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Assessment of different ETO-Dependent Irrigation Levels for Pomegranate on Saving Water and Energy and Maximizing Farm Income

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ABSTRACT

Field experiments were conducted on drip–irrigated pomegranate *(Punicagranatum L.)* trees grown in a private farm at kilometer 76 Cairo/Alexandria Desert Road, Egypt during the 2016 and 2017 growing seasons. The site represents newly reclaimed sandy soil at the west of Nile Delta region. The objectives of this study were to evaluate the effect of different ETo-dependent irrigation levels on amounts of applied irrigation water, water consumptive use, fruit yield and its components, fruit quality, water use efficiency, water productivity, and to develop a local pomegranate crop coefficient (Kc) and yield response factor (Ky) under the experimental conditions, as well as the effect on saving energy and increasing farm income. Four irrigation treatments (120, 100 and 80, and 60% ETo) were compared to farmer irrigation practice. The experimental treatments were laid out in strip plot design with four replicates. Results indicated that distribution uniformity values, conducted at the beginning of each season, were 88 and 90 % in 1^{st} and 2^{nd} seasons, respectively. The 2–season average amounts of applied irrigation water for the 120, 100, 80, and 60% ETo and farmer treatment were 13520, 11270, 9020, 6760, and 18075 m^3 ha^{-1}, respectively. Average values of total fruit yield were 40.2, 38.6, 36.9, 23.8, and 31.8-ton ha^{-1} for the same respective treatments. The highest fruit diameter and weight were produced from irrigation with 120% ETo. The Kc values for the 120% ETo irrigation treatment were 0.14-0.45, 0.45-0.79, 0.79-1.05, and 1.05-0.76 for initial, crop development, mid- and late-season growth stages, respectively. Results showed that pomegranate yield response factor (Ky) was 0.81 indicating that pomegranate trees are moderately tolerant to water stress. Application of the proposed irrigation treatments reduced consumed energy by values varied from 25 to 62% compared with farmer irrigation. The 2-year average net income values of the 120, 100, 80, and 60% ETo irrigation treatments were 117, 106, 91, and 3% higher than that of farmer practice. Under the experiment circumstances it could be concluded that, irrigating pomegranate trees at 80% ETo level saves 9055 m^3/ha of applied irrigation water and 50% of the electric energy In addition, the highest figures of water use efficiency (4.7 kg fruits/m^3 water consumed), water productivity (4.1 kg fruits/m^3 water applied), and net income (91% more), were achieved compared with farmer practice.

Keywords: pomegranate, ETo-dependent irrigation levels, energy saving, drip system, sandy soil, water productivity, water use efficiency, crop coefficient, yield response factor.

INTRODUCTION

Egypt is facing severe shortage in water resources, and demand for water is increasing due to growing population, competition between different water consuming sectors and the expansion in irrigated agriculture as well. Hence, attempts are required to increase the water use efficiency of different crops. Demand management in on-farm irrigation level would be a focus point to reduce the increasing demand of water to match the future supplies, thereby reducing the effect of water stress that the country will be facing. The Egyptian renewable water resources are estimated at 58.3 billion m³ $year^{-1}$. These are divided into 55.5 billion m³ $year^{-1}$ from the Nile River, 500 million m³ $year^{-1}$ from internal renewable surface water resources and 1.3 billion m³ $year^{-1}$ from internal renewable groundwater resources, and 1 billion m³ $year^{-1}$ from the Nubian Sandstone aquifer (FAO, 2016). Egypt depends on irrigated agriculture for more than 95% of agriculture area (Abou Zeid, 2002). Water availability to the agricultural sector is becoming a major constraint to agricultural production, which is the largest consumer of the Egyptian water resources. Egypt's water policy mainly depends on the expansion of modern irrigation techniques in the newly reclaimed soils of desert and irrigation practices improvement in old lands of the Nile Delta and Valley (NWRP, 2002).

The nature of soils in the newly reclaimed lands, where the present experiments were executed, is mainly sandy with low water storage capacity and low fertility and organic matter content as well, (Page *et al*., 1982). It is worthy to mention that, in such areas, irrigation water is extracted from aquifers at depths ranging approximately from 10 to 100 meters or more, so, electrical energy or diesel power are required to operate the pumps and to lift water for irrigating the crops (NAMA, 2017).Under such conditions, the choice of an irrigation method, which accomplish efficient water use, higher crop yield and quality, save energy and enhance farm profits, is the most important issue. In this respect, application of modern irrigation techniques such as drip, bubbler, and sprinkler to increase irrigation efficiency, which is one of the measures utilized for competent use of water, is highly recommended (NWRP, 2002). Drip and sprinkler irrigation systems are considered highly efficient methods of delivering water and fertilizer uniformly to crops (Abu Zeid, 1999). In addition, an advantage in using drip irrigation is that small amounts of water can be used even for saline water (Hanson and May, 2011).

Pomegranate tree is mainly grown in tropical and sub-tropical regions of the world and favor for semi-arid climates (Elfalleh *et al*., 2009, and Ahmet *et al*., 2009). In addition, pomegranate tree is drought tolerant and can be grown in dry weather (Dhinesh and Ramasamy, 2016), thus it is suitable to be cultivated in newly reclaimed lands in Egypt. Pomegranate in tropical and subtropical areas is considered an important fruit crop because of its low cost to produce high quality fruits, economically to establish an orchard and good keeping quality for a long time (Indian Council of Agriculture Research, 2005). Recently, there is an increase in pomegranate cultivation on a large scale in Egypt in newly reclaimed areas. The total cultivated area of pomegranate is about 45,552 hectares, while cultivated area of pomegranate in new land is about 31,322 hectares, which produce about 509,295 tons. The average yield by hectare is estimated to 16.26 ton (Economic Affairs Sector Ministry of Agriculture and Land Reclamation, 2016).

In recent years, Egypt has turned from being a net exporter to a net importer of energy. The country has been experiencing growing shortages of electricity and diesel, currently the primary sources of energy used for irrigation. Furthermore, the government has been gradually lifting its subsidies on fossil fuels, and as a result increasing the costs of energy in the local market. Using irrigation scheduling and fertigation practices in sandy soil are considered useful practices to increase energy use efficiency. The energy required to pump irrigation water for crop production is measured in terms of fuel or electric power use to pump each unit of water. Additionally, the amount of irrigation water pumped depends on several irrigation system factors (specific system design factors, such as the potential irrigation system efficiency, the system design uniformity, and the relative area of coverage, and on crop factors include type of crop, size of plants, plant density, and other production system (Smajstrla *et al*., 1998). Climate factors include solar radiation, temperature, humidity and wind speed, have an effect on the pumped irrigation water (El-Qousy *et al*., 2006). Moreover, management factors include irrigation scheduling decisions which affect irrigation frequencies and durations.

The objectives of this study were to evaluate the effect of different irrigation treatments, derived from the local ETo values, on applied irrigation water, water consumptive use, yield and its components, fruit quality of pomegranate. In addition, water use efficiency, water productivity, yield response factor (Ky) and developing a local crop coefficient (Kc) were considered. Saving both energy and water, enhancing the farm income on sandy soils under drip irrigation and the experimental conditions were under study.

MATERIALS AND METHODS

Experimental site:

Field experiments were conducted on pomegranate *(Punicagranatum L.)* trees in a private farm located at the kilometer 76 Cairo/Alexandria Desert Road, Egypt (30.36 02 N latitude, 31.01 E longitude, with an altitude of 17.90 m above mean sea level) during the 2016 and 2017 growing seasons. The experimental site represents newly reclaimed sandy soil at west Nile delta region. Average monthly weather data at the experimental site are presented in Table 1. These data were used to calculate monthly reference evapotranspiration (ETo) according to the Basic Irrigation Scheduling model (BISm) as described by Snyder *et al.* (2004).

Table 1. Average weather data (2012-2016) and the calculated reference evapotranspiration values at the experimental site.

Months	Srad (MJ m^{-2} day^{-1})	Tmax (°C)	Tmin (°C)	Ws (m s^{-1})	Td (°C)	ETo (mm day^{-1})
January	12.33	18.47	7.45	3.92	4.14	3.18
February	14.44	21.06	8.07	3.89	4.05	4.02
Mach	20.14	25.33	10.43	4.31	4.87	5.84
April	23.48	29.77	13.06	4.26	6.27	7.49
May	25.67	32.22	15.86	4.29	8.30	8.45
June	26.73	36.69	19.83	4.58	12.70	9.82
July	29.06	37.49	20.83	4.34	15.14	9.83
August	27.00	37.86	22.13	4.09	16.27	9.29
September	23.11	35.35	20.80	4.04	15.27	7.99
October	17.84	30.72	17.74	3.89	13.55	5.88
November	13.48	25.54	14.56	3.67	10.96	4.17
December	11.56	20.20	9.58	3.78	6.42	3.23

Srad: Solar radiation, Tmax: mean maximum temperature, Tmin: mean minimum temperature, Ws: mean wind speed, Td: mean dew point temperature, ETo: mean reference evapotranspiration.

***Sources of weather data: https://power.larc.nasa.gov/data-access-viewer**

Samples from the upper 60 cm soil surface were collected at 15 cm interval to determine some soil physical parameters (particle size distribution, bulk density) soil-moisture constants, e.g. field capacity, wilting point, and available water) and some chemical properties e.g. pH, ECe, soluble cations and anions, and soil-moisture constants, e.g. field capacity, wilting point, and available water. Chemical and physical soil analyses were conducted by the standard methods as described by Tan (1996), and values are presented in Table 2. Soil samples were also analyzed for available macro nutrients. The available soil macronutrient values of N, P, and K were 16.00, 5.40, and 62.30 mg kg^{-1}, respectively, which indicated that the soil is characterized by low fertility level and insufficient available water for plant growth. In addition, electrical conductivity (dS m^{-1}) and pH values of the irrigation water were 3.43 and 7.80, respectively.

Experimental design and tested treatments:

The field experiments were laid out in a strip plot design with four replications. The tested irrigation treatments were as follows:

I1: Irrigation with amounts of water equal to 120% ETo.
I2: Irrigation with amounts of water equal to 100% ETo.
I3: Irrigation with amounts of water equal to 80% ETo.
I4: Irrigation with amounts of water equal to 60% ETo.
I5: Farmer treatment (control). The farmer applied irrigation and fertilizer amounts without interference from the researcher. Irrigation treatments started in the second week of February and stopped after harvesting in September of the two seasons. Minimum amounts of irrigation water were applied during the rest of the season.

Pomegranate (*Punicagranatum*L. *Punicaceae*) variety Wonderful was grown in 4 × 2 m, with total planting density of 1250 trees ha^{-1}. The age of pomegranate trees was three years, and irrigated via a surface drip irrigation system, and groundwater is the source of irrigation water. The surface drip system consists of:

1- Irrigation well pump (60 hp) with discharge rate of 100 m^3 hr^{-1}.
2- Sand and screen filters and a venturi fertilizer injector. Fertilizer was applied in 80% of irrigation time (fertigation).
3- The conveying pipeline system consists of:
A- 160 mm PVC main line.
B- 110 mm PVC sub-main line.

C- 50.8 mm PVC sub-sub-main line.

D- The drip lateral lines of 16 mm diameter are connected to the sub-main line. Each lateral line is 24 m long and spaced at 1 to 1.20 m on the sub-main and is equipped with build-in emitters of 4 L h^{-1} discharge rate spaced at 0.357 m. Each lateral has 16 mm PE valve to control the application of irrigation water and mineral fertilizers used. There were two drip lines per tree raw.

Table 2. Particle size distribution, bulk density, soil moisture constants and some chemical properties of the soil at the experimental site.

Soil properties	Soil depth (cm)			
	00 -15	**15-30**	**30-45**	**40- 60**
Particle size distribution:				
Coarse sand, %	69.20	72.51	73.70	75.25
Fine sand, %	25.15	23.10	22.40	20.40
Silt, %	3.78	2.84	2.80	3.50
Clay, %	1.87	1.55	1.10	0.85
Texture class	sand	sand	sand	sand
Bulk density, g cm^{-3}	1.58	1.68	1.74	1.77
Field capacity, % w/w	17.30	16.65	14.70	13.65
Permanent wilting point, % w/w	5.60	5.35	4.80	4.40
Available water, %	11.70	11.30	9.90	9.25
pH (1:2.5)	7.98	7.95	8.10	8.12
ECe, soil paste extract, dS m^{-1}		4.85		
Soluble cations, meq L^{-1}				
Ca^{2+}	14.60	10.10	15.20	10.60
Mg^{2+}	6.80	4.30	6.10	4.10
Na^{+}	46.50	23.50	28.20	20.30
K^{+}	1.10	0.90	1.0	0.90
Soluble anions, meq L^{-1}				
CO_3^{2-}	nd*	nd	nd	nd
HCO_3^{-}	0.40	0.10	0.30	0.20
Cl^{-}	65.40	36.50	46.00	31.80
SO_4^{2-}	3.20	2.20	4.20	3.90

***nd: not detected**

Nitrogen fertilizer (ammonium nitrate, 33.5% N), potassium sulfate (K_2O) and phosphorus as phosphoric acid (60% P_2O_5) were added at the rates of 318, 120 and 684 kg ha^{-1}, respectively. Fertigation started 15 days post flowering. In addition, micro-nutrients, i.e. Fe, Zn and Mn EDTA (13%), were added at the rate of 500:500:500 g ha^{-1} during flowering stage using a regular hand sprayer. The herbicide (Graney star) was injected into the irrigation water 20 days after planting at rate of 19 g ha^{-1} for 20 minutes of irrigation time.

Irrigation water measurements and crop-water relations:

Distribution uniformity (DU):

The water distribution uniformity (DU) was measured in the field and calculated by the equation developed by Keller and Bliesner (1990) as:

$$DU = \frac{Q_n}{Q_a} \times 100$$

Where:

DU = Field distribution uniformity (%);

Qn = Average flow rates collected from emitters at the lowest quarter of the drip line.

Qa = Average flow rates collected from all tested emitters.

Water consumptive use (WCU):

Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$WCU = \sum_{i=1}^{i=4} \frac{\theta_2 - \theta_1}{100} \times Bd \times d$$

Where:

WCU= water consumptive use or crop evapotranspiration, ETc (mm).

I = number of soil layer.

θ2 = soil moisture content after irrigation, (%, by mass).

θ1 = soil moisture content just before irrigation, (%, by mass).

Bd = soil bulk density, (g cm^{-3})

d = depth of soil layer, (mm).

Applied irrigation water:

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ET_o \times I}{E_a\ (1 - LR)}$$

Where:

AIW = depth of applied irrigation water (mm)

ETo = reference evapotranspiration (mm d^{-1}). ETo values were calculated using BISm, Snyder *et al.* (2004).

I = irrigation intervals (days)

Ea = irrigation application efficiency of the drip irrigation system (Ea = 87.2 and 88.8 % in the first and second seasons, respectively).

LR = Leaching requirements (was not considered in this study to avoid the effect on the tested deficit irrigation treatments).

Crop coefficient (Kc):

The local crop coefficient values for pomegranate trees were estimated according to Allen *et al*., 1998 as follows:

$$K_c = \frac{ET_c}{ET_o}$$

Where:

ETc is crop evapotranspiration (mm d^{-1}) ≈ water consumptive use (WCU)

ETo = reference evapotranspiration (mm d^{-1}).

Yield response factor (K_y):

The yield response factor, which links relative yield decrease to relative evapotranspiration deficit, is expressed by the standard formulation given by Vaux and Pruitt (1983) as follows:

$$K_y = \left[(1 - \frac{Y_a}{Y_m}) / (1 - \frac{AIW_a}{AIW_m}) \right]$$

Where:

K_y: yield response factor Y_a: actual yield (t ha^{-1}) Y_m: maximum yield (t ha^{-1})

AIW_a: actual amount of applied irrigation water (m^3 ha^{-1}), and

AIW_m: maximum amount of applied irrigation water (m^3 ha^{-1})

Yield and yield components

Yield component parameters:

1. Fruit weight (g)
2. Fruit diameter (cm)

Fruit chemical parameters:

1. Total soluble solids percentage (TSS %), determined using hand refractometer.
2. Sugar content (Total sugar %), determined according to Daniel and George (1972).
3. Total anthocyanin content (mg100ml^{-1}), determined according to Ranganna (1979).

Marketable yield:

Fruit cracking (%), determine by the following equation according to (El-Akkad *et al*., 2016):

$$Fruitcracking\ (\%) = \frac{No.\ of\ carcked\ fruits}{Total\ No.\ of\ fruits} \times 100$$

Percentage of marketable fruits was determined by the following equation according to (Bishop, 2014) as follows:

$$Marketable\ Fruit\ Yield\ (\%) = \frac{(Total\ no.of\ fruits - no.of\ cracked\ fruits)}{Total\ no.of\ fruits} \times 100$$

Water use efficiency (WUE):

Water use efficiency is calculated according to Stanhill (1986) as:

$$WUE = \frac{Pomegranate\ yield, Y\ (kg/ha)}{Consumed\ irrigation\ water, WCU\ (m^3/ha)}$$

Where:

Y =Pomegranate yield (kg ha^{-1}).

WCU =Water consumed by the crop during entire growing season (m^3 ha–1).

Crop water productivity (WP):

Crop water productivity is calculated according to Zhang (2003) as follows:

$$WP, kgm^{-3} = \frac{Pomegranate\ yield, Y\ (kg/ha)}{Applied\ irrigation\ water\ (m^3/ha)}$$

Energy saving (ES, %):

Energy saving percentage: is the amount of energy saved from operating the irrigation pump according to the tested treatments compared with farmer practice (kwh). The ES values is calculated using the following formula:

$$Energy\ saving\ (\%) = \frac{(Actual\ energy\ used)}{(Energy\ used\ by\ farmer)} \times 100$$

Economic analysis:

Economic analysis was performed to evaluate the economic return of the experimental treatments. The analysis was done through the calculation of differences between costs of production (L.E. ha^{-1}) and income profits (L.E. ha^{-1}) to obtain the net return (L.E. ha^{-1}) of the proposed treatments as compared with farmer practice and to identify the best treatments that achieved the highest net return (L.E. ha^{-1}). All costs of production and income profits were mathematically changed to be per ha. The income profits were calculated from the actual prices of average pomegranate production of 2000 L.E. ton^{-1} at local market and 6000 L.E. ton^{-1} for export (Bulletin of Statistical Cost Production and Net Return, 2016).

Statistical analysis:

Data were statistically analyzed according to the technique of analysis of variance (ANOVA) as published by Gomez and Gomez (1984). Means of the treatments were compared using Least Significant Difference (LSD) at 5% level of significance as developed by Waller and Duncan (1969).

RESULTS AND DISCUSSIONS

Distribution uniformity (DU):

The calculated water distribution uniformity (DU) values, as conducted at the beginning of the 1^{st} and 2^{nd} seasons, were 88 and 90%, respectively. The obtained results showed a little increase in DU values in 2nd season as compared to 1st season. This trend of results was close to that obtained by El-Tomy (2008) and Taha (2012 and 2013), who stated that the distribution uniformity values for lateral lengths of 20, 40 and 60m were 97, 98 and 99 %, respectively.

Applied irrigation water and water consumption:

Results in Table 3 indicated that applied irrigation water was 1370, 1142, 914, 685, and 1835mm in 1^{st} season, 1334, 1112, 890, 667, and 1780mm in 2^{nd} season for the 120, 100, 80, 60% ETo, and farmer treatments, respectively. The farmer irrigation practice exceeded the other tested treatments by 25 to 63% which reflects the need of extension program to avoid over irrigation, reduce the cost of energy used for pumping the effect on crop yield. The obtained results were in line with those of Ren *et al*. (2014), who indicated that the large amounts of applied water by the farmer could cause many environmental problems, where leaching of fertilizer away from root zone to groundwater can occur. Moreover, depletion of irrigation water from the aquifer, and the significant loss of energy used to lift irrigation water. The results in Table (3) indicated, in general, that increasing water availability to the plants increases the water consumption. The highest values of seasonal water consumptive use were 15750 and 15664 m^3 ha^{-1} under irrigation with farmer treatment in 1^{st} and 2^{nd} seasons, respectively. Whereas, the lowest values were 5861 and 5870 m^3ha^{-1} under irrigation with 60% ETo in 1^{st} and 2^{nd} seasons, respectively.

Pomegranate yield and its components:

Results in Table 4 indicated that, there is significant effect of adopted irrigation treatments on fruit diameter, fruit weight, and total fruit yield in the two growing seasons. The highest fruit diameter and weight were produced from irrigation with 120% ETo compared to other treatments. Meanwhile, the lowest fruit diameter and weight were recorded for the 60% ETo and farmer treatments. Fruit diameter and weight increased slightly in 2^{nd} season as compared to 1^{st} one under all irrigation treatments. This result could be due to higher distribution uniformity of the drip system in the 2^{nd} season which inducing more efficient water and fertilizer distribution. These results were in line with those obtained by Kandil and El-Feky (2006) and Khattab *et al*. (2011).

Table 3. Effect of tested treatments on the depths and amounts of applied irrigation water, percent of water saved and water consumption by pomegranate trees during 2016 and 2017 seasons.

Irrigation treatments	2016			2017		
	Applied water (mm) & (m^3ha^{-1})	Saving %	Water consumption (m^3ha^{-1})	Applied water (mm) & (m^3ha^{-1})	Saving %	Water consumption (m^3ha^{-1})
120 % ETo	1370 (13700)	+26	11720	1334 (13340)	+25	11735
100% ETo	1142 (11420)	+38	9774	1112 (11120)	+38	9784
80% ETo	914 (9140)	+50	7821	890 (8900)	+50	7829
60% ETo	685 (6850)	+63	5861	667 (6670)	+63	5870
Farmer	1835 (18350)	-----	15750	1780 (17800)	-----	15664

The results showed that, fruit weight and diameter significantly increased with increasing irrigation level under drip irrigation system. Furthermore, no significant difference between total fruit yields obtained under 120, 100, and 80% ETo treatments in the two seasons. Total fruit yields of these three treatments were significantly higher than that of 60% ETo and farmer treatments. From the obtained results it could be concluded that, irrigating pomegranate tress with amount of water equal to 80% ETo will save about 50% or irrigation water and increase the total fruit yield by 15-17% as compared with farmer practice. The obtained results were in line with those of Ren *et al.* (2014), who stated that pomegranate fruits yield and quality decreased significantly with excess water application.

Table 4. Effect of irrigation treatments on fruit diameter, fruit weight, and total pomegranate fruit yield in 2016 and 2017 seasons.

Irrigation treatments	Fruit diameter (cm)		Fruit weight (g)		Total fruit yield (tha^{-1})			
	2016	2017	2016	2017	2016	%	2017	%
120 % ETo	10.25a	11.15a	610a	662 a	39.21a	+26	41.10 a	+27
100% ETo	9.83ab	10.13b	537ab	589 b	37.60a	+21	39.53 a	+22
80 %ETo	9.29b	9.45 c	464bc	495 c	35.80ab	+15	38.00 a	+17
60% ETo	9.12b	9.20 c	413 c	454 c	23.40c	-25	24.20 c	-24
Farmer treatment	9.12b	9.20 c	428 c	466 c	31.20b	-	32.40 b	-
LSD 0.05	0.72	0.65	102.7	58.6	6.59		4.46	

Pomegranate chemical properties:

Total soluble solids (TSS%), total sugar and total anthocyanin showed significant differences under irrigation treatments as compared to farmer irrigation throughout the two seasons. The three properties increased with reducing the applied irrigation amounts and reached its highest value under irrigation with 60% ETo. The lowest values were obtained from farmer irrigation as a result of increasing the applied irrigation amount (Table 5). These results were similar to those obtained by Khattab *et al.* (2011), who stated that total soluble solids, total sugars and total anthocyanin were gradually decreased with increasing irrigation level.

Table 5. Effect of different levels of irrigation on total soluble solids (TSS, %), total sugars (%), and total anthocyanin (%) of pomegranate fruits in 2016 and 2017 seasons.

Irrigation treatments	TSS (%)		Total sugar (%)		Total anthocyanin (%)	
	2016	2017	2016	2017	2016	2017
120 %ETo	10.05 cd	10.30bc	9.6 ab	9.8 b	2.52 b	2.66 b
100%ETo	11.16 c	11.38 b	10.00 a	10.21 b	2.64 b	3.04 b
80 %ETo	12.63 b	12.84 a	11.20 a	11.52 a	2.84 b	2.97 b
60%ETo	13.85 a	13.12 a	11.45 a	11.78 a	3.45 a	3.56 a
Farmer treatment	8.90 d	9.19 c	8.01 b	8.24 c	1.45 c	3.56 a
LSD 0.05	1.21	1.18	1.93	1.27	0.52	0.49

Marketable and nonmarketable fruit yields:

The results in Table (6) indicated that marketable fruit yields under 120, 100, and 80% ETo were significantly higher than those obtained under 60% ETo and farmers treatments. Furthermore, the values of marketable fruit yields in 2nd season were higher than the values in 1st season under all irrigation treatments. This result could be due to the increase in distribution uniformity of the drip system in the 2nd season which resulted in more efficient water and fertilizer distribution. The decrease of marketable fruits under farmer irrigation treatment could be attributed to excessive applied irrigation water, which increased cracking in pomegranate fruits. These findings were in agreement with those reported by Wen Shui (2009), Samra and Shalan (2013) and Parvizi (2015) who reported that, using drip system to irrigate pomegranate resulted in reductions reached to 50 and 75% of water applied and ETc, respectively, and improved quality attributes of pomegranate fruit as well.

Water use efficiency (WUE) and water productivity (WP):

The results in Table (7) showed that the highest water use efficiency, i.e. 4.58 and 4.85 kgm^{-3}, respectively, in 1st and 2nd seasons were obtained due to irrigating with 80% ETo. The lowest value of water use efficiency was obtained for the farmer practice, and comprised 1.98 and 2.07 kgm^{-3} consume water. In addition, the highest water productivity values of 3.92 and 4.27 kgm^{-3} applied water were obtained as 80% ETo was applied in both seasons. In connection, Parvizi *et al* (2016) stated that, applying water at 50% and 75% of ETc increased water productivity of pomegranate fruit in semi-arid area.

Table 6. Effect of irrigation treatments on marketable and nonmarketable pomegranate fruit yields in 2016 and 2017 seasons.

Irrigation treatments	Marketable fruit yield (tha^{-1})		Nonmarketable fruit yield (tha^{-1})	
	2016	2017	2016	2017
120%ETo	38.70 a	40.81 a	0.51 b	0.29 c
100%ETo	37.14 a	39.29 a	0.46 b	0.24 c
80 %ETo	35.41 a	37.79 a	0.39 b	0.21 c
60 %ETo	23.05 b	24.03 b	0.35 b	0.17 b
Farmer treatment	14.75 b	12.95 b	16.45 a	19.45 a
LSD 0.05	6.08	5.48	1.34	1.50

Table 7. Water use efficiency and water productivity of pomegranate trees as affected by different irrigation treatments 2016 and 2017 growing seasons.

Irrigation treatments	WUE (kg m^{-3} consumed water)		WP (kg m^{-3} applied water)	
	2016	2017	2016	2017
120% ETo	3.35	3.51	2.9	3.1
100% ETo	3.85	4.04	3.3	3.55
80% ETo	4.58	4.85	3.92	4.27
60% ETo	4.00	4.12	3.42	3.63
Farmer treatment	1.98	2.07	1.7	1.82

Crop coefficient (Kc):

The calculated Kc values for the tested irrigation treatments are illustrated in Fig. 1. Results indicated that Kc values increased with increasing applied irrigation water. The Kc values for the 120% ETo irrigation treatments were 0.14-0.45, 0.45-0.79, 0.79-1.05, and 1.05-0.76 for initial, crop development, mid- and late-season growth stages, respectively. The obtained Kc values under the present experimental conditions were close to those reported by Meshram *et al*. (2010) who reported that, the crop coefficient (kc) values at different stages (i.e. initial, crop development, mid- and late-season stages) were 0.15-0.20, 0.20-1.18, 1.18 (constant) and 1.18-0.55, respectively.

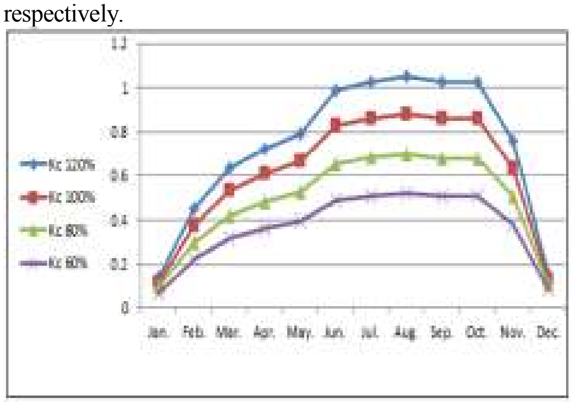

Fig. 1. Crop coefficient curves for pomegranate trees developed through local information for the tested irrigation treatments.

Yield response factor (Ky):

Average values of pomegranate yields obtained from the tested irrigation treatments (60 - 100% ETo) in the two growing seasons were fitted into a linear equation relating the relative yield decrease to the relative decrease in applied irrigation water (Fig. 2). The equation representing the obtained relation can be expressed as:

$$Y = 0.81\,X, \qquad R^2 = 0.8$$

Where:

Y: represents relative yield reduction (1 – Ya/Ym),
X: represents relative reduction in applied irrigation water (1 – AIWa/AIWm), and

The constant 0.81 represents the yield response factor (Ky) that shows the sensitivity of pomegranate crop to the deficit of applied irrigation water.

The obtained Ky value under the experimental condition was less than 1, indicating that the pomegranate trees are moderately tolerant to water stress (i.e. up to 80% ETo). The result agreed with that reported by Tavousi *et al*. (2014) who stated that pomegranate is not sensitive to low and mild drought stress during the growth period and sever stress caused a significant yield reduction.

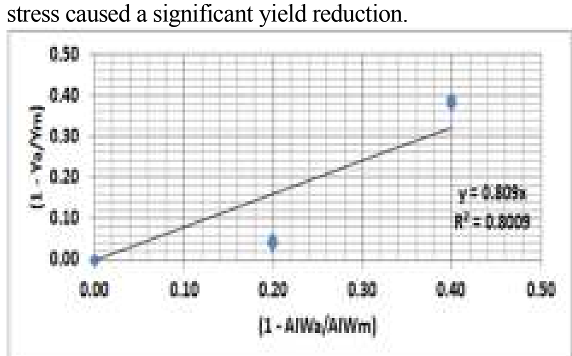

Fig. 2. Pomegranate yield response factor (Ky).

Consumed electrical energy:

Results in Table (8) indicated that the highest values of the seasonal consumed energy were 9414 and 9131 kilowatts 1st and 2nd growing seasons, respectively, under farmer irrigation treatment. Application of all irrigation treatments reduced the consumed electric energy in the both growing seasons by a value varied between 25 and 62% compared to farmer irrigation. The lowest value of seasonal consumed energy was obtained under irrigation with 60% ETo in 1st and 2nd seasons. Energy saving was a result of using deficit irrigation technique which reduced the number of hours used to operate the irrigation pump in all the proposed irrigation treatments.

Cost/Benefit analyses:

The results in Table (9) indicate that, the net income values for the 120, 100, 80% and 60% ETo treatments were 114.2, 105.4, 95.6 and 23.9 %, respectively, higher than the farmer treatment in the 1st season, and 138.6, 129.5, 120.6 and 35.9 % in 2nd season, respectively, in the same order of the adopted irrigation treatments. The higher net income in the 2nd season can be attributed to the increase in marketable fruit yields which may be resulted from improving the efficiency of the drip irrigation system.

Table 8. Effect of irrigation treatments on electric energy saving in the two growing seasons

Irrigation treatments	2016		2017	
	Energy consumed (kW)	Saving (%)	Energy consumed (kW)	Saving (%)
120% ETo	6972	-26	6824	-25
100% ETo	5858	-38	5702	-38
80% ETo	4709	-50	4585	-50
60% ETo	3560	-62	3465	-62
Farmer treatment	9414	-----	9131	----

Table 9. Cost/benefit analyses for the adopted irrigation treatments

Irrigation treatments	Cost elements					Benefit					Net income (LE***)
	Irrigation*	Fertilizer	Pests IPM	Fruits thinning	Total cost (LE)	Local market Ton	Local market Price (LE ton^{-1})	Export market Ton	Export market Price (LE ton^{-1})	Total benefits (LE)	
2016											
Farmer	3295	5766	4294	5000	18355	16.45	2000	14.75	6000	121400	103045
120% ETo	2440	5766	4294	-----	12500	0.51	2000	38.70	6000	233220	220720
100% ETo	2050	5766	4294	-----	12110	0.46	2000	37.14	6000	223760	211650
80% ETo	1648	5766	4294	-----	11708	0.39	2000	35.41	6000	213240	201532
60% ETo	1246	5766	4294	-----	11306	0.35	2000	23.05	6000	139000	127694
2017											
Farmer	3196	6874	4390	5000	19559	19.45	2000	12.95	6000	116600	97140
120% ETo	2388	6874	4390	-----	13704	0.29	2000	40.81	6000	245440	231788
100% ETo	1996	6874	4390	-----	13314	0.24	2000	39.29	6000	236220	222960
80% ETo	1605	6874	4390	-----	12912	0.21	2000	37.79	6000	227160	214291
60% ETo	1213	6874	4390	-----	12477	0.17	2000	24.03	6000	144520	132043

***used for irrigation**
**** Kilowatt (kw) price per LE = 0.45**
*****1$ =17.80 LE.**

CONCLUSION

Based on the results of the present study it could be concluded that:

1. Average amounts of applied irrigation water under 120, 100, 80, and 60% ETo irrigation levels and farmer treatment were 13520, 11270, 9020, 6760, and 18075 m^3/ha, respectively.
2. There was a significant effect of the tested irrigation levels on pomegranate physical and chemical parameters, and on total and marketable fruit yields.
3. Average total fruit yield values were 40.2, 38.6, 36.9, 23.8, and 31.8 ton/ha for the 120, 100, 80, and 60% ETo irrigation levels and farmer treatment, respectively.
4. The Kc values for the 120% ETo irrigation level were 0.14-0.45, 0.45-0.79, 0.79-1.05, and 1.05-0.76 for initial, crop development, mid- and late-season growth stages, respectively. The pomegranate yield response factor (Ky) was 0.81 indicating that pomegranate is moderately tolerant to water stress.
5. Application of the proposed irrigation levels reduced consumed energy by values varied between 25 and 62% compared to farmer irrigation practice.
6. The 2-year average net income values of the 120, 100, 80, and 60% ETo irrigation level were 117, 106, 91, and 3% higher than that obtained under farmer irrigation practice.
7. In case of water shortage, irrigating pomegranate trees in sandy soils with 80% ETo saves 9055 m^3/ha of applied irrigation water, 50% of the energy used for irrigation, gives the highest water use efficiency (4.7 kg fruits/m^3 water consumed) and highest water productivity (4.1 kg fruits/m^3 water applied), as well as achieves 108% more net income compared with farmer irrigation practice.

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تقييم إختلاف مستويات الري المحسوبة بناءا علي البخر- نتح المرجعي علي أداء محصول الرمان و التوفير في مياه الري و الطاقة الكهربية و تعظيم الدخل المزرعى

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قسم بحوث المقننات المائية والري الحقلي – معهد بحوث الاراضي والمياه والبيئة- مركز البـحـوث الزراعية – مـصـر

أجريت تجربة حقلية على أشجار الرمان في مزرعة خاصة تقع بالكيلو ٧٦ طريق القاهرة / الإسكندرية الصحراوي ، مصر خلال موسمى الزراعة لعامي ٢٠١٦ و ٢٠١٧ . يمثل الموقع الأراضي الرملية المستصلحة حديثًا بمنطقة غرب دلتا النيل. تهدف الدراسة إلى تقييم تأثير مستويات مختلفه من مياه الري على كميات مياه الري المضافة، الاستهلاك المائي، محصول الثمار ومكوناته وجودة الثمار وكفاءة استخدام وإنتاجية وحده المياه ، واستنباط معامل المحصول (Kc) ومعامل استجابة المحصول (Ky) تحت ظروف التجربة، بالإضافة إلى التأثيرعلى توفير الطاقة وزيادة الدخل المزرعى في التربة الرملية تحت نظام الري بالتنقيط. - تمت مقارنة أربعة معاملات للري (١٢٠، ١٠٠، ٨٠، ٦٠٪ من جهد البخر- نتح القياسي (ETo) مع ري المزارع. استخدم التصمييم الأحصائى strip-plot فى أربع مكررات. وكانت أهم النتائج المتحصل عليها كما يلي:-- قيم تجانس توزيع المياه كانت ٨٨ و ٩٠٪ للاختبارين في بداية عامى ٢٠١٦ و ٢٠١٧ على التوالي. وبلغ متوسط كميات مياه الري المضافة لـ ١٢٠ و ١٠٠ و ٨٠ و ٦٠٪ ETo ومعاملة المزارع ١٣٥٢٠ ،١١٢٧٠ ، ٩٠٢٠ و ٦٧٦٠ ، ١٨٠٧٥ م^{3}هكتار$^{-1}$ على التوالي ، و بلغ متوسط إنتاجية ثمار الرمان ٤٠.٢ ، ٣٨.٦ ، ٣٦.٩ ، ٢٣.٨ ، و ٣١.٨ طن هكتار$^{-1}$ لنفس المعاملات علي الترتيب - أكبر قطر و وزن ثمرة تم الحصول عليها من الري بنسبة ١٢٠٪ من البخر- نتح المرجعي ETo. و كانت قيم معامل المحصول (Kc) الخاصة بمعاملات الري١٢٠٪ ETo بنسبة هي ٠.١٤-٠.٤٥ ، ٠.٤٥-٠.٧٩ ، ١.٠٥-٠.٧٩ ، ١.٠٥-٠.٧٦ في مرحلة بداية النمو، مرحلة تطور النمو، مرحلة ثبات النمو، ومرحلة النضج أوالحصاد على التوالي،أوضحت النتائج أن معامل استجابة محصول الرمان (Ky) بلغ ٠.٨١ مشيرا إلى أن أشجار الرمان متوسطة التحمل للإجهاد المائي. - أدى تطبيق معاملات الري المقترحة إلى خفض استهلاك الطاقة الكهربائية بنسبة تتراوح بين ٢٥ و ٦٢٪ مقارنة مع ري المزارع. كان متوسط قيم صافي الدخل لمدة عامين لمعاملات الري ١٢٠ ، ١٠٠ ، ٨٠ و ٦٠ ٪ ETo البخر- نتح المرجعي أعلى ب ١١٧ ،١٠٦ و ٩١ و ٣ ٪ مقارنة معاملة المزارع. - من النتائج التي تم الحصول عليها، يمكن الاستنتاج أنه في حالة نقص المياه ان ري أشجار الرمان في الاراضي الرملية بكمية مياه تعادل ٨٠ ٪ من البخر نتح المرجعى (ETo) أدي الي توفير ٩٠٥٥ م^{3} هكتار$^{-1}$ من مياه الري و ٥٠ ٪ من الطاقة المستخدمة للري ، و أعلى كفاءة إستخدام المياه (٤.٧ كجم من الفاكهة م$^{-3}$ من المياه المستهلكة) وأعلى إنتاجية للمياه (٤.١ كجم فاكهة م$^{-3}$ مياه مضافـة) ، بالإضافة إلى تحقيق دخل صافٍ أعلي بنسبة ٩١ ٪ مقارنة مع معاملة المزارع .