J. Plant Production, Mansoura Univ., Vol. 8(8): 821 - 828 , 2017

Effect of Irrigation Techniques and Quantities on Kalamata Olive Trees under North Sinai Conditions

Ghieth, W. M.
Pomology unit, Department of plant production, Desert Research Center, Cairo, Egypt

ABSTRACT

This study was carried out during three successive seasons, (2013, 2014 and 2015) in a private orchard located in North Sinai governorate, Egypt. The study was conducted on 10 years old Kalamata olive trees planted at 6 X 6 m apart grown in sandy soil, under drip irrigation system and uniform in shape and received the common horticultural practices. The aim of this study was conducted to evaluate Kalamata olive trees irrigation techniques which involve two types (whole root-zone irrigation – alternate partial root-zone irrigation) and three levels of regulated deficit irrigation values based on crop evapotranspiration (irrigated with 100%, 80% and 60% of ETc). The obtained results indicate that alternate partial root-zone irrigation increased vegetative growth, number of inflorescences per shoot, number of perfect flowers, crop yield, fruit oil content and fruit quality characteristics as compared with whole root-zone irrigation technique. On the other hand, the previous parameters recorded strong correlation with the highest level of irrigation treatments (100% ETc control treatment) while, regulated deficit irrigation with 60% of ETc recorded the lowest values in these respect while 80% ETc treatment came in between. In general alternate partial root-zone irrigation technique saved at least 20% of irrigation water as compared with whole root-zone irrigation and improving water use efficiency.

Keywords: Kalamata, alternate partial root-zone irrigation, regulated deficit irrigation, olive yield, fruit quality, water use efficiency.

INTRODUCTION

Olive (Olea Europaea L.) is an evergreen tree Follows plant family Oleaceae, one of the oldest trees in the history. Statistical data of Food and Agriculture Organization (FAO, 2014) show that the world area cultivated with olive trees was about 10,272,547 hectares and the world production of olive was 15,401,707 tons. In Egypt, olive cultivation clearly increased during the last two decades. According to the statistics of Ministry of Agriculture and Land Reclamation (2012) which indicated that the total area planted with olive trees reached 202,743 feddan, total production output reached 563,070 ton. The most important areas of olives in Egypt are El-Fayoum, Ismailia, Matrouh, North Saini, Noubaria, Wadi El Natroun and the desert road of Cairo/Alexandria.

Olive Industry Plays an important role in the economies of many countries, because of its ability to face environmental stress conditions and good economic revenue. Kalamata is one of the famous cultivars in North Sinai used mainly for black pickling due to its high marketing value, large size, excellent taste and high pulp/stone ratio. This cultivar characterized by alternate bearing especially under arid conditions of North Sinai region. Water scarcity and the increasing of water demand for irrigation olive groves has led to use many strategies of regulated deficit irrigation approaches so we supposed to select such optimal irrigation management techniques which improve water use efficiency.

Controlled alternate partial root-zone irrigation (CAPRI), which also called partial root-zone drying (PRD) in other references, is a new irrigation technique which can improve the water use efficiency without significant lack of crop yield. It involves part of the root system being exposed to drying soil while the other part is watered normally. The wetted and dried sides of the root system are switched with a frequency according to soil drying level and crop water requirement (Kang and Zhang,2004). Dry and Loveys (2000) indicated that the model of grape root distribution changed when they applied partial root zoon irrigation (PRI). More roots were developed in deeper layers of soil and a larger root system was mentioned under this technique. Han and Kang (2002) referred that the ability of roots to absorb nutrients was also improved horizontally and vertically when the root-zone was partially irrigated and the partial irrigated zone was shifted alternately.

Olive trees are known as a resistant to drought stress, but yield responds clearly to the interest of irrigation Lavee and wonder(1991).So increasing the irrigated area is very difficult in olive cultivation, because of water scarcity and competition with non-agricultural purposes (Fereres *et al.,*2003). Regulated deficit irrigation (RDI) is an important strategy which has been proposed to save water without strong influence on crop yield (Chalmers *et al.,* 1981). RDI has been used in some fruit crops to improve water use efficiency, control vegetative growth and maintain or development fruit quality. To study the effect of regulated deficit irrigation on specific parameters of vegetative growth, flowering, yield and fruit quality of 'Manzanillo' olive trees under drip irrigation system. Mehanna *et al.,*(2012) found that vegetative growth parameters, yield, fruit weight responded negatively to the (RDI) treatments. Trees irrigated with 100% ETc through a long season (control) recorded the highest values, followed in descending order by those irrigated with 66% ETc than 33% ETc . The aim of the present study was to investigate the qualitative and quantitative effect of irrigation techniques and regulated deficit irrigation (RDI) on Kalamata olive tree parameters under North Sinai conditions.

MATERIALS AND METHODS

This study was carried out during three successive seasons, (2013, 2014 and 2015) in a private orchard located in Rafah, North Sinai governorate, Egypt. The study was conducted on 10 years old Kalamata olive trees planted at 6 X 6 m apart grown in sandy soil, under drip irrigation system. All trees are almost uniform in shape and received the common horticultural practices. The orchard soil analysis is given in (Table 1) and water irrigation analysis is given in (Table 2)

Irrigation treatments:

Two techniques of irrigation methods were applied:

1- Whole root-zone irrigation (WRI): Irrigated with the whole amount of irrigation values on both sides of the root system in the same time. Emitters were placed in each side of the tree trunk at a distance of 1m.

2- Alternate partial root-zone irrigation (APRI): APRI is an irrigation technique which depends on irrigating part of the root-zone, while the other part kept without irrigation. Irrigated and dry sides are switched from one-half to the other every two weeks according to Wahbi *et al.,* (2005). Emitters were placed at a distance of 1m on each side of the tree trunk. Main plots(WRI & APRI) divided into three sub plots as levels of regulated deficit irrigation (RDI):

- (Control) 100% of ET_c (crop evapotranspiration).
- RDI-80% of ET_c (crop evapotranspiration).
- RDI-60% of ET_c (crop evapotranspiration).

Table 1. Some physical and chemical analysis of the orchard soil

Physical analysis	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Type of soil
	1	90	5	3	Sandy soil

Chemical analysis	pH	EC dS/m	OM (%)	Cations meq/l				Anions meq/l			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Co_3^{-}	Hco_3^{-}	Cl^{-}	So_4^{--}
	8.3	4.88	0.52	10.5	6.8	28.2	1.1	-	1.91	33.5	11.2

EC = Electrical conductivity OM = Organic matter

Table 2. chemical analysis of water used for irrigation

pH	EC dS/m	Soluble cations (meq/l)				Soluble anions (meq/l)			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$Co3^{-}$	$Hco3^{-}$	Cl^{-}	So_4^{--}
7.47	4.9	7.50	5.00	33.1	0.16	-	1.60	40.00	4.16

EC = Electrical conductivity

Determining (ETo) from Meteorological data by using FAO Penman- Monteith equation: Average age of last 10 years from meteorological data of North Sinai was calculated to compute the reference evapotranspiration (ETo) depending on mean daily values of month periods for air temperature, relative humidity, wind speed and solar radiation by using (CROP –WAT PROGRAM) Smith, (1992) as shown in Table (3).

Table 3. environmental data of the study region (average of 10 years).

10 years (2003-2012)	Max. temp. °C	Min. temp. °C	RH %	WS (km/h)	Sun shine	Rain (mm.m)	SLR (W/m^2)	ET_o ($mm.day^{-1}$)
January	20.5	10.5	78.20	12.9	9.1	21	1.53	1.58
February	22.7	12.5	76.77	12.8	9.8	39	1.76	2.30
March	23.4	13.4	75.73	11.4	12.2	28	2.03	3.46
April	24.6	14.5	76.66	11.4	12.3	22	2.40	4.27
May	25.3	15.3	75.36	9.2	11.9	32	2.48	4.59
June	26.2	16.2	75.81	9.3	10.5	20	2.74	4.62
July	29.5	18.3	74.58	9.3	10.4	16	2.90	4.64
August	31.5	20.4	75.52	10.9	10.3	0.00	3.05	4.65
September	30.1	19.1	74.97	11.4	10.2	0.00	2.69	3.99
October	28.6	18.9	73.83	11.3	9.2	2.03	2.32	3.00
November	25.3	15.4	77.92	11.4	8.9	6.29	1.95	2.13
December	21.4	11.2	77.42	12.8	8.5	9.24	1.59	1.51

WS:Wind speed Air Temp: Air temperature RH: Relative Humidity SLR:Solar radiation
ET_o: References Evapotranspiration Rain:mm. $month^{-1}$ Sunshine:hours. Day^{-1}

The reference evapotranspiration ET_o was calculated by using FAO Penman-Monteith equation, Allen *et al.,* (1998) the equation was given as follow:

$$ET_o = 0.408\Delta\ (Rn-G) + \gamma * (900/\ (T+273))\ U2\ (es-ea) /\ (\Delta+\gamma\ (1+0.34U2))$$

ET_o reference evapotranspiration [mm day^{-1}]
Rn net radiation at the crop surface [MJ m^{-2} day^{-1}],G soil heat flux density [MJ m^{-2} day^{-1}]
T air temperature at 2 m height [°C]
u2 wind speed at 2 m height [m s^{-1}]
es saturation vapor pressure [kPa]
ea actual vapor pressure [kPa]
es - ea saturation vapor pressure deficit [kPa]
Δ slope vapor pressure curve [kPa $°C^{-1}$]
γ psychometric constant [kPa $°C^{-1}$]

Then the crop evapotranspiration (ET_c) was calculated by using the following formula according to Doorenbos and Pruitt, (1977):

$$ET_{crop} = K_c . ET_o \quad (mm.day^{-1})$$

Kc = crop coefficient
ETo = reference crop evapotranspiration ($mm.day^{-1}$)
Where ET_o is the reference evapotranspiration (mm) calculated by the Penman-Monteith method and Kc is the crop coefficient.

Treatments were applied Irrigation program as shown in Table (4) during three studied seasons.

The reaction between Irrigation techniques and quantities was evaluated through the following measurements.

Vegetative growth parameters :

To study vegetative growth parameters, tree height (m) and canopy circumference (m) were measured in late October in each season, trunk diameter (cm) was also measured at fixed point (20 cm) above the soil surface. A sample of thirty uniform shoots of the spring cycle was chosen at random and labeled on each experimental tree to determined seasonal shoots elongation rate. In each season 20 full mature leaves per each tree were taken at random in mid-October to determine leaf area (cm2). Leaf area was estimated by using Portable Area Mod Li 3100 Ali (Li-cor).

Date of blooming :

The beginning of blooming was recorded when about 5% of the flowers were opened and the full blooming stage recorded when 80-85% of the flowers were opened while the end of blooming was recorded at the date in which all flower buds were completely opened and when 90-95% of the flowers had fallen their petals.

Number of flowers per inflorescences:

Thirty (one-year-old) shoots were chosen at random around the canopy and labeled on each tree for each season during full bloom (late April) to count the total number of inflorescences per shoot and number of flower per inflorescences for estimating the percentage of perfect flowers.

Table 4. Irrigation program for Kalamata olive tree under North Sinai conditions.

Month	Amount of irrigation water					
	100% of ET_c Control		RDI-80% of ET_c		RDI-60% of ET_c	
	m^3/fed/day	m^3/fed/month	m^3/fed/day	m^3/fed/month	m^3/fed/day	m^3/fed/month
January	4.64	143.84	3.71	115.072	2.784	86.304
February	6.66	186.48	5.32	149.184	3.996	111.888
March	9.73	301.63	7.78	241.304	5.838	180.978
April	11.65	349.50	9.32	279.600	6.990	209.700
May	12.72	394.32	10.17	315.456	7.632	236.592
June	13.25	397.50	10.60	318.000	7.950	238.500
July	13.64	422.84	10.91	338.272	8.184	253.704
August	13.86	429.66	11.08	343.728	8.316	257.796
September	11.89	356.70	9.51	285.360	7.134	214.020
October	8.82	273.42	7.05	218.736	5.292	164.052
November	6.17	185.10	4.93	148.080	3.702	111.060
December	4.24	131.44	3.39	105.152	2.544	78.864
total		3572.43		2857.94		2143.45

Fruit Set Percentage:

Twenty inflorescences were chosen per tree for counting fruit set. Fruit set was recorded after 75% of petal fall by using the following equation: Percentage of fruit set = (No. of fruit set/ No. of total flowers)100.

Fruit yield and alternate bearing index:

Fruits harvesting was carried out at the normal time and ripening stage of the area when about 75% of olive fruit reached the violet skin color (the suitable stage for olive extraction). Fruits of each tree were weighted as (kg) in each season. The index of alternate bearing was determined for each tree according to the following equation developed by Wilox (1944):

Alternate bearing index = 100 x (different between two successive yields/sum of two successive yields). If the result indicated more than 25% this means that the tree has an alternate bearing habit. While the tree is regular bearing if the result was less than 25%.

Fruit physical characteristics:

A sample of 50 fruit from each tree was randomly chosen to determine fruit weight, fruit volume, fruit length, diameter, flesh weight and stone weight.

Fruit moisture and oil content:

Moisture content was determined by drying 50 g of flesh in an oven at 80 C° until a constant weight. fruit oil content was determined by extraction the oil from the dried flesh (50 g) by means of Soxhleet fat extraction apparatus, using petroleum ether of 60-80 C° boiling point and expressed in percentage of dry weight basis according to A O A C, (1990).

Water use efficiency:

Water use efficiency (WUE) was defined as kilograms of fruit per one cubic meter of water consumed. It was calculated during each season, according to (Yaron *et al.,* 1973) as follows: WUE = Y/CU (kg.m-3) Where: WUE = Water use efficiency (kg.m-3)& Y= Seasonal yield (kg.fed-1)& Cu = Water consumptive use (m3.fed-1)

Statistical analysis :

The data were subjected to analysis of variances (ANOVA) using MSTATC computer program (Russell, 1986) with three replication and each replicate was represented by two trees. Duncan's multiple range test was used for comparison between mean. Means followed by different alphabetical letters in the same column significantly differ at 0.05 level of significance (Duncan, 1955). The same trees were used during three studied seasons.

RESULTS

Depending on previous studies and clear field observations strong evidence was observed about the superiority of alternate partial root-zone irrigation and higher irrigation level specific effect when compared with other treatments. For this, the study aimed primarily to focus on the interaction effect between irrigation techniques and quantities in order to select the best combination treatment which maximizes productivity and increase water use efficiency.

Vegetative growth parameters :

Data of Table 5 clear that the treatment of alternate partial root-zone irrigation with 100% of ETc recorded the highest values of tree parameters, tree height (2.49, 2.86, 3.19 m), tree canopy circumference (10.70, 13.05 and 16.28 m) and trunk diameter (10.70,13.06 and 16.26 cm) during three studied seasons, respectively. while, the treatment of whole root-zone irrigation with RDI 60% of ETc recorded the lowest values, tree height (2.19, 2.52 and 2.80 m), tree canopy circumference (8.70,10.61 and 12.86 m) and trunk diameter (8.70, 10.60 and 12.86 cm) respectively. The other interactions came in between.

Seasonal shoot elongation, Leaf area and Number of inflorescences per shoot:

Results present in Table 6 show that seasonal changes in shoot elongation were positively correlated with alternate partial root-zone irrigation with100% of ETc (35.67, 38.0 and 30.0 cm) during three studied seasons, respectively followed by treatment of 80% of ETc than 60% of ETc however, whole root-zone irrigation with 60% of ETc recorded the lowest value (23.0, 25.0 and 21.0 cm) in all studied seasons, respectively the other interactions came in between. By the same token alternate partial root-zone irrigation with 100% of ETc caused a highly significant increase of leaf area, however, irrigated with whole root-zone irrigation and RDI 60% of ETc recorded the lowest values, in this respect, the other interactions came in between. Similar results were obtained with the number of inflorescences per shoot with alternate partial root-zone irrigation and 100% of ETc (11.00, 8.00 and11.67) during three studied seasons, respectively. On the other hand, treatment of whole root-zone irrigation with RDI 60% of ETc recorded the lowest number of inflorescences per shoot (5.67, 4.67 and 7.00) in the three seasons, respectively. The other interactions were in between in this respect.

Table 5. The interaction effect between irrigation techniques and quantities on tree parameters of Kalamata olive tree under North Sinai conditions.

Treatment		Tree height (m)			Tree canopy circumference (m)			Trunk diameter (cm)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	2.35 c	2.70 c	3.01 c	9.40 d	11.47 d	14.06 d	9.40 d	11.46 d	14.06 d
	80% ET_c	2.26 d	2.60d	2.89 d	8.93 e	10.90 e	13.26 e	8.93 e	10.90 e	13.23 e
	60% ET_c	2.19 e	2.52e	2.80 e	8.70 f	10.61 f	12.86 f	8.70 e	10.60 e	12.86 e
APRI	100% ET_c	2.49 a	2.86 a	3.19 a	10.70a	13.05 a	16.28 a	10.70 a	13.06 a	16.26 a
	80% ET_c	2.43 b	2.79 b	3.11 b	10.30 b	12.57 b	15.59 b	10.30 b	12.56 b	15.60 b
	60% ET_c	2.38 c	2.74 c	3.05 c	10.05 c	12.25 c	14.96 c	9.93 c	12.23 c	14.96 c

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Table 6. The interaction effect between irrigation techniques and quantities on seasonal shoots elongation, leaf area and number of inflorescences per shoot of Kalamata olive tree under North Sinai conditions.

Treatment		seasonal shoots elongation (cm)			Leaf area (cm^2)			Number of inflorescences per shoot		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	28.00 bc	32.00 b	25.00 bc	6.05 c	6.08 b	6.26 b	9.00 b	6.33 b	10.33 b
	80% ET_c	24.00 cd	28.00 c	23.00 cd	5.77 d	5.80 c	5.96 c	7.00 c	5.33 cd	9.33 b
	60% ET_c	23.00 d	25.00 d	21.00 d	5.45 e	5.48 d	5.62 d	5.67 c	4.67 d	7.00 c
APRI	100% ET_c	35.67 a	38.00 a	30.00 a	6.90 a	6.76 a	6.99 a	11.00 a	8.00 a	11.67 a
	80% ET_c	29.67 b	32.00 b	26.00 b	6.58 b	6.15 a	6.34 b	9.33 b	7.00 b	9.67 b
	60% ET_c	27.00 bc	30.00 bc	22.00 cd	6.08 c	5.69 cd	5.84 cd	7.00 c	5.67 bc	7.67 c

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Blooming duration and inflorescence characteristics:

As for the interaction effect between irrigation techniques and quantities on Kalamata olive tree data in table 7 show that the treatment of alternate partial root-zone irrigation with 100% of ET_c were highly interactive for blooming duration, total number of flower per inflorescence and number of perfect flower) however, treatment of whole root-zone irrigation with RDI 60% of ET_c recorded the lowest values in the three studied seasons. The other interactions revealed in between effect in this respect.

Table 7. The interaction effect between irrigation techniques and quantities on blooming duration, and some of the inflorescence characteristics of Kalamata olive tree under North Sinai conditions.

Treatment		blooming duration (day)			number of flower per inflorescence			No. of perfect flower		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	17.00 ab	17.67 a	15.33 b	15.50 b	11.6 b	16.26 bc	8.63 ab	6.23 b	9.30 b
	80% ET_c	15.00 cd	15.33 b	14.33 bc	14.63 bc	9.37 c	15.30 cd	7.90 bc	4.90 cd	7.80 cd
	60% ET_c	13.00 e	13.67 c	13.33 c	12.40 d	7.77 d	13.77 e	6.67 d	4.4 d	7.40 d
APRI	100% ET_c	18.00 a	18.00 a	17.33 a	17.47 a	13.03 a	18.80 a	9.67 a	6.9 a	10.50 a
	80% ET_c	15.67 bc	16.33 b	15.00 b	15.63 b	12 ab	16.70 b	8.36 b	6.13 b	8.73 bc
	60% ET_c	13.67 de	15.00 b	13.67 c	13.67cd	10.16 c	14.57 de	7.63 cd	5.23 c	7.47 d

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

A number of male flower per inflorescence:

Data in Table 8 show that highest values of male flowers were noticed with alternate partial root-zone irrigation and 100% of ET_c, on the other hand, trees irrigated with whole root-zone irrigation and RDI-60% of ET_c recorded the lowest number of male flower per inflorescence. The other interactions were in between in this respect during three studied seasons.

Table 8. The interaction effect between irrigation techniques and quantities on some of the inflorescence characteristics and fruit set of Kalamata olive tree under North Sinai conditions.

Treatment		No. of male flower			Sex expression (%)			Fruit set (%)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	6.87 bc	5.36 bc	6.97 bc	0.55 a	0.53 b	0.57 a	18.15 a	14.96 b	18.28 bc
	80% ET_c	6.73 bc	4.46 c	7.5 ab	0.54 ab	0.52 b	0.51 c	16.44 b	13.38 c	15.83 d
	60% ET_c	5.73 d	3.37 d	6.36 c	0.54 ab	0.57 a	0.53 a-c	13.45 c	10.58 d	12.39 e
APRI	100% ET_c	7.80 a	6.1 a	8.3 a	0.55 a	0.53 b	0.56 ab	19.33 a	18.16 a	22.07 a
	80% ET_c	7.27 ab	5.8 b	7.97 a	0.54 ab	0.52 b	0.52 bc	18.03 a	16.31 b	20.18 a
	60% ET_c	6.63 c	4.93 bc	7.10 bc	0.51 b	0.51 b	0.51 c	16.39 b	12.28 c	17.11 cd

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Sex expression:

Data in Table 8 show that highest values of sex expression were noticed in both first and third seasons with 100% of ET_c under both of irrigation techniques, on the other hand, irrigated with RDI-60% of ET_c recorded the lowest number of sex expression. The other interactions were in between. Conversely, in the second season the highest value of sex expression was obtained with the treatment of whole root-zone irrigation and 60% of ETc, however, no significant differents were noticed between the other treatments.

Fruit set:

data of Table 8 clear that the treatment of alternate partial root-zone irrigation with 100% of ET_c was highly interactive fruit set percentage, however, whole root-zone irrigation and RDI-60% of ET_c recorded the lowest value in this respect. The other interactions came in between effect during three studied seasons.

Fruit shape parameters:

Regarding the interaction effect between irrigation techniques and quantities, data in Table 9 show that irrigation with alternate partial root-zone irrigation with 100% of ET_c caused the highest increase of fruit quality characteristics (Fruit volume, Fruit length and Fruit diameter). While RDI-60% of ET_c with whole root-zone irrigation had the lowest values in this respect. The other interactions came in between during three studied seasons.

Table 9. The interaction effect between irrigation techniques and quantities on some fruit shape parameters of Kalamata olive tree under North Sinai conditions.

Treatment		Fruit volume (ml)			Fruit length (cm)			Fruit diameter (cm)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	4.05 b	4.19 a	4.04 b	2.70 a	2.74 ab	2.76 bc	1.50 ab	1. 50 ab	1.51 ab
	80% ET_c	3.85 c	3.96 b	3.84 c	2.60 ab	2.61 bc	2.66 c	1.46 b	1.46 b	1.46 b
	60% ET_c	3.58 e	3.75 c	3.64 d	2.46 b	2.48 c	2.46 d	1.36 c	1.36 C	1.37 c
APRI	100% ET_c	4.25 a	4.30 a	4.14 a	2.80 a	2.83 a	2.89 a	1.57 a	1.56 a	1.57 a
	80% ET_c	3.94 c	3.97 b	3.92 c	2.69 a	2.67 ab	2.82 a	1.50 ab	1.50 ab	1.51 ab
	60% ET_c	3.72 d	3.78 c	3.74 d	2.63 ab	2.66 ab	2.73 bc	1.43 bc	1.43 bc	1.43 bc

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation.

Fruit quality characteristics:

Data of Table (10) show that alternate partial root-zone irrigation with 100% of ET_c caused the highest increase of fruit quality characteristics (fruit weight, flesh weight and stone weight). When combined with 100% of ET_c while, RDI-60% of ET_c with whole root-zone irrigation had the lowest values in this respect. The other interactions came in between during three studied seasons.

Table 10. The interaction effect between irrigation techniques and quantities on some fruit quality characteristics of Kalamata olive tree under North Sinai conditions.

Treatment		fruit weight (g)			Flesh weight (g)			Stone weight (g)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	4.15 ab	4.15 b	4.22 a	3.66 ab	3.67 a	3.67 a	0.73 ab	0.72 ab	0.72 ab
	80% ET_c	3.84 bc	3.84 b	3.79 bc	3.05 bc	3.05 b	3.05 b	0.70 b	0.69 ab	0.70 ab
	60% ET_c	3.36 c	3.36 c	3.37 c	2.56 d	2.77 c	2.63 c	0.63 b	0.64 b	0.65 b
APRI	100% ET_c	4.85 a	4.64 a	4.60 a	3.73 a	3.77 a	3.80 a	0.86 a	0.82 a	0.79 a
	80% ET_c	4.11 ab	4.12 b	4.18 a	3.36 ab	3.51 a	3.52 a	0.75 ab	0.76 ab	0.75 ab
	60% ET_c	3.87 bc	3.9 b	4.00 b	3.09 bc	3.15 b	3.13 b	0.71 b	0.71 ab	0.72 ab

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Flesh: Stone ratio:

It is clearly noticed that flesh: stone ratio was significantly affected by different irrigation treatments during three studied seasons. Results in table 11 indicated that Flesh /stone ratio had the highest values with 100% of ET_c when combined with whole Root-zone Irrigation while RDI-60% of ET_c with the same irrigation techniques had the lowest values in this respect. The other interactions came in between.

Oil and moisture content:

Data of Table 11 show that the treatment of alternate partial root-zone irrigation and 100% of ET_c had the highest value of Oil content (%) (47.87,48.35 and 47.98) and moisture content % (54.86,55.40 and 56.05) respectively, during three studied seasons. While whole root-zone watering with RDI60% of ET_c recorded the lowest value (42.96,43.39 and 42.98) as Oil content (%) and (44.07,44.51 and 45.02) as moisture content %, respectively. Other treatments were in between.

Table 11. The interaction effect between irrigation techniques and quantities on flesh: stone ratio, oil and moisture content of Kalamata olive tree under North Sinai conditions.

Treatment		Flesh: Stone ratio			Oil content (%) (on dry weight basis)			Moisture content (%)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
WRI	100% ET_c	5.01 a	5.10 a	5.10 a	46.33 a	46.79 a	46.16 a	53.65 a	54.09 a	53.94 a
	80% ET_c	4.36 c	4.42 c	4.36 d	43.99 b	44.43 b	44.01 b	46.87 bc	47.34 bc	47.22 bc
	60% ET_c	4.06 e	4.33 d	4.05 e	42.96 b	43.39 b	42.98 b	44.07 c	44.51 c	45.02 c
APRI	100% ET_c	4.34 d	4.60 b	4.81 b	47.87 a	48.35 a	47.98 a	54.86 a	55.40 a	56.05 a
	80% ET_c	4.48 b	4.62 b	4.69 c	46.14 a	46.60 a	46.16 a	47.43 b	47.90 a	48.28 b
	60% ET_c	4.35 cd	4.44 c	4.35 d	43.49 b	43.93 a	43.51 b	44.56 bc	45.00 bc	45.75 bc

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Crop yield:

As for the interaction effect between irrigation techniques and quantities, data in Table 12 indicate that the highest values of crop yield were noticed with alternate partial root-zone irrigation with 100% of ETc (39.33,31.72 and 43.26 kg/tree) respectively, during three studied seasons. However, irrigated with whole root-zone irrigation with RDI60% of ETc recorded the lowest values of crop yield (25.90,18.70 and 29.60 kg/tree) respectively. The other interactions were in between.

Concerning the specific effect of water applied method data in Table 13 indicate that the highest values of crop yield were obtained with alternate partial root-zone irrigation (34.77, 26.68 and 38.87 kg/tree) respectively, during three studied seasons. However, irrigated with whole root-zone irrigation recorded the lowest values of crop yield (30.58, 23.31 and 34.60kg/tree) respectively.

As for the specific effect of regulated deficit irrigation RDI results in Table 13 reveal that the water stress treatments reduced crop yield so, the 100% of ET_c caused the highest significant increase in this respect, followed by irrigated trees at RDI 80% of ET_c than RDI 60% of ET_c during three studied seasons.

Table 12. The interaction effect between irrigation techniques and quantities on crop yield, alternate bearing index and water use efficiency of Kalamata olive tree under North Sinai conditions.

Treatment		Crop yield (kg per tree)			Alternate bearing index (%)		WUE (kg.m-3)		
		2013	2014	2015	(2013-2014)	(2014-2015)	2013	2014	2015
WRI	100% ET_c	35.41 b	28.16 b	38.95 b	11.33 d	16.00 c	1.15 d	0.91 d	1.27 d
	80% ET_c	30.42 c	23.08 d	34.25 c	13.67 c	19.33 b	1.24 c	0.94 d	1.39 c
	60% ET_c	25.90 d	18.70 f	29.60 d	16.33 a	22.33 a	1.40 b	1.01 bc	1.61 b
APRI	100% ET_c	39.33 a	31.72 a	43.26 a	10.67 d	15.33 c	1.28 c	1.03 bc	1.41 c
	80% ET_c	34.87 b	26.05 c	38.85 b	14,67 bc	20.00 b	1.42 b	1.06 b	1.58 b
	60% ET_c	30.10 c	22.26 e	34.49 c	15.00 b	21.67 a	1.63 a	1.21 a	1.87 a

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation

Table 13. Specific effect of irrigation techniques and quantities on total yield, alternate bearing index and water use efficiency of Kalamata olive tree under North Sinai conditions.

Treatment	Crop yield (kg per tree)			Alternate bearing index (%)		WUE ($kg.m^{-3}$)		
	2013	2014	2015	(2013-2014)	(2014-2015)	2013	2014	2015
	Specific effect of water applied method							
WRI	30.58	23.31	34.60	13.78	13.45	1.26	0.95	1.42
APRI	34.77	26.68	38.87	13.45	19.22	1.44	1.1	1.62
F-Test	*	*	*	n.s	*	*	*	*
	Specific effect of regulated deficit irrigation treatments							
100%ET_c	37.37 a	29.94 a	41.05 a	11.00 c	15.66 c	1.22 c	0.97 c	1.34 c
80% ET_c	32.64 b	24.56 b	36.55 b	14.17 b	19.00 b	1.33 b	1.00 b	1.48 b
60% ET_c	28.00 c	20.48 c	32.45 c	15.66 a	22.00 a	1.50 a	1.11 a	1.74 a

Means followed by the same letter(s) within each column are not significantly different at the 0.05 level, according to Duncan's multiple range test.
WRI: Whole Root-zone Irrigation APRI: Alternate Partial Root-zone Irrigation.

Alternate bearing index:

As for alternate bearing index results take a conversely trend and that is reasonable so, data in Tables 12 indicate that the lowest values of alternate bearing index were noticed with alternate partial root-zone irrigation in combined with 100% of ET_c however, trees irrigated with whole root-zone irrigation with RDI 60% of ET_c recorded the highest values of alternate bearing index. The other interactions were in between. By the same token, there is no shortage of disagreement within the specific effect of water applied method in relation with alternate bearing index except between (2013-2014) seasons because there were insignificant differences between the both irrigation techniques as shown in Table 13. As for the specific effect of regulated deficit irrigation RDI results in Table 13 reveal that water stress treatments increase alternate bearing index. So, treatment of 100% of ET_c recorded the best values in this respect (11.00 %), followed by irrigated trees at RDI 80% of ET_c (14.17 %) than RDI 60% of ET_c (15.66 %) that between (2013-2014) seasons respectively. On the other hand, alternate bearing index between (2014-2015) seasons recorded 15.66 % followed by 19.00% than 22.00 % respectively.

Water use efficiency:

Concerning the water use efficiency WUE (kg of fruits /m^3 of water) for olive trees as affected by water applied method and the levels of regulated deficit irrigation. As for the interaction effect, the represented results in Table 12 indicate that the highest value of water use efficiency ($kg.m^{-3}$) was found with alternate partial root-zone irrigation and RDI-60% of ET_c however, irrigated with whole root-zone irrigation with 100% of ET_c recorded the lowest values of WUE. The other interactions were in between. As for the specific effect of water applied method results in Table 13 indicate that the highest values of water use efficiency WUE were obtained with alternate partial root-zone irrigation (1.44, 1.10 and 1.62 $kg.m^{-3}$) respectively, during three studied seasons. However, irrigated with whole root-zone irrigation recorded the lowest values of crop yield (1.26, 0.95 and 1.42 $kg.m^{-3}$) respectively. In relation to the specific effect of regulated deficit irrigation RDI, water use efficiency was significantly increased with the lower levels of irrigation water (60% of ET_c followed by 80% of ET_c than 100% of ET_c) respectively, during three studied seasons.

DISCUSSION

Vegetative growth parameters

As for the effect of irrigation techniques and quantities on Kalamata olive tree under North Sinai conditions. tree growth parameters were significantly increased with APRI as compared with whole root-zone irrigation. These results go in line with those reported by Dry and Loveys (1998), who found that APRI significantly reduces water use, enhance canopy vigor and maintain yields. In addition shoot elongation were significantly increased with APRI as compared with WRI. These results are in agreement with those reported by Wahbi *et al.,*(2005).

Concerning the effect of regulated deficit irrigation RDI, seasonal changes in shoot elongation were significantly increased with the highest level of irrigation (control treatment 100% ET_c) in comparison with the lower levels of regulated deficit irrigation (80% ET_c and 60% ET_c). Similar observations were reported by Aganchich *et al.,* (2008) who concluded that the vegetative growth was substantially reduced under RDI compared with the control in shoot length on the both seasons.

Blooming duration, inflorescence characteristics and fruit quality characteristics

APRI had the highest number of inflorescences per shoot, Blooming duration, percentage of fruit set and fruit quality characteristics in comparison with WRI during three studied seasons. These results go in line with those reported by Wahbi *et al.,* (2005) who found that under arid conditions the yield of olive was significantly higher under alternate partial root-zone irrigation in comparison with other treatments. Similar results were mentioned by Dry and Loveys (2000) who indicated that grape roots distribution were changed when they applied partial root zoon irrigation (PRI). More roots were developed in deeper layers of soil and a larger root system was mentioned. In addition, Han and Kang (2002) referred that the ability of roots to absorb nutrients was also improved horizontally and vertically when the root-zone was partially irrigated and the partial irrigated zone was shifted alternately. Finally, we may be attributed that flowering and fruiting process depends on perfect water supply and good nutrition.

Concerning the effect of regulated deficit irrigation RDI results in this study reveal that the water stress treatments reduced number of inflorescences per shoot, blooming duration, percentage of fruit set and fruit quality characteristics hence, the 100% of ET_c caused the highest significant values in this respect, followed by irrigated trees at RDI 80% of ET_c and RDI 60% of ET_c during three studied seasons. These results were in the same line of El-Alakmy (2004) who reported that the water stress reduced number of inflorescences per shoot, a percentage of fruit set and fruit quality characteristics in olive trees. As for oil and moisture content results agree with those reported by Lavee and Wodner (1991) who demonstrated that the pattern of oil accumulation does not depend on genetic specificity but rather on environmental conditions, particularly water availability and fruit yield. These results go in line with those reported by (Mehanna *et al.,*2012) who found that yield and fruit parameters responded negatively to the RDI treatments. Trees irrigated with 100% ET_c through a long season (control) recorded the highest values, followed in descending order by those irrigated with 66% ET_c than 33% ET_c generally, lack of water during flower differentiation results in decreasing flowering and fruiting process clearly.

Crop yield, alternate bearing index and water use efficiency

In relation to the effect of alternate partial root-zone irrigation APRI data in tables (12&13) reveal that APRI had the highest number of crop yield in comparison with whole root-zone irrigation WRI. These results agreed with those reported by Wahbi *et al.* (2005), who found that crop yield of olive tree recorded the highest value with APRI in comparison with other irrigation treatments.

Other significant factors were reported by Stoll et al. (2000), who found that partial root-zone drying PRD is a new irrigation strategy which develops water use efficiency (by up to 50%) of grape production without significant crop reduction. The technique was proposed on the basis of controlling transpiration and requires that approximately half of the root system is always maintained in a dry condition while the other parts of the root system are irrigated, the wetted and dried sides of the root system are shifted on a 10-14 day cycle. Abscisic acid ABA concentration in the drying roots increases 10-fold, but ABA concentration in leaves of grapevines under PRD treatment only increased by 60% compared with a fully irrigated control treatment. Stomatal conductance of vines under PRD irrigation was significantly decreased when compared with vines which receiving water to the whole root system. PRD results in increased xylem sap flow, ABA concentration and increased xylem sap pH, those factors probably result in a reduction of stomatal conductance.

As for the effect of regulated deficit irrigation treatments data of Table 12 reveal that the crop yield was increased linearly by increasing the amount of water. The irrigated trees at 100% of ET_c and RDI-80% of ET_c were the highest in this respect. On the other hand, the irrigated trees of RDI-60% of ET_c had the lowest value during three studied seasons. These results go in line with those reported by Alegre *et al*. (2000), they concluded that fruit yield was decreased with the lowest irrigation rate.

In relation to the interaction effect of alternate partial root-zone irrigation and RDI levels data in Table 12 reveal that APRI, when combined with 100% of ETc recorded the lowest number of the alternate bearing index in comparison with whole root-zone irrigation WRI with 100% of Etc. It is clear from previous results that alternate partial root-zone irrigation APRI decreases the value of the alternate bearing index as yield during three studied seasons. In general, yield was nearly similar under alternate partial root-zone irrigation APRI and RDI- 80% of ETc when compared with 100% of ETc with whole root-zone irrigation WRI but the first technique saved at least 20% of irrigation water. In addition, 20% of irrigation water may cause an increase in crop yields if water is applied as APRI rather than WRI.

As for the specific effect of water applied technique data of Tables (12-13) reveal that alternate partial root-zone irrigation was effective in increasing water use efficiency during three studied seasons. Similar results were mentioned by Stoll *et al.,* (2000) and Kang and J. Zhang (2004), who found that partial root-zone drying is an irrigation technique, which increases water use efficiency (by up to 50%) without significant crop reduction. Generally, Part of the root system in drying soil can respond to the stress by sending a root-sourced signal to the shoots that result in a reduction in stomatal conductance and decreased water loss. In relation to the specific effect of regulated deficit irrigation RDI, water use efficiency was significantly increased with the lower levels of regulated deficit irrigation (60% ETc, 80% ET and 100% ETc), respectively during three studied seasons. These results go in line with those reported by El-Alakmy (2008) who indicated that the irrigated trees at RDI-70% of ETc succeeded in increasing water use efficiency followed by the irrigated trees at RDI-35% of ETc in both studied seasons While, 100% of ETc treatment recorded the lowest values in this respect. Finally, when careful irrigation management was used by alternate partial root-zone method with regulated deficit irrigation that led to minimizing evapotranspiration rate and resulting in increased water use efficiency which had positive effects on growth and fruit characteristics.

CONCLUSION

It can be concluded that we can decrease the irrigation water quantities to 80% of ET_c by using alternate partial root-zone irrigation APRI and obtain the same crop yield by using 100% of ETc with whole root-zone irrigation WRI technique on Kalamata olive tree under North Sinai conditions.

REFERENCES

Aganchich, B., A. El Antrari ,S. Wahbi, H. Tahi, R. Wakrim and R. Serraj (2008). Fruit and oil quality of mature olive trees under partial root-zone drying in field condition. Grasas Y Aceites, 59 (3): 225-233.

Alegre, S.; J. Marsal; M. J. Tovar; M. Mata; A. Arbonés and J. Girona (2000). Regulated deficit irrigation in olive trees (*Olea Europaea* L.) cv. Arbequina for oil production. Proceedings of 4th International Symposium on Olive Growing. Valenzano (Bari) Italy. 25-30 September 2000.

Allen R.G., L.S. Pereira, D. Raes and M. Smith (1998) Crop evapotranspiration. guidelines for computing crop water requirements. FAO Irrigation and Drainage. Paper no. 56, FAO, Rome.

A O A C (1990). Official Methods of Analysis 15th ed., Association of Official Agriculture Chemists Washington DC, USA.

Chalmers, D.J., P.D. Mitchell and L. Vanheek , (1981). Control of peach-tree growth and productivity by regulated water-supply, tree density, and summer pruning. Journal of the American Society for Horticultural Science, 106 (3): 307–312.

Doorenbos, J. and W.O. Pruitt (1977). Crop water requirements. FA_O, Irrigation and drainage, paper No. 24.Rome.

Dry, P.R. and B.R. Loveys (1998). Factors influencing grapevine vigour and potential for control with partial root zone drying. Aust.J. Grape Wine Res,4:140-148.

Dry, P.R. and B.R. Loveys (2000). Partial drying of the root-zone of grape. I. Transient changes in shoot growth and gas exchange. Vitis, 39: 3–7.

Duncan, B.D. (1955). Multiple Range and Multiple F-tests. Biometrics, 11: 1-42.

El-Alakmy, H. A. (2004). Regulated deficit irrigation in 'Picual' olive trees for oil production. M.SC. Thesis. Faculty of Environmental Agricultural Sciences at El-Arish, Suez Canal University, Ismailia, Egypt.

FAO.(2014).The Statistical Database (FAOSTAT). Rome, Italy: Food and Agriculture Organization of the United Nations. Available in: in: http://faostat. fao. org.

Fereres, E., D.A. Goldhamer and L.R. Parsons, (2003). Irrigation water management of horticultural crops. Hortscience, 38 (5): 1036–1042.

Han, Y.L. and S.Z. Kang (2002). Effects of the controlled partial root-zone irrigation on root nutrition uptake of maize (Zea mays). Transactions of Chinese Society of Agricultural Engineers,18 (1): 57-59.

Kang SZ and J. Zhang (2004). Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. Journal of Experimental Botany, Vol. 55,(407):2437–2446.

Lavee, S. and M. Wodner (1991). Factors affecting the nature of oil accumulation in fruit of olive (*Olea Europaea* L.) cultivars. Journal of Horticultural Science, 66, 583-91.

Mehanna, H.T , R.G. Stino ,I. Saad El-Din and A.H. Gad El-Hak (2012). The influence of deficit irrigation on growth and productivity of Manzanillo olive cultivar in desert land. Journal of Horticultural Science & Ornamental Plants, 4 (2): 115-124.

Ministry of Agriculture and Land Reclamation (2012). Agricultural Statistics, Volume:2.

Smith, M.; (1992). CROPWAT-A computer program for irrigation planning and management. FAO Irrig. Drain. Paper 46, Rome, 1992.

Russell, D.F.; (1986). MSTATC Director, Crop and Soil Sciences Department, Michigan State University, Computer Program Package Version 2.10.

Stoll, M.; L. Brian and D. Peter (2000). Hormonal changes induced by partial root-zone drying of irrigated grapevine. J. Exp. Bot., 51: 1627-1634.

Wahbi, S.; R. Wakrim; B. Aganchich; H. Tahi and R. Serraj (2005). Effect of partial root-zone drying (PRD) on adult olive tree (Olea Europaea) in field conditions under arid climate I. Physiological and agronomic responses. Agric.Ecosystems and Envi.,106:289-301.

Wilox, J.C.(1944).Some factors affecting apple yield in Okanagan Valley Sci.Agric.,25: 189-213.

Yaron, B.; J. Shalhevet and D. Shimishi (1973). Patterns of salt distribution under trickle irrigation. Ecological Studies; Analysis and Syntheses. Vol. 4, Springer Velary, Berlin, pp: 389-394.

أثر تقنيات الري وكمياته على أشجار الزيتون صنف الكلاماتا تحت ظروف شمال سيناء

وائل موسى غيث

وحدة الفاكهة - قسم الانتاج النباتي - مركز بحوث الصحراء - القاهرة – مصر

أجريت هذه التجربة في مزرعة خاصة في رفح , محافظة شمال سيناء على مدار ثلاث مواسم زراعية بداية من ٢٠١٣حتى ٢٠١٥على اشجار زيتون صنف كلاماتا عمرها عشر سنوات مزروعة على مسافات ٦x٦ في تربة رملية تروى بنظام الري بالتنقيط متشابهة تقريبا في الشكل وتخضع للمعاملات البستانية المتعارف عليها واجريت هذه التجربة من أجل تقييم سلوك اشجار زيتون الكلاماتا تحت ظروف تقنيتين من تقنيات الري وهما (الري الكلى للمجموع الجذري وهو الاسلوب الشائع –والري الجزئي المتبادل للمجموع الجذري) تحت ثلاث مستويات من الخفض المنظم لماء الري (١٠٠% -٨٠% -٦٠%) من النتح بخر المحصولى ومن استقراء نتائج التجربة تبين أن تقنية الري الجزئي المتبادل للمجموع الجذري حسنت من خصائص النمو الخضري ومقاييسه وكذلك مواعيد التزهير وصفات النورات والثمار وأيضا كمية المحصول ونسبة الزيت مقارنة بتقنية الري الكلى للمجموع الجذري وعلى الجانب الاخر سجلت خصائص النمو السابقة ارتباطا وثيقا مع القيم الاعلى من معدلات الخفض المنظم لماء الري حيث سجلت خصائص النمو والتزهير والاثمار تفوقا واضحا مع معاملة الكونترول ١٠٠% من النتح بخر المحصولى بينما سجلت معاملة الخفض المنظم ٦٠% نتح بخر محصولي القيم الاقل وسجلت معاملة ال ٨٠% نتح بخر محصولي قيم متوسطة بين القيمتين السابقتين وعموما اوضحت نتائج الدراسة ان تقنية الري الجزئي المتبادل للمجموع الجذري وفرت على الاقل ٢٠ % من مياه الري المقررة مقارنة بتقنية الري الكلى للمجموع الجذري وحسنت من كفاءة استخدام مياه الري بشكل واضح .