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Response of olive cultivars (*Olea europaea* L.) to induced water stress

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Abstract

The ability of olives to adapt harsh environmental conditions makes its cultivation possible where plants are frequently exposed to high temperatures and scarcity of water. As the annual crop evapotranspiration far exceeds the rainfall in Kuwait, supplemental irrigation is essential for plant production. Under this conditions, efficient irrigation strategy is crucial for sustainable olive production. Therefore, the irrigation study comprising of five cultivars (Arbequina, Barnea, Coratina, Koroneiki and UC13A6) and three levels of irrigation (50, 75 or 100% of ET_p) was conducted during 2006 - 2008. The results showed that none of the cultivars was adversely affected by even the highest water stress level (50% of ETp), indicating that these cultivars were able to tolerate severe and prolonged drought conditions. However, cultivar differences in plant height, stem diameter, number of branches and weight of pruned materials were significant at $P \leq 0.01$. Overall, cultivars Barnea and Coratina exhibited better adaptability to deficit irrigation and grew more vigorously than other cultivars. UC13A6 was most affected by the harsh growing conditions of Kuwait.

Key words: Olive, evapotranspiration, cultivars, adaptability, deficit irrigation, water stress

Introduction

Olive is a hardy fruit tree that can withstand prolonged drought conditions and requires 30 to 40% less water than *Prunus* and citrus (Bongi and Paliotti, 1994). In perennial fruit crops, such as olive, mild water stress or deficit irrigation has positive response on fruit yield (Mitchel *et al.*, 1984; Lampinen *et al.*, 1995; Marsal *et al.*, 2002). In Picual olives, Moriana *et al.*, (2003) showed more favourable yield responses to deficit irrigation at 60 and 80% of full evapotranspiration than full irrigation during bearing year and rainfed in the nonbearing year. Although olive tree is well known for its adaptation to severe and prolonged water stress (Giorio et al, 1999; Sofo *et al.*, 2004; Connor and Fereres, 2005; Boussadia *et al.*, 2008), water deficit affects active growth, fruit development and product quality (Chartzoulakis *et al.*, 1992; Wahbi *et al.*, 2005, Gomez-Rico et al, 2007). In olive trees, even when just 30% of the crop evapotranspiration (ETc) was covered, a significant reduction in the concentration of phenolic compounds was observed in Ascolana, Kalamata and Noceralla (Patumi *et al.*, 1999). However, this was not the case in cultivars, Leccino and Frantoio (Mangliulo *et al.*, 2003) and Cornicabra (Gomez-Rico *et al.*, 2007). In Arbequina also, significant differences in oil phenolic content was reported between trees supplied with water to cover 25% of ETc and those receiving water at all other ETc rates, but not between 65, 75 and 100% ETc (Motilva *et al.*, 2000). Moriana *et al.* (2007) suggested that the effect of irrigation on oil phenolic contents occurs year round and not just during the oil accumulation phase. Scarce and contradictory information are available on the amount of water required to obtain quality-quantitatively good production from different olive cultivars. Such a difference is probably due to varying degrees of cultivar adaptability to the pedoclimatic conditions and agronomic practices adopted in the field trials (Dettori *et al.*, 1989; Patumi *et al.*, 1999; 2002).

In Kuwait, irrigation is essential in commercial plant production activities to ensure optimum vegetative development, yield and product quality. Because of limited supply of good quality water for irrigation in the country, drought deficit irrigation at selected phenological stage is a favoured option to optimize economic gains and minimize environmental damage. However, in Kuwait, drought is often accompanied by other environmental constraints such as high light and temperatures, very low relative humidity, strong winds and dust storms. Under such conditions, it is important to develop sound and efficient irrigation strategy where irrigation scheduling techniques are based on the plant’s actual need at different phenological stages and under fluctuating environmental conditions. In view of this, studies reported here were conducted during 2006-2008 to determine the response of selected cultivars to induced water stress at various stages of development.

Materials and methods

Climatic conditions: Kuwait is a small, flat to gently undulating desert country extending between latitudes 28^0 33’ and 30^0 05’ N and longitudes 46^0 33’ and 48^0 30’ E in the north-eastern part of the Arabian Peninsula. The climate is classified as hyperarid (precipitation / potential evapotranspiration = < 0.05) and is characterized by extremely hot dry summers with long, intense sunshine hours and moderately cool short winters with occasional rain (Middleton and Thomas, 1997). The average daily maximum and minimum temperatures varies between 18.9 ^{0}C during January and 46.8 ^{0}C in July and between 8.2 ^{0}C during January and 28.3 ^{0}C during July, respectively (Annual Statistical Report, 2006). The rainfall which occurs anytime between mid October and late April, is minimal; averaging about 115 mm year^{-1} (fluctuates between 25 and 250 mm), but the evaporation is very high, ranging from 3.1 to 21.6 mm d^{-1}. The relative humidity is low, and strong, dry and hot northwesterly winds prevail during summer, particularly in June and July. Weather conditions during the investigation were harsh and fluctuated considerably. The total precipitation during the study period (October 2006-August 2008) was 130.5 mm (thirty year average is 110 mm year^{-1}), whereas the daily average minimum and maximum relative humidity during this period ranged between 31.49% in May 2007 and 92.1% in January 2007. During the study, the monthly maximum and minimum temperature ranged were 52.0 ^{0}C in August, 2007 to 2.54 ^{0}C in January 2008, and 33.0 ^{0}C in August 2008 to 2.01^{0}C in January 2009, respectively.

Study site: The soil in the experimental site was predominately sandy with an average pH and ECe values of 7.33 and 6.88 dS m^{-1}, respectively. The soil contained very little organic matter and had poor water retention capacity. The irrigation water used in the study was brackish with pH of 7.64, an average electrical conductivity around 5.0 dS m^{-1} and SAR of 8.01 (Bhat *et al.*, 2008)

Plant material and planting: Five cultivars, *viz.*, Barnea, Coratina, Arbequina, Koroneiki and UC13A6 were selected for this study. Plants were acclimatized to prevailing weather conditions prior to planting in the field in the third week of October 2006. For planting, 50-cm diameter planting holes were dug and backfilled with a soil mixture containing equal proportions of sandy loam soil and sphagnum peat moss by volume. After planting, plants were allowed to fully establish in the field before imposing irrigation treatments. During the initial period a uniform irrigation regime using fresh water (ECe = 1.0 dS m^{-1}) was used to secure good plant establishment.

Treatment details: Experimental plants were subjected to water stress by applying predetermined quantities of water based on the water requirements (Table 1). These values were calculated based on results of an earlier study (Suleiman *et al.*, 2004; Taha and Bhat, 2002). Three water stress treatments (50, 75, 100 % ET_p) and five varieties were tested in this experiment. Any rainfall received during the week was adjusted in the ensuing week. A timer and a portable water meter were used to measure the amount of water applied to each treatment. The precise record of amount of water applied at each irrigation was recorded using the water meter to determine the total amount of water added in each treatment. The total amount of water applied in the three irrigation treatments were 11,770, 8,863 and 5,995 liters per plant, respectively. The experiment was carried out in a complete randomized block design with three irrigation levels, three replications, three plants per replication and five cultivars (a total of 135 plants).

Table 1. Volume of water applied in the 100 ETp irrigation treatment

Month	Amount (mm) of water applied/ plant/ day	
	First year	Second year
January	2.3	2.3
February	3.2	3.2
March	5.1	5,1
April	5.4	5.6
May	7.4	7.4
June	7.4	7.4
July	7.4	11.6
August	7.4	11.6
September	5.6	9.4
November	3.8	6.4
December	2.3	2.8

Data on plant height, stem diameter (dia.) and number of branches per plant were recorded at bimonthly intervals, whereas the shoot length, leaf area, petiole length, chlorophyll index and weight of pruned material was recorded after 14 months of initiation of the irrigation treatments. Data were analyzed for ANOVA using the ‘R’ procedure (Crowley, 2005) and the least significant difference was calculated using the Little and Hill (1978) procedures.

Results

Plant height: During the first 15 months from the start of the irrigation treatments, the growth rate of various cultivars ranged from -7.48 (UC13A6) to 57.05 % (Barnea) in 100% ETp; 8.98 (UC13A6) to 59.62% (Coratina) in 75% ETp treatment; and -10.99 (UC13A6) to 57.81% (Barnea) in the 50% ETp treatment (Table 2). The performance of UC13A6 was significantly poor at all irrigation levels. However, irrigation levels did not appear to have any significant influence in all cultivars.

Stem diameter: The average relative growth rate in stem diameter during the first 15 months ranged from 17.85 (UC13A6) to 231.74% (Coratina) in the 100% ETp treatment; 52.21 (UC13A6) to 234.34% (Coratina) in the 75% ETp treatment; and 13.38 (UC13A6) to 186.24% (Barnea) in the 50% ETp treatment (Table 2). While the differences among varieties were significant at $P \leq 0.01$, irrigation levels did not seem to have any influence on stem diameter.

Number of branches: The growth rate in branches produced by plants under various treatments ranged from 122. 91% (UC13A6) to 240.6% (Arbequina) in the 100% ETp treatment; 153.69% (UC13A6) to 225.6% (Arbequina) in the 75% ETp treatment; and 62.96% (UC13A6) to 204.6% (Coratina) in the 50% ETp treatment (Table 2). Significantly fewer branches were produced by the cultivar UC13A6 than other cultivars. The highest number of branches was produced by cultivars Arbequina and Coratina under all the treatments.

Shoot growth, number of nodes and internodal length of new shoots: The plants remained more or less dormant during summer months and resumed normal growth in September when the weather turned moderate. The average length of new shoots ranged from 14.7 (UC13A6) to 32.9 cm (Koroneiki) in the 100% ETp treatment; 11.9 (UC13A6) to 36 cm (Coratina and Koroneiki) in the 75% ETp treatment; and 11.3 (UC13A6) to 33.4 cm (Coratina) in the 50% ETp treatment (Table 3). The average number of nodes on the new shoots ranged from 8.3 (UC13A6) to 13.4 (Arbequina) in 100% ETp treatment; 9.2 (UC13A6) to 13.4 (Koroneiki) in 75% ETp treatment; and 8.6 (UC13A6) to 14.4 (Arbequina) in the 50% ETp treatment (Table 3). Irrespective of the treatment, the internodal length, in absolute terms, was the lowest in UC13A6 and the highest in Coratina; however, water stress did not seem to have any influence on the internodal length.

Leaf area and chlorophyll index and petiole length: The irrigation treatments did not have significant effects on the leaf area and petiole length, but reduced the leaf chlorophyll contents (Table 4).

Weight of pruned material: The weight of pruned materials after 15 months of start of the irrigation treatments was the highest

Table 2. Relative growth rate of olive cultivars in different irrigation treatments

Cultivars	ETp (%)	Relative growth rate height (%)		Relative growth rate stem diameter (%)		Relative growth rate number of branches (%)	
		8 month	15 month	8 month	15 month	8 month	15 month
Arbequina	100	17.11	51.62	68.34	208.78	89.86	240.71
	75	19.56	52.87	76.67	188.24	109.30	225.26
	50	17.89	53.20	41.56	176.83	84.47	188.52
Barnea	100	12.11	57.05	68.78	189.11	67.95	129.39
	75	12.73	55.81	63.05	183.51	65.70	155.66
	50	17.84	57.81	58.85	186.24	88.13	151.48
Coratina	100	12.04	41.95	74.77	231.74	89.46	185.63
	75	15.45	59.62	82.82	234.34	92.31	196.23
	50	11.42	48.56	51.41	179.92	142.20	204.60
Koroneiki	100	5.90	25.58	58.13	187.73	59.21	146.04
	75	12.11	23.79	39.82	146.63	105.87	181.95
	50	8.23	25.44	56.98	167.03	52.18	136.21
UC13A6	100	-28.86	-7.48	-52.65	17.85	-43.74	122.91
	75	-19.22	8.98	-41.29	52.21	-34.14	153.69
	50	-35.0	-10.99	-46.38	13.38	-61.08	62.96
Significance - Variety		***	***	***	***	***	*
LSD (*P*=0.05) - Variety		7.93	16.21	19.33	40.94	31.73	69.41
Significance - Irrigation		ns	ns	ns	ns	ns	ns

***, * denotes that treatment means are significant at $P \leq 0.01$ and $P \leq 0.001$, respectively; ns = treatment means not significantly different at $P \leq 0.05$.

in Barnea plants that were irrigated at 100% ETp and lowest in UC13A6 plants that were irrigated at 50% ETp (Table 3).

Physical plant condition: Except for UC13A6, the physical condition of the plants was normal in all irrigation treatments. Barnea plants, in general were more vigorous than others in all irrigation treatments. Irrespective of irrigation treatments, leaves in UC13A6 were chlorotic and significantly smaller especially during summer months.

Time of major phenological stages: Plants of all varieties went through a phase of slow growth during summer months. The rapid growth stage coincided with the return of moderate weather conditions in September-October. None of the plants produced flowers during the first 15 months from the start of the irrigation treatment.

Table 3. Average shoot length, internodal number and internodal length of olive cultivars in different irrigation treatments

Cultivar	Treatment (% ETp)	Average shoot length (cm)	Number of nodes	Internodal length (cm)	Pruned weight (kg plant^{-1})
Arbequina	100	24.5	13.4	1.8	3.11
	75	27.1	13.2	2.1	2.73
	50	28.1	14.4	2.0	1.55
Barnea	100	27.1	11.3	2.4	4.33
	75	33.9	12.1	2.8	3.84
	50	32.4	12.2	2.6	4.06
Coratina	100	30.8	10.3	3.0	4.68
	75	36.9	11.4	3.3	3.85
	50	33.4	10.7	3.2	2.99
Koroneiki	100	32.9	13.0	2.5	2.82
	75	36.0	13.4	2.7	3.08
	50	31.1	12.6	2.5	2.60
UC13A6	100	14.7	8.3	1.7	0.33
	75	11.9	9.2	1.3	0.45
	50	11.3	8.6	1.2	0.23
Significance – Cultivar		ns	ns	ns	***
Significance – Irrigation		ns	ns	ns	ns
LSD at $P \leq 0.05$					1.90

ns = Treatment means are statistically not different at $P \leq 0.05$;
*** = significant at $P \leq 0.001$.

Table 4. Average leaf area, chlorophyll index and petiole length of olive cultivars in different irrigation treatments

Cultivar	Treatment (% ETp)	Average leaf area (cm^2)	Chlorophyll index	Petiole length (cm)
Arbequina	100	3.7	56.4	5.1
	75	5.2	71.0	5.1
	50	4.6	60.4	4.1
Barnea	100	4.3	66.5	3.1
	75	5.2	65.3	3.6
	50	5.7	34.4	5.2
Coratina	100	5.5	74.2	3.3
	75	9.0	86.9	4.2
	50	7.5	53.2	4.4
Koroneiki	100	2.6	69.4	2.6
	75	3.5	37.7	3.3
	50	2.6	40.8	3.2
UC13A6	100	2.6	88.9	2.8
	75	2.8	60.5	2.1
	50	4.7	47.1	4.0
Significance (Irrigation)		ns	ns	ns
Significance (Cultivars)		ns	ns	ns

ns = Treatment means are statistically not different at $P \leq 0.05$.

Discussion

In the present study, the vegetative growth was not adversely affected by water stress during the 15 months after the initiation of the trial; however, one year is considered too short period to arrive at a definite conclusion regarding the water requirement. The ability of olive trees to acclimatize to amount of water available in the root zone is associated with changes in the leaf at morphological, anatomical and physiological levels, which takes some time. Furthermore, the plants were exposed to other stresses in the field, such as unusually frequent sand storms and aerial salt sprays. Olive trees adapted to drought and other prevailing conditions reveal enhanced sclerophylly with high density of the foliar tissues and the presence of thick cuticle and trichome layers (Bacelar *et al.*, 2004). Drought stress was found to reduce the size of epidermal and mesophyll cells with a parallel increase in cell density in Koroneiki and Mastoides cultivars (Bosabalidis and Kofidis, 2002). It also increased the density of stomata and nonglandular hairs, but decreased the size of individual stomata. These changes would have implications on the physiological processes like transpiration and photosynthesis. Under conditions of high water vapour deficit of the air, the olive trees prevent excess water loss by closing their stomata (Fernandez *et al.*, 1997; Moriana *et al.*, 2002). A number of researchers have observed that low water availability affects growth and biomass accumulation, reduce leaf area, leading to shedding of older leaves (Bacelar *et al.*, 2007), reduce leaf water potential (Wahbi *et al.*, 2005; Kasraoui *et al.*, 2006; Giorio *et al.*, 1999), reduce stomatal conductance (Giorio *et al.*, 1999; Ben Ahmed et al, 2007; Bacelar *et al.*, 2006; 2007) and lower photosynthetic activity and transpiration rates (Nogues and Baker, 2000). Dichio *et al.* (2003) and Santos *et al.* (2007) reported that the osmotic adjustment of olive trees leads to a large amount of water being extracted from the soil, which may reduce the effect of irrigation in low-density olive orchards. Water deficit before flowering might affect fruit weight (Tognetti *et al.*, 2006) and during pit hardening, could reduce fruit production (Goldhamer *et al.*, 1994) and oil yield (Moriana *et al.*, 2003), although olive trees have a high capacity to recover from water stress (Goldhamer, 1999; Moriana *et al.*, 2002; 2003; 2007; Rousseaux *et al.*, 2007). d'Andria *et al.*, (2004) found that yield and fruit quality are positively affected by irrigation. Perez-Lopez *et al.* (2007) observed a reduction in trunk growth rates around 0.2 mm d^{-1} to values around 0.1 mm d^{-1} during the fruiting year compared to nonfruiting year in fully irrigated young olive trees. Therefore, it is important to establish a strategy of subjecting trees to water stress during the period when they will have limited yield consequences, although peak crop yield is obtained at 100% ETc. Cultivar differences in water utilization and the prevailing environmental conditions must be taken into consideration in developing a cultivar-specific irrigation scheduling. The management practices such as pruning and training, use of hydrophilic polymers and mulches and fertilizer applications must be tailored toward profitable olive production while saving consistent amounts of irrigation water.

The results clearly showed that the five cultivars tested in this study, namely Arbequina, Barnea, Coratina, Koroneiki and UC13A6, were able to tolerate deficit irrigation at 50% ETc. The inherent varietal differences were evident in respect to vegetative growth performance in harsh environmental conditions of Kuwait. Cultivars, Barnea and Coratina were more vigorous than others through out the duration of the study. In contrast, UC13A6 exhibited reduced growth rates and foliar injury particularly during the summer months. The study is being continued to assess the effects of induced water stress on flowering, fruiting and plant development during nonbearing stages in these varieties.

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