ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF
AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 7 (4): 285-296, 2008
ISSN 1812-5379

Response of Manzanillo Olive (*Olea europaea*, L.) Cultivar to Irrigation Regime and Potassium Fertigation under Tabouk Conditions, Saudi Arabia

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Abstract: The present study was carried out during 2004 and 2005 growing seasons on 7 years old Manzanillo olive (*Olea europaea*, L.) trees grown in Tabouk (36 24' 51.4" E and 28 34' 55.0" N, 765 m ASL), Kingdom of Saudi Arabia (KSA) with drip irrigation system. The aim of the present investigation is to study the effect of irrigation regime and potassium fertigation on vegetative growth, leaf water contents, total chlorophyll, olive fruit and oil yield, fruit quality and nutrients content of Manzanillo olive trees grown under Tabouk conditions. The trees received irrigation water at 25 and 35 m^3/tree/year. Potassium fertigation was applied at rates of 0, 200, 300 and 400 mg L^{-1} K in irrigation water in the form of potassium sulphate (48% K_2O). The obtained results revealed that high level of K fertigation (400 mg L^{-1}) improved the vegetative growth parameters, leaf water content and olive fruit and oil yields. Potassium fertigation at high level improved the fruit quality and nutrients contents of leaves and fruits, especially at high level of irrigation water (35 m^3/tree/year). Generally, it can be concluded that applying water at 35 m^3/tree/year and K fertigation at 400 mg L^{-1} under drip irrigation system in Tabouk enhanced vegetative growth, fruit and oil yield and improved water and nutrients contents for Manzanillo olive trees.

Key words: Irrigation regime, fertigation, fruit quality, olive irrigation

INTRODUCTION

Olive cultivation has an important role in agricultural production. Since, it increases the land value especially where soil is unsuitable for other fruit crops due to its capability to grow under several conditions (Sansoucy, 1984). Olive is one of the fruit crops that can grow in sandy soil due to its capability to tolerate drought and soil stresses. The production of olives in these areas is generally low due to the poor soil fertility and low water holding capacity. Accordingly, it seems that trees are not only in need of nutrient macronutrients application but also the application of some microelements. The fertilization program in most olive orchards did not take an important place, especially K and B fertilization (although such elements play an important role in growth, leaf constituents and water status improvement). From the view of water saving and good fertilization management of olive trees, the drip irrigation system can be used to insure good distribution of soil moisture in the root zone depth without rising the soil moisture which cause a low production of olive trees. Also, fertigation leads to good distribution of nutrients and increases the utilization efficiency of applied fertilizers besides saving the fertilizers and labor costs (Karmeli and Keller, 1975).

Potassium is an important element for plant growth as plays a vital role in plant growth, early maturity, yield (Hoskinson, 1964; Richmond and Ray, 1966), nutrient absorption (Purcell *et al*., 1982); photosynthetic activity (Oosterhuis, 1993; Wullschleger and Oosterhuis, 1992) and also has an important role in nutrient and sugar translocation in plant and turger pressure of plant cell (Mengel and Kirkby, 1987). The main function of K is the activation of numerous enzyme systems involved in the formation of organic substances and in the build-up of compounds such as starch or protein. Potassium is involved in cell enlargement and in triggering the growth of young (meristematic) tissues. Potassium also improves the water status of the plant and Water Use Efficiency (WUE) in general. In addition K also promotes photosynthesis and the transport of the assimilates (carbohydrates etc.) to the storage organs (fruits, roots). It has been reported that K improves the tolerance of plants to stress and makes plant more resistant to drought. Potassium is involved in many aspects of the plant physiology (Marschner, 1986). It is reported to activates more than 60 enzyme systems, aids in photosynthesis, favors high energy status, maintains cell turgor, regulates opening of leaf stomata, promotes water uptake, regulates nutrients translocation in plant, favors carbohydrate transport and storage, enhances N uptake and protein synthesis and promotes starch synthesis. Potassium is involved in plant meristematic growth (Mengel and Kirkby, 1987). The growth process is initiated by a plasmalemma located ATPase which pumps H^+ out of the cytoplasm into the apoplast. The acidification of the apoplast results in a lossening of cell wall material and in the activation of hydrolyzing enzymes. The release of H^+ depends much on the presence of K^+ in the apoplast (Hager *et al.*, 1971). Phytohormones, which are involved in the growth of meristematic tissues, are enhanced in effect by potassium. Thus Cocucci and Rosa (1980) showed a synergistic effect between K^+ and indole acetic acid on plant growth, also, Green (1983) reported that the effect of gibberellic acid and cytokinins on plant growth was much enhanced by potassium. These examples indicate that K^+ plays a crucial role in plant growth. In this respect Ferreira *et al.* (1986), Jordao and Lietao (1990), Kunwar *et al.* (1990), Loupassaki *et al.* (1993) and Abdel-Nasser and EL-Shazly (2001) reported that K fertilization increased vegetative growth of olive trees. Perica *et al.* (1994) reported that potassium fertilizer, sprayed (4% KNO_3 applied four times during July and August) or applied to the soil (1 kg K_2O per tree as potassium sulphate in early July), increased the potassium content of the leaves and slightly decreased the content of magnesium. Nitrogen and P contents of the leaves were increased by potassium spray applications. Marcelo and Jordao (1994) studied the effect of potassium on yield and some fruit quality parameters of olive tree. Potassium application rates were considered (0, 80, 160, 240 kg ha^{-1} of K_2O). There are no significant ($p>0.05$) mean effects were found due to K application on fruit yield, ripeness index, fruit mean weight, fat content and on olive oil yield. Conversely, significant ($p\leq 0.001$) differences were found between the annual mean yields and fruit quality parameters.

Potassium is of utmost importance for the water status of plants. It has a most important role in osmotic regulation. It is responsible for plant cell turgidity and leaf water potential (Humble and Hsiao, 1969). Uptake of water in cells and tissues is frequently consequence of active K^+ uptake (Lauchli and Pfluger, 1978). Green and Muir (1978) reported that in plants suffering K deficiency, growth rate, cell size and water content of the tissues were reduced. The lower water loss of plants well supplied with K is due to a reduction in transpiration rate (Brag, 1972) which not only depends on the osmotic potential of mesophyll cells but also controlled to a large extent by the opening and closing of stomata. El-Shazly and Abdel-Nasser (1994) reported that K application improved leaf water status of grapevines.

Leaf chemical constituents were found to be improved in well K fertilized plants. Such effect could be due to the increase in plant and root growth, which improved nutrients uptake and translocation and increase in all metabolic processes (Mengel and Kirkby, 1987).

Thus, the aim of the present investigation is to study the effect of irrigation regime and potassium fertigation on vegetative growth, leaf water contents, leaf total chlorophyll, olive fruit and oil yield, fruit quality and nutrients content of leaf and fruit of Manzanillo olive trees grown under Tabouk conditions.

MATERIALS AND METHODS

Field experiment was conducted in a private orchard farm at Tabouk (36 24′ 51.4″ E and 28 34′ 55.0″ N, 765 m ASL) during two successive seasons 2004 and 2005 on 7 years old Manzanillo olive (*Olea europaea*, L.) trees grown under drip irrigation system. The trees were planted at 6×6 m apart (or 270 trees ha^{-1}). These were irrigated from deep well and received the same horticultural management. Forty healthy, uniform and regular bearing olive trees were used in this study. The experimental site is dominated by a sandy texture. Some physical and chemical soil properties are shown in Table 1.

Table 1: Some physical and chemical characteristics of the experimental soil used in the present study

	Soil depth (cm)		
Parameters	0-30	30-60	60-90
Particle size distribution (%)			
Sand	89.9	91.2	92.6
Silt	6.0	4.3	4.0
Clay	4.1	4.5	3.4
Texture class	Sand	Sand	Sand
Bulk density (Mg m^{-3})	1.56	1.64	1.73
Saturation water content (m^3 m^{-3})	0.385	0.377	0.356
Field capacity (m^3 m^{-3})	0.151	0.138	0.143
Permanent wilting point (m^3 m^{-3})	0.064	0.059	0.067
Available water content (m^3 m^{-3})	0.083	0.081	0.079
Organic matter content (%)	0.83	0.61	0.57
$CaCO_3$ (%)	7.7	9.0	9.8
pH (1: 1 water suspension)	7.39	7.35	7.48
Electrical conductivity (1: 1) (dS m^{-1})	1.27	1.39	1.53
Soluble cations (meq L^{-1})			
Ca^{2+}	4.65	5.36	5.85
Mg^{2+}	3.54	3.46	3.58
Na^+	3.66	4.56	5.22
K^+	0.79	0.42	0.53
Soluble anions (meq L^{-1})			
CO_3^-+HCO_3^-	1.98	1.28	2.53
Cl^-	4.02	4.79	5.29
SO_4^{-2}	6.63	7.75	7.28
Available soil nutrients (mg kg^{-1}) soil			
N	109	105	110
P	16.4	15.3	13
K	164	152	158
Fe	3.63	2.8	2.17
Mn	3.56	2.8	2.12
Cu	0.49	0.38	0.38
Zn	1.24	1.16	1.23

Irrigation regime: The trees were irrigated through drip irrigation network and the chemical analysis of irrigation water used is shown in Table 2. The trees were divided into two groups: group A (these were supplied with 25 m^3/tree/year) and group B (these were supplied with 35 m^3/tree/year). The monthly rate of irrigation during the months of year is shown in Table 3.The irrigation requirements were calculated according to the following equation:

$$ET_{crop} = \frac{ET_{drip}}{E_i \times (1 - LR)}$$

Where:

ET_{crop}: The crop evapotranspiration, (mm day^{-1})

ET_{drip}: The water consumptive use under drip irrigation system, (mm day^{-1})

$$ET_{drip} = K_r \times K_c \times ET_0$$

where, K_r is the reduction factor that reflects the percent of soil covering. K_r can be calculated by the equation of Freeman and Garzoli (Karmeli and Keller, 1975):

$$K_r = GC + 0.5 \times (1 - GC)$$

where, GC is the ground cover (plant canopy area divided by soil area occupied by one plant assumed as GC = 0.4). K_c is the crop coefficient ranging from 0.4 to 0.65 for olive plants (Allen *et al.*, 1998). ET_p is the potential evapotranspiration calculated by Penman-Monteith Equation (Allen *et al.*, 1998). E_a is the efficiency of irrigation system (assumed as 90% for drip irrigation system). LR is the Leaching Requirements required for salt leaching (assumed as 20%).

Irrigation treatments were started at November for both studied seasons. The irrigation water was supplied 3 h per day in early morning three times weekly, increased to 4 h in the period of maximum consumption (July and August) and reduced to 2 h in November, December and January.

Fertigation: The fertigation with nutrients solution (Table 4) containing all essential plant nutrients was done three times weekly during the period from February to June and two times weekly during the rest of the year, except that the fertigation was stopped at October, November, December and January. All the trees were received the recommended doses of N, P, K and micronutrients, but distributed over all the year. Potassium fertigation was applied at rates of 0, 200, 300 and 400 mg L^{-1}. Each irrigation group consists of 4 rows, 5 trees for each as replicates. Each row represents one K rate treatment. The treatments were arranged in split plot technique in randomized complete block design, where irrigation levels represent the main plots and the K rates were devoted to the subplots.

Table 2: Analysis of well irrigation water used in the present study

Parameters	Value
pH	7.36
EC (dS m^{-1})	0.51
Soluble cations (meq L^{-1})	
Ca^{2+}	1.21
Mg^{2+}	1.06
Na^+	2.65
K^+	0.11
Soluble anions (meq L^{-1})	
CO_3^{-2}	-
HCO_3^-	1.39
Cl^-	1.95
SO_4^{-2}	1.67
Macronutrients (mg L^{-1})	
NO_3	24.00
HPO_4	3.56
Micronutrients (mg L^{-1})	
Fe	4.20
Mn	0.73
Cu	0.15
Zn	0.08
B	0.39

Table 3: Mean monthly air temperature, potential evapotranspiration and daily water applied to olive trees during 2004 and 2005 growing seasons

	Average air temperature (°C)		Potential evapotranspiration ET_0 (mm day^{-1})		Applied water (L/tree/day)	
Month	2004	2005	2004	2005	Low	High
January	14.3	13.1	3.60	3.47	45	63
February	14.2	15.3	3.74	3.87	45	63
March	16.7	19.7	4.27	4.65	65	91
April	23.1	21.9	5.37	5.21	65	91
May	28.8	27.5	6.36	6.18	88	123
June	29.8	30.0	6.62	6.64	88	123
July	31.6	32.2	6.82	6.90	94	131
August	33.4	31.5	6.84	6.59	94	131
September	29.8	26.0	6.04	5.55	85	119
October	26.3	27.4	5.26	5.40	65	91
November	19.2	19.5	4.21	4.21	45	63
December	14.4	14.3	3.57	3.57	45	63

Table 4: Concentration and sources of nutrients used for preparing the nutrient solution used for olive fertigation

Element	Concentration (mg L^{-1})	Source
N	140	Ammonium nitrate
P	60	Ortho-phosphoric acid
K	Variable (0-400 mg L^{-1})	Potassium sulphate
Ca	200	Calcium nitrate
Mg	50	Magnesium sulphate
Fe	4.5	Fe-EDTA
Mn	1	Mn-EDTA
Cu	0.1	Cu-EDTA
Zn	0.1	Zn-EDTA
B	0.5	Borax
Mo	0.05	Ammonium molybdate
Na_2-EDTA	35	Ethylene diamine tetra acetic acid-disodium salt

Regarding the effect on vegetative growth, trunk circumference for each tree was tagged and measured at the beginning and the end of the experiment in both seasons. Percent of net increase of trunk circumference was calculated. Twenty shoots per tree were tagged at random for all tree directions at the beginning of each growing season and the average shoot length was determined at first of October for both seasons. In addition, fifty mature leaves per tree from tagged shoots were collected randomly and the leaf area were measured using portable leaf area meter (Mussche *et al*., 2001). Volume index was calculated using the equation for one-half of a prolate spheroid (Turrell, 1946) as follows:

$$V = 0.5236 \times H \times D^2$$

where, V is the volume index, (m^3), H is the canopy height (m) and D is the canopy diameter (m).

At first of October for each season, sample of 100 leaves (one-year old) was collected randomly from each tree at a constant height and at all direction of the trees for analysis. Each leaf sample was divided into two portions. In the first portion, leaves were washed with tap water, distilled water, air-dried then oven dried at 65°C to a constant weight. The dried samples were ground and then digested with concentrated sulfuric acid +30% hydrogen peroxide according to the method of Wolf (1982). Total N was determined by micro-Kjeldahl method (Jackson, 1973). Phosphorus was determined according to the method of Murphy and Riley (1962). Potassium determined by Flame Photometer (Jackson, 1973). Leaf contents of calcium, magnesium and micronutrients (Fe, Mn, Cu and Zn) were determined by atomic absorption spectrophotometer (Carter, 1993). Leaf boron content was colorimetrically determined according to Jackson (1973). In the other portion of each leaf sample (fresh leaf material), total chlorophyll content was determined according to Moran and Porath (1980). Total Water Content (TWC) and Relative Water Content (RWC) were determined by the method of Weatherly (1950). Free Water Content (FWC) and Bound Water Content (BWC) were determined according to Abdel-Rasoul *et al.* (1987).

At harvest time (late of September) of each season, yield of each tree was recorded as kg/tree. Sample of 250 fruits was collected randomly from each tree to determine the physical and chemical fruit characteristics, i.e., average fruit weight and flesh weight and percentage. Fruit oil percent was determined by extracting the oil from the flesh by the method reported in AOAC (1980). The oil yield as kg/tree was calculated according to the following equation:

$$\text{Oil yield (kg tree}^{-1}) = \text{Fruit yield} \times \text{Oil (\%)} \times \text{Flesh (\%)}$$

Sample of 25 fruits from each tree was collected randomly to determine the nutrients content. In each sample, the flesh was separated from each fruit, washed with tap water, distilled water, air dried and then oven dried at 65°C to a constant weight (72 h). The dried flesh was ground and then digested with concentrated sulfuric acid + 30% hydrogen peroxide according to the method of Wolf (1982).

The obtained results of both studied seasons were subjected to analysis of variance according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

Vegetative growth: All vegetative growth parameters (Table 5, 6), i.e., percent of increase in trunk circumference, average shoot length, tree height, canopy diameter, volume index and leaf area markedly increased with increasing the amount of irrigation water in both seasons. The increments of high over the low irrigation were 3.05, 4.45, 1.18, 1.69, 4.69 and 3.25%, respectively in the first season. The corresponding values for the second season were 4.13, 4.23, 0.96, 1.42, 3.83 and 3.65%, respectively. Such increments may be due to that increasing water supply improved the root function, consequently enhanced nutrients uptake and metabolic processes that led to increase tree growth (Mengel and Kirkby, 1987). The effect of water regime on increasing olive trees growth was confirmed by Andria and Morelli (2002). Fruit weight and number of fruit per plant of five cultivar of olive trees increased with increasing of water supply. Girona *et al.* (2002) studied the response of young olive trees to different water supplies. Irrigation treatments where based on crop coefficients (Kc), 0.25, 0.38, 0.50, 0.57, 0.64, 0.71 and 0.85. Trees that received higher Kc grew faster and comparatively received substantially more water than the expected solely by Kc's. Dichio *et al.* (2002) studied the soil water availability and relationship between canopy and roots in young olive trees (cv. coratina). The ratio between root and leaf dry weight was always greater in non-irrigated plants compared to irrigated ones. Roots explored a soil volume ranged from 0.5 m^3 in the first year to 16.8 m^3 in the seventh year for irrigated plants and from 0.5 m^3 to 13.4 m^3 for non-irrigated ones. Also, the study showed that increased canopy growth by 79% compared to non-irrigated plants. In non-irrigated plants, canopy growth (but not root growth) was drastically reduced, as a defiance strategy against water deficit, making for a better root/leaf ratio and consequently greater water availability for leaves.

Also, increasing K fertigation rate significantly increased all vegetative growth. Such increment on vegetative growth may be explained on the basis that

Table 5: Vegetative growth parameters of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation level during 2004 growing seasons

Treatments: Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Increase in trunk diameter (%)	Average new shoot length (cm)	Tree height (cm)	Canopy diameter (cm)	Volume index (m^3)	Leaf area (cm^2)
25	0	10.86	10.43	228.0	203	4.924	4.35
	200	11.78	10.93	234.0	206	5.204	4.52
	300	12.76	12.16	239.0	208	5.420	4.68
	400	13.12	13.23	247.0	212	5.822	4.92
35	0	11.05	10.95	230.0	205	5.067	4.30
	200	11.99	11.43	237.0	209	5.427	4.62
	300	13.21	12.86	243.0	213	5.781	4.97
	400	13.76	13.58	249.0	216	6.096	5.18
Mean effect of irrigation level (m^3/tree/year)							
25		12.13	11.69	237.0	207.3	5.342	4.62
35		12.5	12.21	239.8	210.8	5.593	4.77
LSD 0.05		1.22	0.34	0.62	3.1	0.209	0.15
Mean effect of K level (mg L^{-1})							
0		10.96	10.69	229.0	204	4.996	4.33
200		11.89	11.18	235.5	207.5	5.315	4.57
300		12.99	12.51	241.0	210.5	5.600	4.83
400		13.44	13.41	248.0	214	5.959	5.05
LSD 0.05		0.23	0.41	2.22	1.52	0.113	0.06
Interaction effect, irrigation×K rate							
LSD 0.05		0.32	0.58	3.15	2.15	0.16	0.09

Table 6: Vegetative growth parameters of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation level during 2005 growing seasons

Treatments: Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Increase in trunk diameter (%)	Average new shoot length (cm)	Tree height (cm)	Canopy diameter (cm)	Volume index (m^3)	Leaf area (cm^2)
25	0	10.8	10.6	229	205	5.044	4.38
	200	11.7	11.1	236	209	5.401	4.55
	300	12.7	12.5	242	211	5.646	4.67
	400	13.2	13.3	251	214	6.025	4.99
35	0	11.1	10.9	231	208	5.236	4.42
	200	12.2	11.7	238	211	5.553	4.69
	300	13.2	12.9	245	214	5.877	4.95
	400	13.8	13.6	253	218	6.298	5.21
Mean effect of irrigation level (m^3/tree/year)							
25		12.1	11.8	239.5	209.8	5.529	4.65
35		12.6	12.3	241.8	212.8	5.741	4.82
LSD 0.05		0.9	0.6	3.1	1.9	0.156	0.20
Mean effect of K level, mg L^{-1}							
0		10.9	10.7	230.0	206.5	5.140	4.40
200		11.9	11.4	237.0	210.0	5.477	4.62
300		12.9	12.7	243.5	212.5	5.761	4.81
400		13.5	13.5	252.0	216.0	6.161	5.10
LSD 0.05		0.1	0.4	1.9	0.4	0.062	0.08
Interaction effect, irrigation×K rate							
LSD 0.05		0.2	0.6	2.7	0.6	0.087	0.11

K-fertilization can improve the nutritional status of plant or may be involved in improvement of the root system ability to uptake more nutrients. The improvement of nutrient status of plant will be helpful in more vegetative growth (Mengel and Kirkby, 1987). Also, such increment on vegetative growth may be due to the fact that K is involved in plant meristematic growth (Mengel and Kirkby, 1987), or due to the synergistic effect between K and indole acetic acid and the enhancement of K on gibberellic acid and cytokinins effects on plant growth (Coccuci and Rosa, 1980; Green, 1983). The effect of K on increasing olive trees growth was confirmed by Ferreira *et al.* (1986), Jordao and Lietao (1990), Kunwar *et al.* (1990), Loupassaki *et al.* (1993) and Abdel-Nasser and El-Shazly (2001).

The percentages of increment of vegetative growth measurements as a result of K application at 400 mg L^{-1} as compared with the control treatment were 22.63, 25.44, 8.29, 4.80, 19.27 and 16.63%, respectively in the first season. The corresponding values for the second season were 23.85, 26.17, 9.56, 4.60, 19.86 and 15.91%, respectively.

According to the interaction between irrigation regime and K treatments, the best vegetative growth was attained with the highest rate of K (400 mg L^{-1}) and the high rate of irrigation (35 m^3/tree/year or 9450 m^3/ha/year). This result was true for both experimental seasons.

Leaf total chlorophyll: The data obtained clearly indicate that both irrigation levels and K rates significantly increased leaf content of total chlorophyll (Table 7, 8). Such increase may be due to improve the tree growth as a result of more water absorption and more uptakes of N, Mg and Fe, such elements have close association in chlorophyll biosynthesis (Raghavendra, 2000). Also, such increases might be due to increase photosynthesis rate as a result of more absorption of available nutrients, which cause an increase in growth and photosynthesis efficiency. These results agreed with those reported by Ferreira *et al.* (1986) and Abdel-Nasser and El-Shazly (2001). The K fertilization increased leaf total chlorophyll of olive trees.

Table 7: Leaf total chlorophyll and water contents of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation level during 2004 growing seasons

Treatments			Water content (%)			
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Total chlorophyll (mg/100 g FW)	Free	Bound	Total	Relative
25	0	131.2	16.7	44.3	61.0	72.5
	200	142.1	17.3	44.4	61.7	74.6
	300	153.8	17.6	44.9	62.5	75.8
	400	161.4	18.0	45.7	63.7	76.3
35	0	135.1	16.9	44.9	61.8	72.9
	200	148.2	17.3	45.3	62.6	75.2
	300	157.3	18.1	45.1	63.2	76.1
	400	172.1	18.8	45.1	63.9	77.2
Mean effect of irrigation level (m^3/tree/year)						
25		147.1	17.4	44.83	62.23	74.8
35		153.2	17.78	45.1	62.88	75.4
LSD 0.05		2.79	0.56	0.19	0.74	2.17
Mean effect of K rate (mg L^{-1})						
0		133.2	16.8	44.6	61.4	72.7
200		145.2	17.3	44.85	62.15	74.9
300		155.6	17.85	45.0	62.85	76.0
400		166.8	18.4	45.4	63.8	76.8
LSD 0.05		1.43	0.17	0.52	0.38	0.58
Interaction effect, irrigation×K rate						
LSD 0.05		2.02	0.24	0.74	0.54	0.82

Table 8: Leaf total chlorophyll and water contents of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation level during 2005 growing seasons

Treatments			Water content (%)			
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Total chlorophyll (mg/100 g FW)	Free	Bound	Total	Relative
25	0	135.4	16.9	44.9	61.8	72.9
	200	144.8	17.5	45.1	62.6	74.7
	300	157.8	17.7	45.4	63.1	75.9
	400	165.2	18.2	46.2	64.4	76.5
35	0	138.9	17.1	45.2	62.3	73.2
	200	150.2	17.4	45.6	63.0	75.7
	300	160.1	18.3	45.4	63.7	76.4
	400	173.2	18.8	45.9	64.7	77.5
Mean effect of irrigation level (m^3/tree/year)						
25		150.8	17.6	45.4	63.0	75.0
35		155.6	17.9	45.5	63.4	75.7
LSD 0.05		1.4	0.1	0.2	0.2	0.1
Mean effect of K rate (mg L^{-1})						
0		137.2	17	45.1	62.1	73.1
200		147.5	17.5	45.4	62.8	75.2
300		159.0	18	45.4	63.4	76.2
400		169.2	18.5	46.1	64.6	77.0
LSD 0.05		1.4	0.1	0.3	0.2	0.2
Interaction effect, irrigation×K rate						
LSD 0.05		2.0	0.2	0.4	0.3	0.3

Leaf water contents: Data presented in Table 7 and 8 indicate a significant effects of both irrigation level and K application rate i.e., Free Water Content (FWC), Bound Water Content (BWC), Total Water Content (TWC) and Relative Water Content (RWC), especially at the high level of irrigation in both seasons. The same results were observed by Abdel-Nasser and EL-Shazly (2001). Also, increasing K application rate in irrigation water significantly increased the leaf water contents in both seasons. The leaf water contents were increased by about 9.52, 1.79, 3.91 and 5.64% for FWC, BWC, TWC and RWC, respectively in the first season as K rate increased from nil to 400 mg L^{-1}. The corresponding values for the second season were 8.82, 2.21, 4.03 and 5.33%, respectively. The improvement effect of both irrigation level and K rate application may be due to improve the vegetative growth resulted in increasing water and nutrients absorption (Mengel and Kirkby, 1987).

The role of K in osmotic regulation and its responsibility of plant cell turgidity and leaf water potential would interpret such results. Also, Lauchli and Pfluger (1978) reported that uptake of water in cells and tissues is frequently a consequence of active K^+ uptake. In addition, Green and Muir (1978) reported that in plants suffering K deficiency, growth rate and cell size and water content of the tissues were reduced.

The lower water loss of plants well supplied with K is due to a reduction in transpiration rate (Brag, 1972) which not only depends on the osmotic potential of mesophyll cells but also controlled to a large extent by the opening and closing of stomata. Boussadia *et al.* (2008) studied the effect of water deprivation on plant water status of two olive tree cultivars (cv Koroneki and Meski). The results showed that both the leaf water potential (Ψw) and the Relative Water Content (RWC) of the two varieties decreased with increasing levels of drought stress. Koroneiki showed higher (less negative) values of Ψw and lower values of RWC than the Meski, particularly during severe drought stress.

Regarding the effect of the interaction between irrigation regime and K fertigation, the data indicated that irrigation regime in combination with K fertilization were better in improving leaf water status under the present experimental conditions. The best water status was attained with K at 400 mg L^{-1} combined with 35 m^3/tree/year. Maintenance of high leaf water content ensure better hydration and more favorable internal water relations of tissues with a possibly higher pressure potential which reflect good tree condition (Gardner and Ehling, 1965).

Fruit yield and oil percent: The data shown in Table 9 revealed that increasing water supply from 25 to 35 m^3/tree/year markedly increased the fruit yield (kg/tree) in both studied seasons. Such increments were 4.80 and 4.69% for both seasons, respectively. The improving effect of water supply in increasing fruit yield may be due to that increasing water supply, enhanced nutrients uptake and metabolic processes, thereby increasing the yield formation (Mengel and Kirkby, 1987). Also, the effect of water regime on increasing the fruit yield of olive was confirmed by Andria and Morelli (2002) they found

Table 9: Fruit yield, oil content and oil yields of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2004/2005 growing seasons

Treatments		2004			2005		
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Fruit yields (kg $tree^{-1}$)	Fruit oil content (%)	Oil yield (kg $tree^{-1}$)	Fruit yield (kg $tree^{-1}$)	Fruit oil content (%)	Oil yield (kg $tree^{-1}$)
25	0	61.3	17.3	7.861	63.6	17.7	8.53
	200	65.2	17.9	8.968	66.7	18.2	9.34
	300	69.7	18.2	9.854	70.4	18.5	10.26
	400	72.4	18.8	11.384	74.7	19.0	11.91
35	0	62.8	17.8	8.232	64.1	17.9	8.55
	200	66.7	18.3	9.062	68.3	18.7	9.42
	300	74.3	19.0	11.324	76.8	19.1	11.80
	400	77.7	19.5	12.984	79.4	19.9	13.43
Mean effect of irrigation regime (m^3/tree/year)							
25		67.15	18.05	9.517	68.85	18.35	10.01
35		70.375	18.65	10.401	72.15	18.9	10.80
LSD 0.05		1.651	0.12	0.183	0.95	0.18	0.34
Mean effect of K fertigation rate (mg L^{-1})							
0		62.05	17.55	8.047	63.85	17.80	8.54
200		65.95	18.10	9.015	67.50	18.45	9.38
300		72.00	18.60	10.589	73.60	18.80	11.03
400		75.05	19.15	12.184	77.05	19.45	12.67
LSD 0.05		0.845	0.20	0.367	1.322	0.21	0.21
Interaction effect, irrigation×K rate							
LSD 0.05		1.196	0.28	0.520	1.879	0.29	0.29

that fruit yield of olive increased with increasing of water supply. They explained the positive yield response to irrigation was attributed both to increased mean fruit weight and number of fruit per plant. Also, El-Shazly and Abdel-Nasser (2001) and Harhash and Abdel-Nasser (2001) confirmed the present results.

Clear increases in fruit yield were noticed also with increasing K application rates from 0 to 400 mg L^{-1} in both seasons. These increases were 20.95 and 20.57% for both seasons. Such increments might be attributed to the role of K in stimulate tree growth due to increase the nutrients uptake, thereby improve the fruit set and enhanced many metabolic processes such as carbohydrate transport (Marschner, 1986). These results may gain support from those obtained by Klein and Lavee (1977), Marcelo and Jordao (1994), Mostafa *et al.* (2000) and EL-Shazly and Abdel-Nasser (2001). The K fertilization increased fruit yield of olive trees.

As regard to oil percent, the data in Table 9 clearly indicate a significant effect of both water supply and K application rate in increasing the oil fruit content. Increasing water supply from 25 to 35 m^3/tree/year clearly increases oil percent by 3.32 and 2.99%, respectively in both seasons.

Regarding to the effect of K application rate, the data revealed that oil percent was increased by 9.11 and 9.27%, respectively in both seasons as K rate increased from 0 (control) to 400 mg L^{-1}.

Oil yield (kg/tree) significantly increased as irrigation level increased from 25 to 35 m^3/tree/year. The increases were found to be 9.29 and 7.89% in both seasons. Also, K application rate significantly increased the oil yield by 51.41 and 48.36%, respectively in both season as K rate increased from 0 to 400 mg L^{-1}. Enhancing fruit oil content of olive trees due to K fertilization was previously reported by Hatim (1977), Loupassaki *et al.* (1993), Marcelo and Jordao (1994), Mostafa *et al.* (2000) and EL-Shazly and Abdel-Nasser (2001).

Fruit quality: Increasing irrigation water from 25 to 35 m^3/tree/year significantly increased fruit characteristics, i.e., fruit weight, flesh weight and % flesh. It is clear that fruit weight was increased by 17.78 and 18.47%, respectively as irrigation level increased from 25.0 to 35 m^3/tree/year in both studied seasons. The corresponding values were 18.86 and 18.32% for flesh weight, respectively. The increase of flesh weight is responsible for increasing the oil yield (Table 10).

As regard to the effects of K fertigation rate, the data clearly indicate a significant increase in fruit characteristics. Increasing K level from nil (control) to 400 mg L^{-1} increased the fruit weight by 81.69 and 83.39% in both studied seasons, respectively. The corresponding increases in flesh weight were 154.12 and 106.78%, respectively. It is clear that the high values of fruit characteristics were corresponding with the high level of both K and irrigation water applications. These increases are reflected on the increases of both fruit and oil yields (Smith, 1955; El-Shazly and Abdel-Nasser, 2001).

Table 10: Fruit quality of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2004 and 2005 growing seasons

Treatments		2004			2005		
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Fruit weight (g)	Flesh weight (g)	Flesh (%)	Fruit weight (g)	Flesh weight (g)	Flesh (%)
25	0	2.78	2.06	74.14	2.80	2.12	75.67
	200	4.05	3.11	76.73	4.07	3.13	76.90
	300	4.42	3.43	77.56	4.40	3.46	78.59
	400	4.94	4.13	83.60	4.96	4.16	83.90
35	0	3.11	2.29	73.62	3.09	2.30	74.41
	200	4.89	3.63	74.23	4.98	3.67	73.71
	300	5.30	4.25	80.18	5.32	4.28	80.43
	400	5.78	4.95	85.62	5.85	4.97	84.95
Mean effect of irrigation regime (m^3/tree/year)							
25		4.05	3.18	78.01	4.06	3.22	78.77
35		4.77	3.78	78.41	4.81	3.81	78.37
LSD 0.05		0.03	0.06	0.81	0.14	0.06	1.81
Mean effect of K fertigation rate (mg L^{-1})							
0		2.95	2.18	73.88	2.95	2.21	75.04
200		4.47	3.37	75.48	4.53	3.40	75.31
300		4.86	3.84	78.87	4.86	3.87	79.51
400		5.36	4.54	84.61	5.41	4.57	84.42
LSD 0.05		0.03	0.08	1.79	0.08	0.07	2.07
Interaction effect, irrigation×K rate							
LSD	0.05	0.05	0.11	2.53	0.11	0.11	2.92

Table 11: Leaf nutrients content of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2004 growing season

Treatments		Macronutrients leaf content % (DW)					Micronutrients leaf content (mg kg^{-1}) (DW)				
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
25	0	1.72	0.16	0.78	0.75	0.16	221.2	24.0	12.8	30.1	48.2
	200	1.80	0.17	0.85	0.82	0.18	274.2	25.2	17.4	33.2	59.3
	300	1.91	0.19	0.93	0.88	0.19	303.2	27.0	21.2	40.0	68.4
	400	1.99	0.23	1.08	0.95	0.21	359.0	31.0	31.2	46.8	82.7
35	0	1.74	0.15	0.75	0.78	0.17	223.1	24.3	12.9	30.5	51.3
	200	1.87	0.19	0.92	0.85	0.17	279.3	26.7	19.0	37.0	63.7
	300	1.98	0.23	1.12	0.97	0.19	312.4	29.9	25.8	43.6	78.2
	400	2.05	0.26	1.23	1.05	0.23	375.2	34.8	40.2	51.2	91.4
Mean effect of irrigation regime (m^3/tree/year)											
25		1.86	0.19	0.91	0.85	0.19	289.4	26.8	20.7	37.5	64.7
35		1.91	0.21	1.01	0.91	0.19	297.5	28.9	24.5	40.6	71.2
LSD 0.05		0.01	0.03	0.02	0.04	0.01	10.2	0.7	0.4	0.9	3.5
Mean effect of K fertigation (mg L^{-1})											
0		1.73	0.16	0.77	0.77	0.17	222.2	24.2	12.9	30.3	49.8
200		1.84	0.18	0.89	0.84	0.18	276.8	26.0	18.2	35.1	61.5
300		1.95	0.21	1.03	0.93	0.19	307.8	28.5	23.5	41.8	73.3
400		2.02	0.25	1.16	1.00	0.22	367.1	32.9	35.7	49.0	87.1
LSD 0.05		0.03	0.01	0.02	0.03	0.01	6.3	1.0	1.3	1.7	1.3
Interaction effect, irrigation×K level											
LSD 0.05		0.05	0.02	0.03	0.04	0.02	8.9	1.5	1.8	2.4	1.8

Table 12: Leaf nutrients content of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2005 growing season

Treatments		Macronutrients leaf content % (DW)					Micronutrients leaf content (mg kg^{-1}) (DW)				
Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
25	0	1.75	0.18	0.79	0.77	0.18	227.8	25.2	12.9	29.7	50.3
	200	1.85	0.19	0.89	0.85	0.21	273.6	25.9	18.2	32.7	62.6
	300	1.94	0.21	1.01	0.91	0.23	309.7	27.8	22.7	41.3	70.1
	400	2.05	0.26	1.17	0.97	0.26	364.0	32.1	32.4	45.3	85.3
35	0	1.79	0.17	0.82	0.81	0.18	229.8	25.7	13.2	30.4	52.7
	200	1.89	0.19	0.97	0.88	0.20	282.4	27.6	19.6	35.8	65.4
	300	2.06	0.24	1.11	1.02	0.24	316.7	30.1	24.8	43.1	77.6
	400	2.13	0.27	1.28	1.11	0.27	381.6	35.6	35.6	48.7	88.9
Mean effect of irrigation regime (m^3/tree/year)											
25		1.90	0.21	0.97	0.88	0.22	293.8	27.8	21.6	37.3	67.1
35		1.97	0.22	1.05	0.96	0.22	302.6	29.8	23.3	39.5	71.2
L.S.D. 0.05		0.20	0.02	0.05	0.04	0.02	8.4	1.2	4.5	3.1	3.2
Mean effect of K fertigation (mg L^{-1})											
0		1.77	0.18	0.81	0.79	0.18	228.8	25.5	13.1	30.1	51.5
200		1.87	0.19	0.93	0.87	0.21	278.0	26.8	18.9	34.3	64.0
300		2.00	0.23	1.06	0.97	0.24	313.2	29.0	23.8	42.2	73.9
400		2.09	0.27	1.23	1.04	0.27	372.8	33.9	34.0	47.0	87.1
LSD 0.05		0.04	0.01	0.04	0.01	0.01	4.4	0.8	1.6	1.3	3.0
Interaction effect, irrigation×K level											
LSD 0.05		0.06	0.02	0.06	0.02	0.02	6.2	1.1	2.2	1.8	4.2

Leaf nutrients content: Increasing irrigation level significantly increased leaf content of nutrients (N, P, K, Ca, Mg, Fe, Mn, Cu, Zn and B) (Table 11, 12).

The same trend was noticed with increasing K application rate. Such increase may be attributed to the increase of vegetative growth and improvement of water and nutrients absorption. The beneficial effect was noticed at the highest levels of water (35.0 m^3/tree/year) and K application (400 mg L^{-1}), in which it improved the nutrients status of olive leaves (Abdel-Nasser and EL-Shazly, 2001). These results are in harmony with those obtained by Perica *et al*. (1994), Loupassaki *et al.* (1993) and EL-Shazly and Abdel-Nasser (2001).

Fruit nutrients content: The data clearly indicate significant effects of irrigation levels and K rates on increasing fruit content of nutrients. Such increments may be due to improving the tree growth that reflected on more absorption of water and nutrients. Such effects resulted in increasing the nutritional value of olive fruits (Table 13, 14).

Table 13: Fruit nutrients content of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2004 growing season

Treatments: Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Macronutrients leaf content % (DW): N	P	K	Ca	Mg	Micronutrients leaf content (mg kg^{-1}) (DW): Fe	Mn	Cu	Zn	B
25	0	1.27	0.17	1.98	0.24	0.62	76.8	8.1	15.3	4.8	12.9
	200	1.37	0.19	2.07	0.27	0.67	79.5	8.7	16.1	5.2	14.1
	300	1.43	0.23	2.17	0.31	0.71	84.6	9.5	16.8	5.9	15.8
	400	1.50	0.27	2.26	0.36	0.79	91.1	10.2	17.9	6.7	17.3
35	0	1.30	0.19	2.02	0.27	0.65	78.8	8.6	15.9	5.2	13.5
	200	1.41	0.21	2.13	0.29	0.72	82.5	9.3	16.8	5.9	14.8
	300	1.47	0.26	2.21	0.32	0.78	86.8	9.9	17.5	6.5	16.4
	400	1.52	0.30	2.34	0.38	0.85	93.5	10.8	18.2	7.2	18.1
Mean effect of irrigation regime (m^3/tree/year)											
25		1.39	0.22	2.12	0.30	0.70	83.0	9.1	16.5	5.7	15.0
35		1.43	0.24	2.18	0.32	0.75	85.4	9.7	17.1	6.2	15.7
L.S.D. 0.05		0.02	0.01	0.15	0.03	0.07	0.9	0.1	0.4	0.5	0.2
Mean effect of K fertigation (mg L^{-1})											
0		1.29	0.18	2.00	0.26	0.64	77.8	8.4	15.6	5.0	13.2
200		1.39	0.20	2.10	0.28	0.70	81.0	9.0	16.5	5.6	14.5
300		1.45	0.25	2.19	0.32	0.75	85.7	9.7	17.2	6.2	16.1
400		1.51	0.29	2.30	0.37	0.82	92.3	10.5	18.1	7.0	17.7
LSD 0.05		0.01	0.01	0.02	0.01	0.01	0.5	0.2	0.2	0.1	0.1
Interaction effect, irrigation×K rate											
LSD 0.05		0.02	0.02	0.03	0.02	0.01	0.7	0.2	0.3	0.2	0.2

Table 14: Fruit nutrients content of Manzanillo olive trees grown under Tabouk conditions as influenced by irrigation regime and K fertigation rate during 2005 growing season

Treatments: Irrigation regime (m^3/tree/year)	K rate (mg L^{-1})	Macronutrients leaf content % (DW): N	P	K	Ca	Mg	Micronutrients leaf content (mg kg^{-1}) (DW): Fe	Mn	Cu	Zn	B
25	0	1.24	0.16	1.99	0.21	0.65	79.3	8.7	15.6	4.6	13.1
	200	1.36	0.18	2.12	0.24	0.69	82.6	9.1	16.4	5.3	14.6
	300	1.44	0.24	2.19	0.29	0.77	86.9	9.8	17.0	6.1	15.9
	400	1.53	0.26	2.31	0.35	0.83	95.4	10.5	18.1	6.9	17.6
35	0	1.29	0.18	2.07	0.25	0.69	81.5	8.9	15.8	5.1	13.6
	200	1.40	0.21	2.18	0.29	0.79	86.5	9.5	16.8	5.8	15.0
	300	1.48	0.27	2.29	0.31	0.84	91.3	10.4	17.7	6.6	16.3
	400	1.55	0.32	2.38	0.39	0.89	98.7	11.2	18.9	7.4	17.9
Mean effect of irrigation regime m^3/tree/year											
25		1.39	0.21	2.15	0.27	0.74	86.1	9.5	16.8	5.725	15.3
35		1.43	0.25	2.23	0.31	0.80	89.5	10.0	17.3	6.225	15.7
L.S.D. 0.05		0.04	0.01	0.02	0.01	0.03	4.2	0.3	0.3	0.6	0.4
Mean effect of K fertigation (mg L^{-1})											
0		1.27	0.17	2.03	0.23	0.67	80.4	8.8	15.7	4.85	13.4
200		1.38	0.20	2.15	0.27	0.74	84.6	9.3	16.6	5.55	14.8
300		1.46	0.26	2.24	0.30	0.81	89.1	10.1	17.4	6.35	16.1
400		1.54	0.29	2.35	0.37	0.86	97.1	10.9	18.5	7.15	17.8
LSD 0.05		0.03	0.01	0.03	0.02	0.04	1.2	0.3	0.4	0.3	0.2
Interaction effect, irrigation×K rate											
LSD 0.05		0.04	0.02	0.05	0.03	0.05	1.7	0.4	0.5	0.4	0.2

CONCLUSION

Generally, the most important outcome of the present study is clarifying the important role of K fertigation for improving the olive vegetative growth that enhance yield of olive trees. It is reflected on improving the fruit quality and increasing the nutritional value of olive fruits. In conclusion, the promising treatment in this study was the combination of K at 400 mg L^{-1} with irrigation regime at 35 m^3/tree/year. Thus, it is recommended using such treatment for obtaining good response of Manzanillo olive trees to irrigation regime and K fertilization under similar conditions.

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