as dramatic as it was the previous year and fruit size was linearly related to water application treatment ($r^2 = 0.84$ and 0.59 for early and late harvests). In 2003, olive fruits were overall smaller than the previous year and the relative reduction in fruit weight with decreasing applied water was less, particularly for the later harvest. There was a 40% reduction in weight from the highest to lowest water application treatment the first harvest but only a modest 12% reduction on the second harvest. The mean individual fruit weight increased from first to second harvest but the weight gains on those from the most water-deprived treatments made substantially larger gains. Although no rainfall occurred before the first harvest in either year, over 5 cm and over 10 cm of rain occurred between the two harvests in 2002 and 2003, respectively. This rainfall may have been partly responsible for increases in fruit size and the reduction in treatment differences at the second harvest.

3.6. *Maturity index*

Maturity index as described by Hermoso-Fernández et al. (1991) was determined at both harvests in 2003 and decreased with increases in applied water (Berenguer et al., 2006; Hermoso-Fernández et al.) in three of the four harvests. In 2002, however, maturity index increased with increasing applied water ($r^2 = 0.81$) for the first harvest but for the second harvest, the maturity index decreased with increased applied water ($r^2 = 0.75$). At the first harvest, fruits from high water-application treatments began to mature sooner than those from water deprived trees. However, by the second harvest, fruits from the low water treatments matured much more rapidly and had a higher index (4.8) than those trees with higher water applications (3.7). Therefore, it was unexpected that trees with higher irrigations were first to show changes in maturity but once fruits from water stressed-trees began to change maturity, they did so at a much faster rate. In 2003, the maturity index decreased linearly with increased applied water for both harvests ($r^2 = 0.88$ and 0.87 for first and second harvests) even though the maturity index increased at the second harvest across all treatments. It is uncertain what role the effective rainfall between harvests played on olive fruit maturity.

3.7. *Percent oil extraction*

Olive oil was extracted using the Abencor method (Martínez et al., 1975). In 2002, the percentage of olive oil extracted with the Abencor decreased linearly ($r^2 = 0.92$–0.93) with increased applied water (Fig. 6). The slope was slightly higher for the earlier harvest. These data also indicate that it may be more beneficial to harvest water-stressed trees earlier than non-stressed trees in order to optimize oil extraction.

In 2003, the same behavior in extractable oil verses irrigation treatment was observed. For the earlier harvest, oil extraction decreased linearly ($r^2 = 0.91$) with increased applied water. At the later harvest, the oil extracted for olives in low water-application treatments decreased while those with the highest water applications increased. Perhaps the >10 cm of rainfall between harvests may have influenced this behavior particularly regarding hydration of fruit from low water application treatments. The overall result was that there were no significant differences ($r^2 = 0.04$) in extractable oil among treatments for the second harvest.

3.8. *Total oil per tree*

When data from olive harvests and oil extraction percentages are combined, total oil yields are obtained (Fig. 7). In 2003, there was a poor correlation ($r^2 = 0.56$) between oil yields per tree and irrigation treatment for the earlier harvest. However, for the second harvest there was a good second order relationship ($r^2 = 0.94$) between applied water and oil yield. This same type of relationship was found by Moriana et al. (2003). Total oil yield per tree increased with applied water reaching a maximum at 299 mm (75% ET). This is primarily attributed to the lack of difference in percent extractable oil among treatments the second harvest while yields increased with applied water. Again the effective rainfall that occurred between harvests may have played a key role in this finding.

Fig. 7 also indicates that the time of harvest can make a large difference in oil yields particularly if orchard is very well

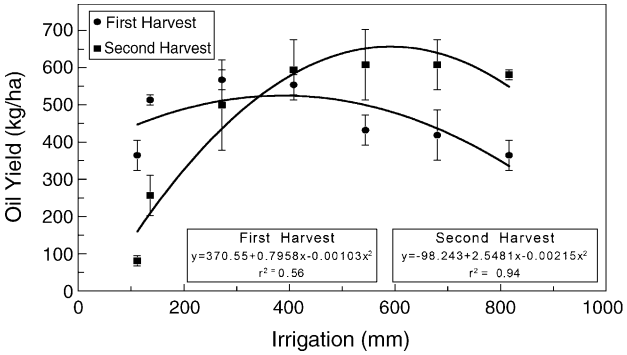

Fig. 7 – Oil yield (kg/ha) in 2003 in relation to applied water.

watered or very water deprived. If the orchard receives less than 33% ET_c, early harvests are more favourable whereas if the orchard receives more than 90% ET_c, a later harvest is more desirable. On the other hand those that are moderately stressed, between 55 and 75% ET_c, timing was less critical.

Data from both harvests in 2002 also indicate that oil yield per tree follows a second order relationship with increased applied water ($r^2 = 0.87$ and 0.71). However, these data indicate that an optimum oil extraction is achieved over a rather wide range of treatments (i.e. 196–491 mm (ET_c 40–89%)). This broad range occurs due to a reduction in oil extraction percentage with increased applied water offsetting the increases in fruit yield. Treatments that applied more or less water resulted in a lower overall oil yield. However, it is unclear whether the Abencor was equally effective at extracting oil from olive samples from each treatment. Although a correlation between effectiveness in oil extraction and irrigation treatment was not conducted, it may be possible that some oil produced under the high-water treatments is difficult to completely extract with the Abencor method (J. Girona, personal communication, 2003).

In order to determine the optimal level of irrigation for olive oil production, water deficit relations with key oil quality parameters must also be considered. These characteristics were evaluated in our companion paper by Berenguer et al. (2006). In that study, data on oil chemical and sensory characteristics indicate that those intermediate irrigation treatments provided the best overall balance in oil quality.

3.9. *Influence on return bloom the following year*

The amount of fruit load on trees in 1 year has a huge effect on shoot growth, flowering, fruit set, and fruit load in the next. Olives bear their flowers and fruit on 1-year-old shoots. As shoot growth is reduced, the number of nodes available for flowering and fruit set the following year is therefore also reduced. This contributes to alternate bearing but there are a number of other management, meteorological, and nutritional factors that influence it as well. We were therefore interested in determining the impacts these irrigation treatments over two consecutive years had on trees when they returned to normal irrigation practices carried out by the orchard managers.

All irrigation plots resumed to normal grower practices in 2004 with a seasonal water application of 320 mm. In late April, there was a striking visual difference in return bloom on trees that were well watered versus those that were poorly watered the previous 2 years. The number of inflorescences was counted on new growth of branches that were tagged and measured in 2003. Branches on trees that were irrigated at the lowest two rates the previous 2 years contained five times more flowers than those that received the two highest water application treatments. These two high-water treatments stimulated vigorous vegetative growth in 2003, which occurred at the expense of reproductive growth in 2004. Bloom counts on trees that had the intermediate three water application amounts were highly variable resulting in an r^2 value of only 0.50 (number of inflorescence per branch versus previous year's water application rate) across all treatments. Despite this large difference in early bloom count between extreme treatments, the large tree size and greater shoot growth that occurred on trees in the two highest water application treatments largely compensated for the light return bloom. A very weak correlation ($r^2 = 0.26$) between fruit yield and previous years water application treatments was found at the end of the year where yields were higher in trees that were previously stressed. The average yield across all treatments in 2004 was 6.1 kg/tree and there was no significant difference in relation to fruit size. The important finding here is that yields were not adversely affected when grossly under-irrigated trees in previous years returned to normal irrigation practices.

4. Conclusions

Our irrigation study indicates that applied water has a large influence on olive tree growth, tree water relations and fruit production, including yield, fruit size, and fruit density. Fruit set, on the other hand, was only affected the first year where it was maximum between 71 and 89% ET_c and fruit retention was not affected either year. Interestingly though, oil yields were not as dramatically affected across treatments because a reduction in percentage of olive oil extracted decreased linearly with increasing applied water and offset to a large extent differences in fruit yields. In both years, oil yields were not significantly reduced under treatments of 70–75% ET_c.

When the results reported here are merged with those where oil quality was evaluated (Berenguer et al., 2006), intermediate irrigation treatments emerge as those that are optimal under these experimental conditions. Although all irrigation treatments produced oils of "extra virgin" quality, a sustained season-long irrigation deficit of approximately 33–40% ET_c, resulted in excellent oil chemical parameters, flavor, and stability. Therefore, there is a rather broad range between irrigation amounts that maximize production (70–75% ET_c) and those that maximize quality (33–40% ET_c). The optimal amount is somewhere in between and choice will depend upon a number of factors including the desire to achieve quantity over quality or quality over quantity.

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