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Full Length Research Paper

Determination of fruit and oil characteristics of olive (*Olea europaea* L. cv. 'Gemlik') in different irrigation and fertilization regimes

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We evaluated plant growth, fruit and oil characteristics of olive (*Olea europaea* L. cv. 'Gemlik') grown on different fertilization and irrigation treatments. Irrigation regimes included rainfed-control (T_0), two treatments with 50% (T_{50}) of the full irrigation treatment (T_{100}) which received 100% class-A pan evaporation. Four fertilization treatments included unfertilized-control (F_0), traditional fertilization (F_1) and application of P and K during different growing stages (F_2 - F_3). Experiments were conducted in each of three years considered as repeated units in a repeated measurement design. Fruit and total oil yields of olive increased about three times in highest irrigation and fertilization combination compared to rainfed and unfertilized treatments. The fruit and oil yield increased from 11.46 and 2.78 kg/tree (T_0F_0) to 30.07 and 7.12 kg/tree ($T_{100}F_3$), respectively. Mean fruit weight (from 2.87 to up to 4.24 g) and pulp stone ratio (from 3.68 to up to 5.60) also increased with additional water as P and K applied during flowering and endocarp hardening stages, respectively. Fertilization treatments had little effect on fatty acid compositions while additional irrigation resulted in increased palmitic and linoleic acid and decreased oleic acid content. Monounsaturated fatty acids/polyunsaturated fatty acids ratio was also decreased with irrigation supplements.

Key words: *Olea europaea* L.*,* fertigation, fruit yield and quality.

INTRODUCTION

The olive tree (*Olea europaea* L.) is known to be resistant to drought and especially suitable to cultivating in regions with the Mediterranean climate. Although olive trees are highly tolerant to drought, there are reports indicating that olive trees also respond to additional irrigation. For example, an optimum yield was obtained using 800 - 1000 mm applied water (Baratta et al., 1986); and additional irrigation was reported to affect growth parameters of olive trees as well as yield, oil content and quality of the fruit (Proietti and Antognozzi, 1996; Patumi et al., 2002; Magliulo et al., 2003; Gomez-Rico et al., 2007). Compared to rainfed condition, extra water resulted in increased shoot growth, canopy volume and trunk diameter of young olive trees and considerable improvement was gained on fruit yield and quality however, little or no improvement was obtained in terms of oil content and quality (Patumi et al., 2002; Magliulo et al., 2003; Grattan et al., 2006; Perez-Lopez et al., 2007). Oil content remained similar with different irrigation regimes using several different varieties (Motilva et al., 2000; d'Andria et al., 2004; Gomez-Rico et al., 2007) while 'Muhasan' had substantial increase in oil content when no irrigation was applied (Lavee et al., 2007). Although different irrigation regimes did not affect most of the fatty acid contents (Patumi et al., 2002; d'Andria et al., 2004), oleic acid amount was found to be declined as the increase in water applied in irrigation regime (Berenguer et al., 2006; Gomez-Rico et al., 2007). Additional irrigation however, increased the palmitic and linoleic acid content (Gomez-Rico et al., 2007). Total oil yield also varied with different water amounts and as the water increased about 75% ET, highest total yield was attained due to increase in fruit num-

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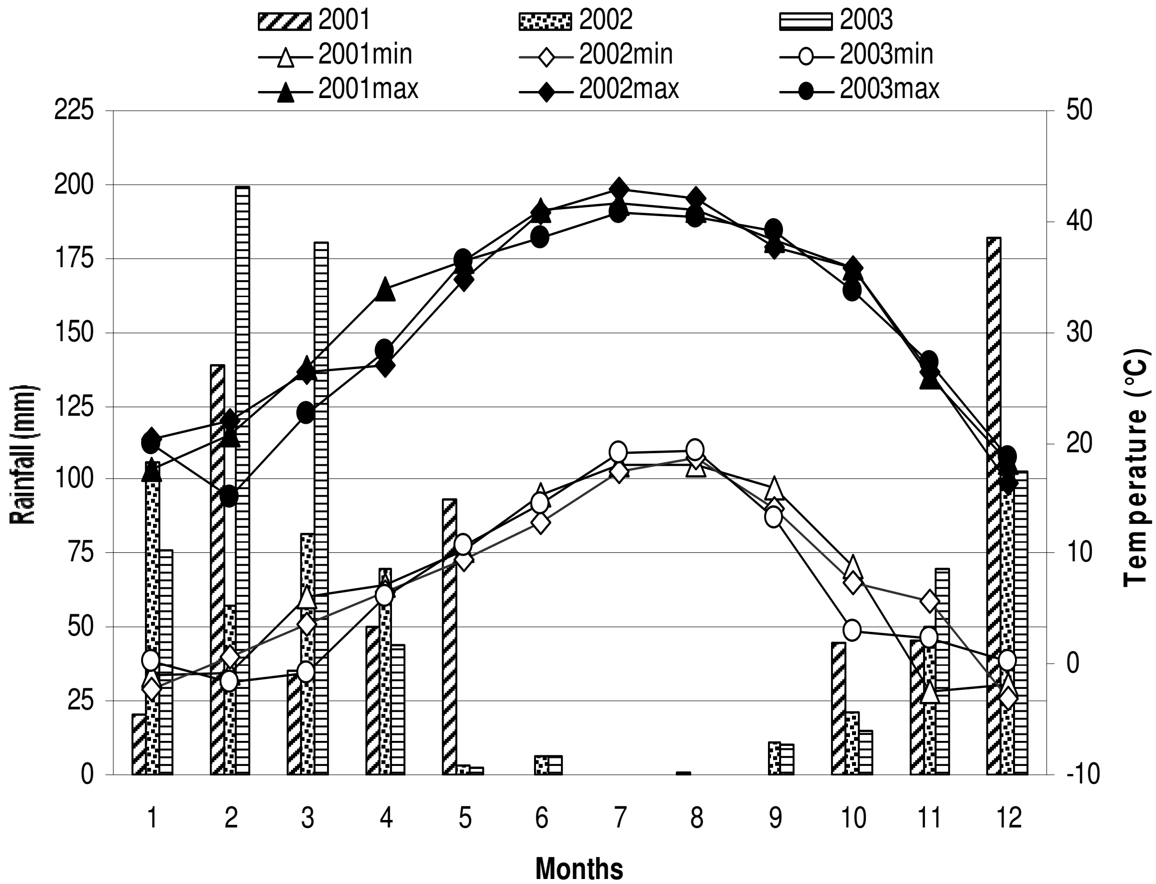


Figure 1. Weather condition at experimental site from 2001 to 2003.

ber per tree (Motilva et al., 2000; d'Andria et al., 2004).

In traditional olive cultivation, olive orchards are fertilized at the end of winter since there was no rainfall or irrigation during summer. However, due to erosion, leaching, volatilization, denitrification and fixation, olive can use only 20% of the total N in such application (Miller and Smith, 1976; Fernandez-Escobar et al., 2004). Furthermore, farmers have to apply several times more fertilizer than annual requirement of plant (Fernandez-Escobar et al., 1994; Fernandez-Escobar and Marin, 1999). Therefore, inevitable results would be less fertilizer use efficiency, increased production costs and environmental pollution due to underwater contamination (Bouma, 1997; Fernandez-Escobar et al., 2004). Applying fertilizers with irrigation (fertigation) has been found to be easy and inexpensive method especially when the resources are limited. Therefore, time and rate of fertilizer could be properly modified to increase fertilizer, especially N, use efficiency (Özgümüş, 1996; Hagin and Lowengart, 1996; Bar-Yosef, 1999).

Nutrient requirements of plants change with respect to their developmental stages. In general, plants need N almost all stages while they need more P during flowering and more K during fruit development and oil accumulation stages. Through fruit maturity, N content in leaves decreased (Fernandez-Escobar et al., 1999), during oil accumulation K concentration decreased in leaves but increased in fruit indicating that more K is required in such period (Jordao et al., 1994; Soyergin and Katkat, 2002; Inglese et al., 2002).

Recently, increase in table olive and olive oil consumption increased the demand and rapid establishment of new olive tree orchards has started in countries such as Turkey where olive trees are widely grown. Such orchards are being established in valleys with fertile soils and modern cultivation techniques are being initiated. Fertigation systems are expected to increase yield and quality of olive and related products. However, number of studies investigating the effects of fertigation system on olive trees is limited. Therefore, the objective of this study was to determine effect of fertigation systems, applied in different growth stages of olive trees on plant growth, fruit and oil characteristics of olive in the Eastern Mediterranean conditions.

MATERIALS AND METHODS

The experiments were carried out from 2001 to 2003 on the experimental farm of Kırıkhan Fruit Production Station (36° 18′ E, 36° 27′ N; 103 m) in Hatay province located in Eastern

Table 1. Fertilization application procedures.

F_0 :	No fertilization was applied.
F_1 :	Traditional Fertilization: Each of N (600 g/tree), P (400 g/tree) and K (500 g/tree) was applied once during initial developmental stage (beginning of March).-
F_2 :	K (500 g/tree) during initial developmental stage (beginning of March), P (400 g/tree) before flowering (end of April), and equal amount of N (40 g/tree) was applied during each irrigation period.
F_3 :	P (400 g/tree) during initial developmental stage (beginning of March), K (500 g/tree) before endocarp hardening (end of June), and equal amount of N (40 g/tree) was applied during each irrigation period.

Mediterranean Region of Turkey. Meteorological data for Kırıkhan County was presented in Figure 1.

'Gemlik' is used in this study since it has been widely grown in the region and consumed for its black table olives and for its oil (Canözer, 1991). The olive orchard was established with 1 year old olive trees rooted under mist-propagation in 1996. The planting density was 6 x 3 m in clay loam soil with 1.5% organic matters and 7.5 pH. The trees were trained as goblet canopy shape. Until the experiment started, all the plots were irrigated and fertilized equally to ensure the uniform tree development. Different irrigation and fertilization regimes were commenced in 2001.

Experiment was designed as randomized complete block design with four replications in a factorial combination of three irrigation and four fertilization regimes. Irrigation regimes included rainfed control (T_0). Two treatments were 50% (T_{50}) of the full irrigation treatment (T_{100}) which received 100% class-A pan evaporation. Fertilization application procedures were depicted in Table 1.

Fertilization treatment in T_0 was performed as fertilizers were sprinkled under the canopy and mixed with soil using hand hoes, while in T_{50} and T_{100} fertilizers were applied after being dissolved through venturi injection system. Fertilizers were applied as urea (46% N), potassium sulphate (51% K) and mono-ammonium phosphate (12% N, 61%P).

Irrigation amount was calculated according to Class A pan evaporation (Epan) (Dorenbos and Pruitt, 1977) at a meteorological station near to the experimental field. Pan evaporation data were adjusted with pan coefficient (Kp = 0.8) and a crop coefficient (Kc = 0.66 - 0.70) with respect to the developmental stages of trees (Vermeiren and Jobling, 1980). Percentage of canopy shading area was measured and used in calculation of required irrigation water amount. The plots were irrigated by drip irrigation method. The polyethylene drip lines with 16 mm in diameter having in-line drippers at the 0.75 m intervals were installed in the beginning of the research. The average discharge of the drippers was 3.7 L h^{-1} under a pressure of 1.0 bar. Two drip lines were employed for each tree row in the plots. The drip lines were installed at 1.0 m interval. Irrigation water was taken from the deep well in the experimental station. Water quality was suitable on use of olive tree irrigation. Irrigation was started from May. The subsequent events were done every 14 day intervals. Irrigation was ended on beginning of October each year. The water use efficiency (WUE, gram/plant/mm) was determined as the ratio of olive yield to the water use for a particular treatment (Howell et al., 1990).

Trunk section area and canopy volume were measured in November, every year. Trunks were marked 30 cm above the soil surface with red stain and measurements were done with compass at the same place in each year. Canopy volume (CV) was calculated from measurements of canopy height and spread, assuming its shape to be a prolate spheroid and thus applying the formula:

$$CV = 4/3\ \pi ab^2$$

Where a, is half of canopy height (m), and b is half of canopy spread (m) (Westwood 1993).

Fruits were harvested by hand in the second week of November and the total yield (kg/tree) was determined at the black maturity stage. The olive maturity index was determined according to the method proposed by the National Institute of Agronomical Research of Spain, based on a subjective evaluation of the olive skin and pulp colors. The procedure consists of distributing a randomly taken sample of 100 fruit in eight groups: intense green (group N = 0), yellowish green (group N = 1), green with reddish spots (group N = 2), reddish brown (group N = 3), black with white flesh (group N = 4), black with < 50% purple flesh (group N = 5), black with ≥50% purple flesh (group N = 6) and black with 100% purple flesh (group N = 7). The index is expressed as: $\Sigma\ (N_i\ n_i)/100$, where N is the group number and n is the fruit number in that group (Uceda and Frias, 1975).

Hundred healthy fruit samples were randomly selected from each replicate. Fruit weight, width, and length were measured. The stone was then removed; pulp and stone were weighed separately. The pulp to stone ratio was determined. Water content was determined from the difference between fresh and dry mass and expressed as a percentage (Agar et al., 1998). Briefly, twenty olives from each replicate were transferred into a Petri dish and weighed before the dishes were placed in an oven at 105°C until a constant mass was reached (that is., until all water was removed from the samples). The dried olives were used to determine oil content. Olives were ground by mortar and pestle, and 10 g of the paste was put into a Soxhlet cartridge. The oil was extracted with 150 ml of hexane at 70°C for 6 h. Although the oil was extracted from the dried samples, the percent oil content was calculated on fruit fresh mass basis from collected hexane.

Olive oil extraction was performed following the procedures of Agar et al. (1998). About 1000 g olives were triturated with mortar and pestle. After triturating, malaxation of the paste was done very slowly for 30 min. Then about 50 ml of water was added to 1 kg of paste to continue malaxation for additional 30 min. Paste was squeezed through four layers of cheesecloth. Extraction was continued by adding 20 - 30 ml more water and pressing again until all oil was extracted. The filtrate was centrifuged at 3000 x *g* to separate the oil from the wastewater. Oil was collected by a Pasteur pipette, filtered through Whatman No. 2 filter paper and placed in dark glass bottles and kept for further analyses.

Free acidity, peroxide value and fatty acid composition were determined in oil samples following analytical methods described in Regulation EEC/2568/91 (European Union Commission, 1991). Free acidity, expressed as percentage of oleic acid, was determined with a potassium hydroxide titration. Peroxide value, expressed as meq O_2 kg^{-1} of oil, was analyzed by iodometry. Fatty acid transmethylation was carried out with methanolic potassium hydroxide. An oil sample (0.2 g) was mixed with 0.2 ml of methanolic KOH 2 N and 3 ml of hexane. After strong shaking (1 min), the hexane solution was analyzed to determine the fatty acid methyl ester content. The composition of FAMEs was determined by gas chromatography performed on a Hewlett Packard 6890 GC

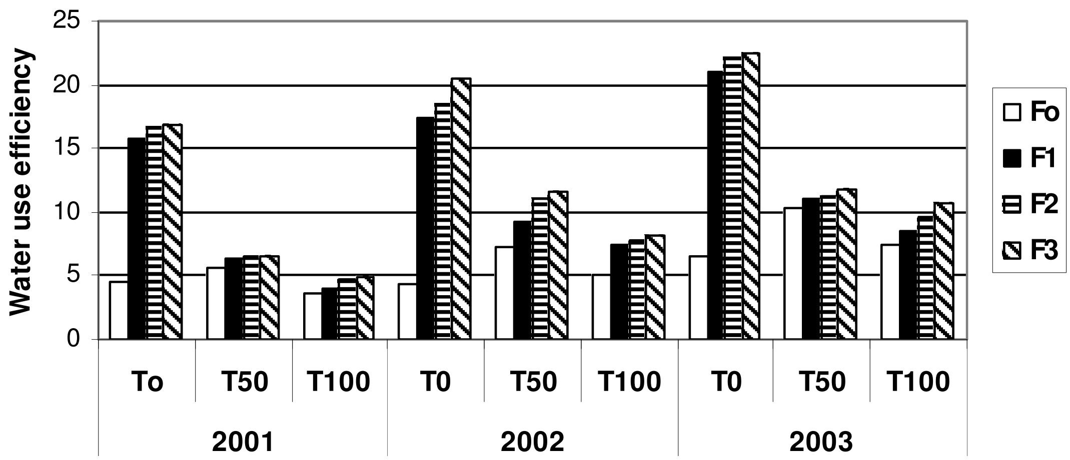


Figure 2. Water use efficiency (WUE) for irrigation and fertilization treatments.

equipped with a HP 18593 autosampler, controller, a FID detector, fitted with a HP-Innowax column (30 m, 0.32 mm I.D., and 0.5 µm film thickness) (Agilent Technologies, Inc. Santa Clara, CA, USA). The FAMEs were identified based on Rf of known standards (Sigma). Injector and detector temperature was 220 and 250°C, respectively. Oven temperature was held at 150°C for 5 min, then increased to 220°C at 15°C min^{-1}, and held for 5 min at the final temperature. Helium was used as the carrier gas at a flow rate of 45 mL min^{-1}.

Except for total yield, total oil yield, trunk section area and canopy volume for which three years were combined for analysis of volume for which three years were combined for analysis of variance, all other data were analyzed using a repeated measures (years) analysis of variance. Mean separations were carried out by least significant difference (LSD) test assessed at the 5% significance level (SAS, 2005).

RESULTS AND DISCUSSION

Although air temperatures had similar trend for three years rainfall amount dramatically changed in each year (Figure 1). Figure 1 also shows that olive trees barely had rainfall during all experimental years especially fruit developmental stage (from June to September) which is highly critical for fruit yield as well as quality.

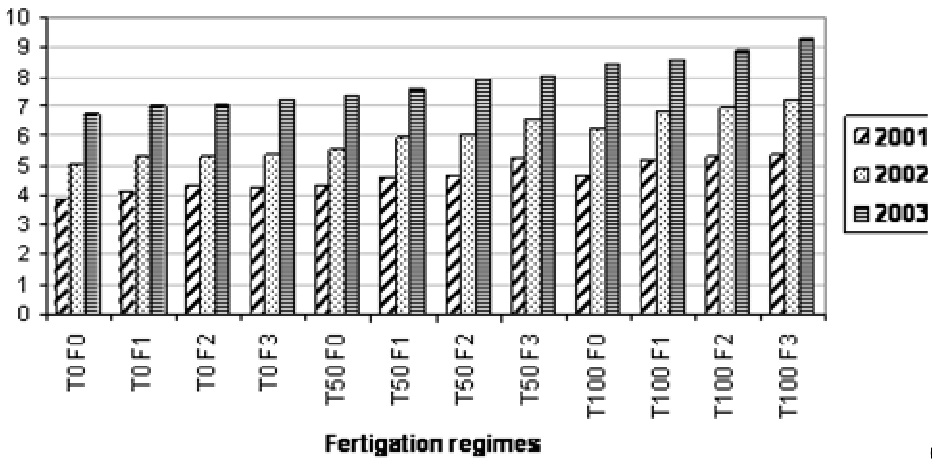
Irrigation amount and water use efficiency

According to irrigation program, T_{50} treatment was applied with 492.1, 533.0 and 518.0 mm of well water; and T_{100} involved 984.1, 1065.9 and 1036.1 mm water during 2001, 2002, and 2003, respectively. Numbers of irrigations were 12, 11, and 12 with respect to the years. Amount of irrigation water seemed to change due to different climates each year. Additionally, water requirements of young olive trees increased as they were developing subsequent years.

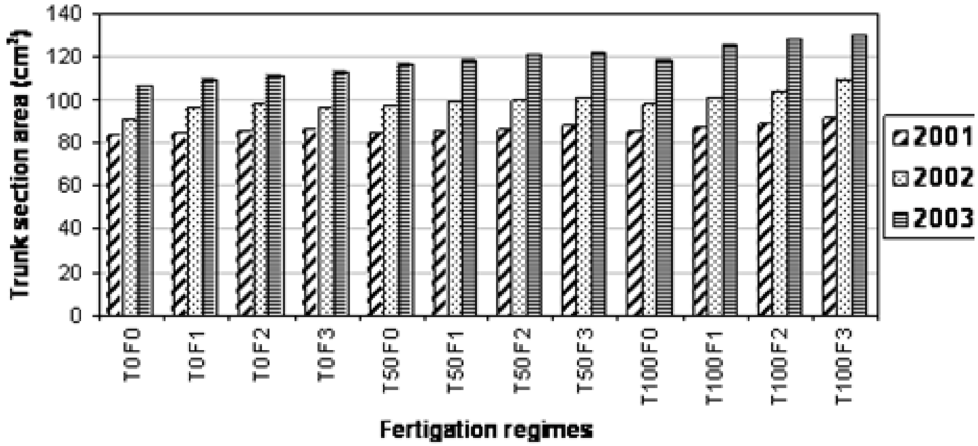
The water use efficiency (WUE) was related to irrigation water and fertilization for three years are shown in Figure 2. The mean WUE values ranged from 3.55 to 22.41. The olive irrigation WUE decreased with increasing irrigation water amount. About 50% decrease in WUE was observed in T_{50} treatment regardless of fertilization treatments; while in T_{100} WUE was decreased to 38%. Under T_0 condition, we also analyzed the effect of fertilization methods and found that WUE values in fertilized treatments increased up to 3.98 times (F_3) compared to unfertilized one. In the same irrigation regimes, WUE values increased from F_1 to F_3, accordingly. Each following year had more WUE values than did the previous year.

Trunk section area and canopy volume

Since the tree size is an important factor in crop performance we analyzed the effect of irrigation and fertilization treatments on trunk section area and canopy volume development. The eight years old olive trees had significantly different trunk section area and canopy volume measurements as the amount of water or fertilization treatment was manipulated. After the three year irrigation and fertilization treatments, highest trunk section area and canopy volume were obtained from $T_{100}F_3$ (Figure 3). Compared to control, T_{50} and T_{100} had about 8 and 14% more trunk section area, respectively, while F_3 had 6.5% more (Figure 3). Canopy volume increased 10% with T_{50} and 25% with T_{100} compared to T_0. Fertilization during F_3 increased canopy volume about 10% compared to F_0 treatment (Figure 3). Such results were expected since previous studies showed linear increase as the amount of water increased regardless of cultivars used (Magliulo et al., 2003; d'Andria et al., 2004). Both studies also indicated that 33% of ETc



(a)



(b)

Figure 3. Effect of fertigation on canopy volume (a) and trunk section area (b) under three irrigation regimes (T_0, T_{50} and T_{100}) and four fertilization treatments (F_0, F_1, F_2, and F_3).

resulted in similar size to that of rainfed and our results showed 50% of ETc had significantly bigger size than did the control implying that critical threshold for size variables should be between 33 - 50% of ETc.

Total fruit yield

In T_{50} irrigation regime increased total yield about 5 - 10% in each fertilization treatment while the increase was about 10 - 25% in T_{100}. At rainfed condition, however, manipulation of fertilization treatments did not significantly increase the yield and the lower yields were obtained in all fertilization treatments in the rainfed condition (Figure 4). Our results suggested that irrigation be followed by appropriate fertilization for increased fruit yield otherwise fertilizing will have no use in rainfed conditions. Previous studies found positive effects of additional water on fruit yield (d'Andria et al., 2004; Grattan et al., 2006; Lavee et al., 2007; Gomez-Rico et al., 2007), however, little is known about the effect of fertilization application methods on total fruit yield. Three year combined results showed that there was significant irrigation × fertilization interaction and the highest yield was obtained from $T_{100}F_2$ and $T_{100}F_3$ indicating that additional irrigation along with suitable fertilization treatment could increase the fruit yield of olive trees (Figure 4). The results also showed that there was about 3 fold increase from T_0F_0 (11.46 kg/tree) to $T_{100}F_3$ (30.07 kg/tree).

Maturity index and fruit water content

Additional irrigation significantly prolonged the ripeness of 'Gemlik' and the latest maturity was obtained from T_{100} (Table 2). Using different cultivars, Berenguer et al. (2006) and Gomez-Rico et al. (2007) also found that additional irrigation supplements resulted in lower maturity index values than did the rainfed. Fertilization

Table 2. Fruit and oil characteristics of 'Gemlik' under three irrigation (T_0, T_{50}, and T_{100}) and four fertilization treatments (F_0, F_1, F_2, and F_3).

Source	Maturity index	Mean fruit Weight (g)	Fruit diameter (mm)		Stone Weight(g)	Pulp/stone ratio	Oil content (%FW)	Total oil yield (kg/tree)	Fruit water content (%)	Acidity (% oleic)	Peroxide value (meq O_2/kg)
			equatorial	longitudinal							
Irrigation											
T_0	5.23 a	2.99 c	16.48 c	20.60 c	0.62 b	3.85 c	24.71 a	3.17 c	47.55 c	0.47 b	6.03
T_{50}	4.85 b	3.46 b	17.16 b	21.52 b	0.65 a	4.34 b	23.62 b	4.82 b	50.29 b	0.49 b	6.12
T_{100}	4.32 c	3.87 a	17.58 a	22.33 a	0.65 a	5.00 a	23.37 b	6.07 a	52.89 a	0.52 a	6.18
$LSD_{0.05}$	0.11	0.08	0.35	0.36	0.02	0.15	0.34	0.18	0.48	0.01	n.s.
Fertilization											
F_0	4.68 c	3.15 c	16.81 b	21.07 c	0.63	3.96 c	23.65 b	3.87 d	49.04 c	0.51 a	6.18
F_1	4.70 bc	3.41 b	17.01 ab	21.35 bc	0.64	4.35 b	23.80 b	4.56 c	50.16 b	0.49 ab	6.15
F_2	4.82 b	3.57 a	17.18 ab	21.64 ab	0.64	4.61 a	23.93 ab	4.99 b	50.65 ab	0.49 ab	6.11
F_3	5.01 a	3.64 a	17.30 a	21.86 a	0.64	4.67 a	24.23 a	5.32 a	51.14 a	0.48 b	6.01
$LSD_{0.05}$	0.13	0.09	0.40	0.42	n.s.	0.17	0.39	0.20	0.55	0.02	n.s.
Irrigation × Fertilization											
$T_0 \times F_0$	5.16	2.87 d	16.07	20.01	0.61	3.68 e	24.23	2.78 f	46.59	0.48	6.07
$T_0 \times F_1$	5.18	2.96 d	16.44	20.50	0.61	3.82 de	24.63	3.11 f	47.42	0.46	6.05
$T_0 \times F_2$	5.25	3.05 cd	16.64	20.84	0.62	3.91 c-e	24.83	3.30 f	47.85	0.47	6.02
$T_0 \times F_3$	5.35	3.09 cd	16.79	21.05	0.62	3.99 c-e	25.14	3.47 ef	48.36	0.46	5.99
$T_{50} \times F_0$	4.69	3.33 cd	17.00	21.29	0.63	4.26 cd	23.54	4.26 d	49.17	0.52	6.27
$T_{50} \times F_1$	4.75	3.45 cd	17.05	21.31	0.65	4.36 bc	23.53	4.73 cd	50.14	0.48	6.20
$T_{50} \times F_2$	4.88	3.53 b	17.26	21.67	0.65	4.43 bc	23.56	5.08 c	50.97	0.47	6.08
$T_{50} \times F_3$	5.10	3.57 bc	17.32	21.84	0.66	4.42 bc	23.87	5.35 bc	51.22	0.47	5.97
$T_{100} \times F_0$	4.20	3.30 c	17.35	21.93	0.65	4.05 b-e	23.17	4.71 cd	51.70	0.51	6.23
$T_{100} \times F_1$	4.17	3.82 ab	17.54	22.26	0.65	4.86 b	23.23	5.85 b	52.91	0.53	6.22
$T_{100} \times F_2$	4.34	4.13 ab	17.63	22.41	0.64	5.51 a	23.40	6.57 ab	53.13	0.52	6.21
$T_{100} \times F_3$	4.58	4.24 a	17.78	22.70	0.64	5.60 a	23.69	7.12 a	53.85	0.50	6.09
$LSD_{0.05}$	n.s.	0.60	n.s.	n.s.	n.s.	0.56	n s.	0.76	n.s.	n.s.	n.s.

treatments, however, showed contrasting results. There was no significant difference between F_0 and F_1 while other fertilization treatments had significantly higher maturity index than that of control (Table 2). Little increase in fertilizer amount did not affect the maturity of olive fruit (Fernandez-Escobar et al., 2002). Water content was also significantly increased as the water amount increased and the highest water content was obtained from T_{100} as expected. Little or no difference was observed between water content of control and deficit irrigation treatments (Morales-Sillero et al., 2007; Gomez-Rico et al., 2007). Fertilization at F_3 resulted in the highest maturity index and water content values (Table 2).

Fruit weight and fruit diameters

Repeated measure ANOVA showed that there was no significant interaction between years and main effects. However, considering three years, fruit weight was highly affected by irrigation x fertilization interaction ($P < 0.01$: Table 2). Rainfed

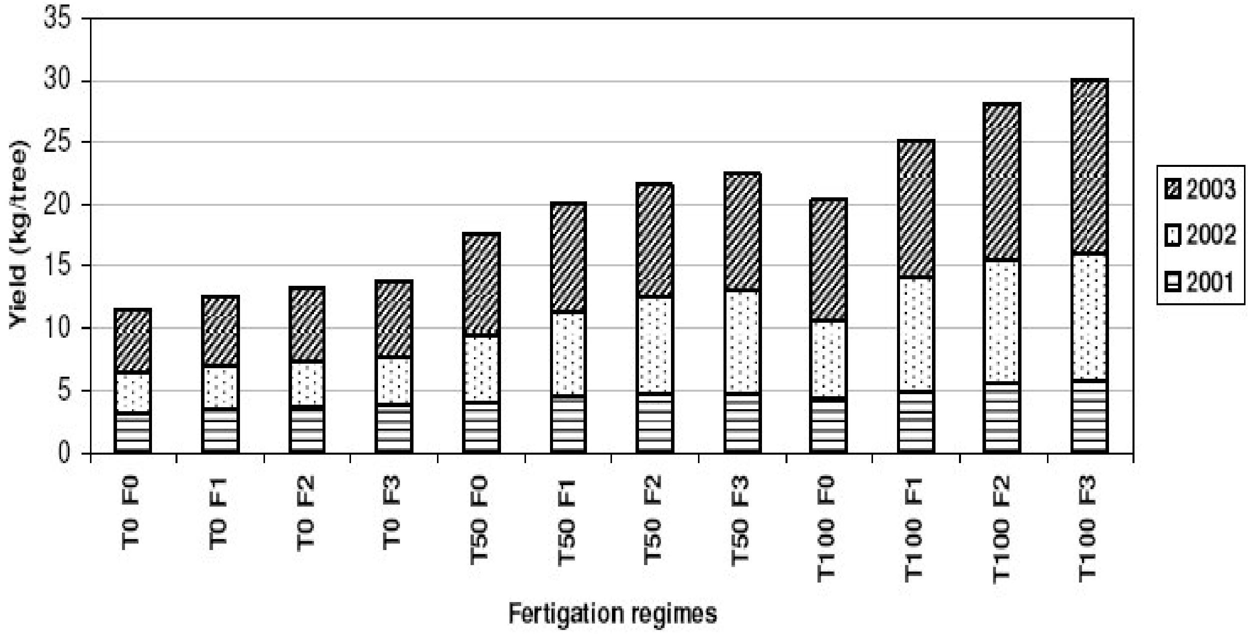


Figure 4. Effect of fertigation on total fruit yield under three irrigation regimes (T_0, T_{50} and T_{100}) and four fertilization treatments (F_0, F_1, F_2, and F_3).

olive trees had the lowest fruit weight, regardless of the fertilization treatments (Table 2). Addition of water (T_{50}) with conventional fertilization (F_1) did not increase the fruit weight as compared to the rainfed trees (Table 2). As the amount of water increased utilization of fertilizers was increased and the highest fruit weight was obtained from T_{100} with F_3 (Table 2). Therefore, the results suggested that using traditional fertilization with 50% required water (T_{50}) was not economical to increase fruit weight. Previous results showed that 66% of ETc yielded significantly high fruit weight compared to control (Patumi et al., 1999; Magliulo et al., 2003) and in addition to supplemental irrigation, modified fertilization treatments probably boost up fruit weight. Equatorial (FD_E) or longitudinal (FD_L) fruit diameters was also increased as the amount of water increased (Table 2). Our results are in corroboration with those of d'Andria et al. (2004) who found greater fruit width and length in increased irrigation supplements using several cultivars. Inglese et al. (2002) reported also that fertilization during stone hardening increased the fruit size.

Stone weight and pulp/stone ratio

Rainfed olive trees had lower stone weight than did T_{50} or T_{100} while no significant difference between T_{50} and T_{100} for stone weight (Table 2). Significant irrigation × fertilization interaction was obtained for pulp/stone ratio and the lowest pulp/stone ratio values were obtained from rainfed olive trees and highest ones were obtained from the highest irrigation treatments with F_2 and F_3 treatments Table 2). However, fertilizing duringF_2 was not significantly different from F_3 (Table 2) indicating that fertilization during these periods may not change the pulp/stone ratio. Irrigated olive trees had higher pulp/stone ratio compared to control treatments (Proietti and Antognozzi, 1996; Magliulo et al., 2003; d'Andria et al., 2004; Lavee et al., 2007) and K fertilization during stone hardening also increased pulp/stone ratio (Inglese et al., 2002).

Oil content and total oil yield

Oil content was generally either slightly affected (Lavee et al., 2007; Gomez-Rico et al., 2007) or not affected (Motilva et al., 2000; Patumi et al., 2002; d'Andria et al., 2004) by irrigation supplements. Our results showed that oil content was significantly declined by the supplemental irrigation treatments and the highest oil content was obtained from rainfed conditions (Table 2). Altering fertilization applications marginally affected oil content and more fertilizer treatments to soil tended to result in less oil content when compared to controls (Morales-Sillero et al., 2007); however, our results showed that higher oil content was obtained in supplemental fertilization than in control treatment (Table 2). Potassium fertilization during stone hardening may have increased the oil content probably due to K requirement in this stage is higher for oil accumulation from leaves to fruit (Jordao et al., 1994; Soyergin and Katkat, 2002; Inglese et al., 2002). Increasing water amount from T_{50} to T_{100} did not significantly change the oil content.

Three-year total oil yield, however, was significantly affected by irrigation and fertilization as observed by significant irrigation × fertilization. Alteration of fertilization treatments in rainfed condition did not have any effect on total oil yield while additional irrigation resulted in optimal use of fertilizers in terms of obtaining high oil yield (Table 2). For example, compared to fertilization control treatment ($T_{50}F_0$) 26% more oil yield was obtained in $T_{50}F_3$ while 51% more oil yield was obtained in $T_{100}F_3$ than in $T_{100}F_0$. Compared to control, fertilization treatments were found to increase the total oil yield (Morales-Sillero et al., 2007) similar findings was also found for supplemental irrigation treatments (Patumi et al., 2002; d'Andria et al., 2004; Lavee et al., 2007).

Acidity and peroxide value

There was significant irrigation × fertilization interaction ($p < 0.05$) and while more irrigation seemed to increase acidity, K fertilization, especially applied during endocarp hardening, decreased the acidity as compared to the control treatment (Table 2). Several reports also showed that acidity increased with supplemental irrigation (Berenguer et al., 2006; Gomez-Rico et al., 2007) but insignificant changes were observed for altered fertilization treatments (Morales-Sillero et al., 2007). Although acidity seemed to be affected by both irrigation and fertilization, acidity level of 'Gemlik' was much below the limits of 1% oleic acid established by European Economic Community Legislation (1991) for high quality oils (that is. extra virgin olive oil). Peroxide value, however, was affected neither by irrigation nor by fertilization treatments. Same legislation set peroxide value upper limit as 20 meq O_2 kg^{-1} which is also much higher than our results (Table 2). Varying results was obtained from previous studies while some indicated that irrigation supplement increased the peroxide value (Berenguer et al., 2006; Gomez-Rico et al., 2007), others found insignificant changes (d'Andria et al., 2004; Patumi et al., 2002). Namely, while fertilization treatments changed the peroxide value in one year, it was not changed the other year (Morales-Sillero et al., 2007). It could be said that acidity and peroxide value were highly affected by environmental conditions.

Fatty acid compositions

There was significant change in fatty acid composition when irrigation or fertilization treatments were modified but no interactions were detected. Especially irrigation differences changed all fatty acids and related variables although fertilization modifications changed the arachidic acid and ratio of unsaturated/saturated fatty acids (Table 3).

Previous studies using different cultivars and/or irrigation levels showed varying results. For example, as the irrigation amount increased, Berenguer et al. (2006) and Gomez-Rico et al. (2007) observed significant changes in fatty acid composition while Patumi et al. (2002) and d'Andria et al. (2004) observed no changes. Modifications in N and K fertilization methods yielded also contrasting results since Inglese et al. (2002) showed significant changes in fatty acid compositions in 'Carolea' while Simoes et al. (2002) found decreases in saturated fatty acid content and increases in ratio of unsaturated/saturated fatty acids as N and K amount increased. Oleic acid is a significant source of monounsaturated fatty acids and its high content in oil compositions makes them more resistant to oxidation that causes rancidity (Aparicio et al., 1999; Gutierrez et al., 1999; Aguilera et al., 2005). Additional irrigation significantly decreased the oleic acid content while increased palmitoleic acid (Table 3). Similar findings were also reported for supplemental irrigation treatments (Berenguer et al., 2006; Gomez-Rico et al., 2007). Amount of polyunsaturated fatty acids such as linoleic and linolenic acids increased at irrigated conditions while lowest values obtained at control treatment (Table 3). Ratio of unsaturated/saturated fatty acid was higher in control treatment than irrigated or fertilized ones (Table 3). Increased amount of fertilizer was also found to decrease oleic acid (Morales-Sillero et al., 2007). Only palmitic acid, a major saturated fatty acid, was significantly higher while arachidic acid was lower than the control treatment as the amount of water increased (Table 3). In addition, arachidic acid was the only fatty acid affected from fertilization treatments and F_3 yielded significantly lower arachidic acid than control treatment (Table 3). Total saturated fatty acid composition was also significantly increased with more water input while it was not affected with the different fertilization treatments. There was also no higher order interaction regarding total saturated fatty acid. We also analyzed the monounsaturated and polyunsaturated fatty acid compositions and found that, compared to rainfed control treatments, less monounsaturated and more polyunsaturated fatty acid compositions were obtained from irrigated treatments and ratio of monounsaturated/ polyunsaturated fatty acids were significantly higher in control treatment than irrigated ones (Table 3). Elevated amount of irrigation was also found to decrease MUFA/PUFA ratio (Berenguer et al., 2006; Gomez-Rico et al., 2007).

Conclusion

In this study, the fertigation treatments, used in different growth stages of olive trees, made significant changes

Table 3. Fatty acid composition of 'Gemlik' under three irrigation (T_0, T_{50}, and T_{100}) and four fertilization treatments (F_0, F_1, F_2, and F_3).

Source	Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Arachidic C20:0	SAF	MUFA	PUFA	UFA/SAF	MUFA/PUFA
Irrigation												
T_0	13.54 c	1.31 b	2.76 a	73.24 a	7.94 b	0.64 b	0.41 a	16.87 c	74.55 a	8.57 b	4.94 a	8.74 a
T_{50}	14.18 b	1.35 ab	2.66 ab	71.22 b	8.60 a	0.67 a	0.37 b	17.21 b	72.57 b	9.27 a	4.76 b	7.89 b
T_{100}	14.79 a	1.38 a	2.59 b	70.54 b	8.80 a	0.68 a	0.35 c	17.73 a	71.92 b	9.49 a	4.60 c	7.63 b
$LSD_{0.05}$	0.29	0.04	0.11	0.81	0.27	0.02	0.01	0.32	0.82	0.28	0.11	0.30
Fertilization												
F_0	14. 03	1.33	2.79	71.40	8.46	0.65	0.39 a	17.44	72.73	9.11	4.70 b	8.06
F_1	14. 06	1.34	2.66	71.74	8.48	0.66	0.38 ab	17.10	73.08	9.14	4.83 a	8.07
F_2	14.29	1.35	2.62^s	71.86	8.44	0.67	0.38 ab	17.28	73.22	9.11	4.77 ab	8.11
F_3	14.30	1.37	2.61	71.66	8.39	0.68	0.36 b	17.27	73.03	9. 07	4.77 ab	8.12
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.02	n.s.	n.s.	n.s.	0.12	n.s.
Irrigation × Fertilization												
$T_0 \times F_0$	13.33	1.28	2.87	72.30	8.00	0.63	0.43	17.29	73.58	8.63	4.77	8.58
$T_0 \times F_1$	13.54	1.30	2.74	73.38	7.94	0.63	0.42	16.70	74.68	8.58	5.01	8.76
$T_0 \times F_2$	13.90	1.32	2.72	73.97	7.91	0.64	0.41	17.03	75.29	8.55	4.93	8.86
$T_0 \times F_3$	13.40	1.34	2.70	73.30	7.89	0.65	0.39	16.48	74.65	8.53	5.06	8.79
$T_{50} \times F_0$	14.18	1.34	2.78	71.62	8.41	0.66	0.39	17.35	72.96	9.07	4.74	8.11
$T_{50} \times F_1$	14.28	1.33	2.63	71.56	8.61	0.67	0.37	17.28	72.90	9.27	4.77	7.92
$T_{50} \times F_2$	14.17	1.35	2.59	71.09	8.76	0.68	0.37	17.13	72.44	9.43	4.79	7.73
$T_{50} \times F_3$	14.11	1.36	2.61	70.84	8.57	0.69	0.36	17.08	72.20	9.26	4.78	7.85
$T_{100} \times F_0$	14.60	1.37	2.70	70.50	8.94	0.67	0.36	17.66	71.87	9.61	4.62	7.54
$T_{100} \times F_1$	14.37	1.38	2.59	70.28	8.89	0.69	0.36	17.32	71.65	9.58	4.70	7.52
$T_{100} \times F_2$	14.80	1.39	2.54	70.54	8.66	0.69	0.35	17.69	71.93	9.35	4.60	7.75
$T_{100} \times F_3$	15.39	1.40	2.53	70.85	8.72	0.70	0.33	18.25	72.24	9.42	4.48	7.72
$LSD_{0.05}$	n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	n.s.	n.s.	n.s.	n.s.

NS: Non-significant, SAF: saturated fatty acids, UFA: unsaturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids.

made significant changes especially in fruit and oil characteristics compared to traditional fertilization methods. Effect of irrigation seemed to be more important than that of fertilization during different growth stages. All variables except peroxide values significantly changed with different irrigation treatments; however, fertilization mostly affected fruit characteristics while its influence on oil quality seemed negligible. Significant two way interaction especially regarding fruit and oil yield may imply that using 100% of ETc (T_{100}) along with F_3 be useful for higher fruit and oil yield.

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