Productivity of date palm as affected by irrigation in a sandy soil

Ahmed M. TAHA[1], Hamdy E. KHALIFA[1]

[1] *Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), Egypt*

[*] *Corresponding author ahmedtaha362@yahoo.com*

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Abstract

A field experiment was conducted on drip irrigated date palm trees (Barhi var.) in a private farm during the 2020 and 2021 seasons to evaluate the effect of five irrigation treatments (120, 100, 80 and 60 % ETo and farmer practice) on amounts of applied irrigation water (AIW), consumptive use (CU), date yield and its components, fruit quality, water use efficiency (WUE), water productivity (WP), consumed electric energy, net income, a local date crop coefficient (Kc) and yield response factor (Ky). Results revealed that, average ETo values varied between 1.26 mm/day in December and 9.85 mm/day in July. The 2–year average AIW values were 17 377, 14 546, 11 715, 8 885 and 24 680 m^3/ha for the 120, 100, 80 and 60 % ETo treatments and farmer practice, respectively. Highest and lowest fruit yields of 39.2 and 15.2 t/ha were recorded for the 120% and 60% ETo treatments, respectively. The WP values of the same treatments were 2.27 and 1.23 kg fruits/m^3. Seasonal average Kc value of 0.74 is obtained for the 120 % ETo treatment. The Ky value of 1.187 is obtained for the Barhi variety. The lowest consumed energy (64.7 %) and highest net income (31.8 %) were recorded for 60 % and 120 % ETo treatments compared with farmer practice.

Keywords: Date palm, Water use efficiency, water productivity, crop coefficient, yield response factor, energy saving, net income

INTRODUCTION

Water scarcity is the most severe problem for the sustainability of agricultural production all over the world. The intensity of this problem is increasing in most cultivated areas, especially in the arid and semiarid regions, due to increasing population, competition with other sectors, and the negative impact of climate change. In Egypt, the availability of fresh water is limited, while the demand for this important resource is continuously on the rise. At the same time, agricultural sector is the main consumer (80 %) of water resources. More than 95% of the irrigated lands depend on irrigation (Abou Zeid, 2002). The *per capita* share of cultivated land is very low (< 0.01 feddan/capita/year), therefore expanding newly land use for field and horticultural crops is essential but it will intensify pressure on water availability for agricultural sector. Under such conditions, the choice of an irrigation method, which accomplishes 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).

Date palm (*Phoenix dactylifera* L.) is one of the key fruits in dry and semiarid regions. It represents a large part in the economy, society, and environment in the Middle East and North Africa. It is well adapted to the desert environment, for it can tolerate high temperatures and salinity stress. Date palm can tolerate soil salinity up to 4 dS m^{-1} without reduction in yield; however, shortage of irrigation water may reduce yields (Ayers and Westcot, 1985; Al-Ghobari, 2000; Chao and Krueger, 2007; Brouk and Fishman, 2016; Elfeky and Elfaki, 2019).

Egypt is considered the highest country for date production over the world with area harvested of 48,031 ha and annual production reaching 1,603,762 tons in 2019, around 18% of the global date production and 24.4% from Arab countries dates' production. The average yield of the date palms is about 102 kg/palm calculated on the basis of bearing palms. A figure which is very high compared to the world average that is of about 50 kg/palm. The reason for this high yield is: 1) good access to water, since the date palm trees benefit from the irrigation of associated crops, 2) more than half of the production is soft dates, which means the fruits contain around 40-50% water, and 3) significantly higher tree density per hectare as compared to other countries in the region. In the near future, the Ministry of Agriculture and Land Reclamation aims to cultivate additional 2.5 million palm trees by using modern agricultural methods, in order to optimize irrigation water, improve the cultivation of dates for the domestic consumption and to improve the trade export (FAO, 2008; Siddeq *et al.*, 2014; FAOSTAT, 2019; and Report Linker, 2020).

The Barhi cultivar is one the date palm soft varieties. In Egypt, it is cultivated in Giza, El-Beheira, Ismailia, Monofia, El-Minya governorates of and El-Bahariya Oasis. Barhi cultivar requires moderate relative humidity and temperature. The yield of a single palm tree is about 100-150 kg/year and the main physical characters as fruit length (cm), width (cm), and weight (g) are 4.96, 2.41, and 11.9, respectively, and the fruit texture is soft (El-Sharabasy and Rizk, 2019).

Large differences of date palm water requirements were reported by the researchers. These differences are mainly due to location, climate, trees age and varieties, method of calculating crop water requirements and the irrigation system used (Mohebi, 2005). In Tunisia, Al-Buzaidi (1982) found that the least yearly water requirements were 63 m^3/tree, while the actual water requirements, including a wide range of losses were 95 m^3/tree. Al-Amoud *et al.* (2000) stated that the average amounts delivered to date palms were 108, 216 and 324 m^3/tree/year for water regimes of 50 %, 100 % and 150 % of evaporation rate, respectively. Al-Ghobari (2000) reported that the total annual amount of water in the southwestern district of Saudi Arabia as 136 m^3/tree. Alazba (2004) indicated that the actual yearly water use of the date palm ranged from 137 and 55 m^3/tree in Eastern district to 195 and 78 m^3/tree in the central area for surface and trickle irrigation, respectively. Abdul Baki and Aslan (2005) estimated the total annual depth of water required for date palm to vary from 2700 and 3000 mm. Kassem (2007) concluded that the water use of 15-year-old palms (cv. Sukariah) over a season on a commercial farm in Saudi Arabia, using both the Bowen ratio energy balance method and a soil water balance approach, the actual annual water use of drip irrigation system to be 1780 and 1640 mm, respectively. In Jordan, Mazahrih *et al.* (2012) used a simple water balance approach and found that actual evapotranspiration (ET) rates by 11-year-old palms (cv. Medjool) were 1300, 1600, 1800 and 2000 mm and the seasonal totals of water applied were 27, 40, 53 and 67 m^3 $tree^{-1}$ (156 trees ha^{-1}) for four drip-irrigated water regimes of 50, 75, 100 and 125 % ETc, respectively. Alamoud *et al.* (2012) studied the water use by date palm trees in seven areas in Saudi Arabia. The highest annual amount was 80 m^3/tree, while the lowest was 59.4 m^3/tree. They concluded that, the average daily date palm water use was 184.4 l/day for all regions. In Syria, Carr (2013) showed that mean actual evapotranspiration rates varied between 0.5 mm/d (winter) and 3.5 mm/d (summer). Sadik *et al.* (2018) stated that the highest date palm yield was recorded for drip system, full irrigation (100%) and soil mulching treatment. The calculated seasonal actual evapotranspiration (ETc) for full irrigation treatment was 1839 mm/season. Al Omran *et al.* (2019) stated that, the overall average irrigation water requirement for eight sites was 8342 m^3/ha/year. While, the amounts added by the farmers in adjacent fields varied from 12,050 to 13,717 m^3/ha/year. The productivity ranged between 5406 kg/ha and 8400 kg/ha and water use efficiency values varied from 0.55 and 0.83 kg/m^3. Montazar *et al.* (2020) reported that cumulative ETa across six sites in California ranged from 1299 to 1500 mm with a mean daily ETa of 7.2 mm day^{-1} in June–July and 1.0 mm day^{-1} in December at the site with the highest crop water consumption. The mean monthly Kc values varied between 0.63 (December) and 0.90 (June) in the non-salt-affected, sandy loam soil date palms. Mattar *et al.* (2021) stated that, deficit irrigation (50% ETc) of date palms reduced date yields on average 86 kg/tree, whereas the yield increased under over-irrigation (150% ETc) to 123.2 kg/tree. Mohammad *et al.* (2021) concluded that, the total annual amount of applied irrigation water for controlled sub-surface drip system (CSIS) with sensor-based irrigation scheduling (S-BIS) method, time-based irrigation scheduling method (T-BIS), and traditional surface irrigation (TSI) was 21.0, 22.8 , and 58.7 m^3/tree, respectively. They also reported that, the annual cumulative value of water consumption (ETc) was 2137 mm, and water productivity of the CSIS with S-BIS (1.783 kg m^{-3}) and T-BIS (1.44 kg m^{-3}) methods was significantly higher compared to the TSI (0.531 kg m^{-3}).

Few information are available on the impact of adequate and deficit irrigation on date palm yield and quality. Therefore, the objectives of this study were to evaluate the effect of four ETo-dependent irrigation levels (120, 100, 80, and 60% ETo) compared with farmer practice (control) on amounts of applied irrigation water, water consumptive use, fruit yield and its components (20 fruit weight, no. of bunches/tree, and fruit yield/tree), some physical and chemical fruit quality parameters, water use efficiency, water productivity, electric energy used for irrigation, farm net income and to develop a local date palm coefficient (Kc) and yield response factor (Ky) under the experimental conditions.

MATERIALS AND METHODS

Experimental site description

A field experiment was conducted on date palm trees (Barhi variety) in a private farm (30.36 N, 31.01 E and 17.90 m above mean sea level) Cairo/Alexandria desert road, Egypt during the 2020 and 2021 growing seasons. The experimental site represents the newly reclaimed sandy soil of west Nile delta region.

Soil physical, chemical, and nutritional characters

Samples from the upper 60 cm soil surface were collected at 15 cm intervals to determine main soil physical parameters (particle size distribution, textural class, and bulk density), hydro-physical constants (field capacity, wilting point, and available soil moisture), and some chemical properties (pH, ECe, and soluble cations and anions). Physical and chemical soil analyses were conducted by the standard methods described by Klute (1986) and Tan (1996).The obtained values are presented in Table 1.

Soil samples were also analyzed for main macronutrients. The values of available soil N, P, and K macronutrients were 16.0, 5.40, and 62.3 mg kg^{-1}, respectively.

Samples from irrigation water were collected and analyzed (Table 1).

Agro-meteorological data

A 2-year (2018 and 2019) average monthly agro-meteorological data obtained from a nearby METOS weather station were used in this study. The station measures rainfall, air temperature, air humidity, solar radiation, and wind speed and direction. The data showed that the highest monthly mean temperatures were 35.9 °C, 36.1 °C, and 35.3 °C during the summer months of June, July, and August, respectively, while the lowest monthly mean temperatures were 8.77 °C, 5.36 °C, and 8.38 °C during the winter months of December, January, and February, respectively. The highest monthly mean solar radiation energy value was 46.1 MJ m^{-2} day^{-1} in July, while the lowest monthly mean solar radiation energy was 9.75 MJ m^{-2} day^{-1} in December. The highest monthly mean relative humidity value was 98.0 % during November and the lowest monthly mean relative humidity was 23.2 during May. The highest monthly mean wind speed was 3.25 m sec^{-1} during May, while the lowest monthly mean wind speed was 1.73 m sec^{-1} November. The METOS weather station also calculates daily ETo values. The data used to calculate reference crop evapotranspiration values for this experiment are presented in Table 2.

Table 1: Particle size distribution, textural class, bulk density, soil moisture constants, some chemical properties of the soil, and analysis of irrigation water at the experimental site

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	40-60
Particle size distribution				
Coarse sand, %	69.2	72.5	73.7	75.2
Fine sand, %	25.1	23.1	22.4	20.4
Silt, %	3.78	2.84	2.80	3.50
Clay, %	1.87	1.55	1.10	0.85
Textural class	sand	sand	sand	sand
Bulk density, g cm^{-3}	1.58	1.68	1.74	1.77
Field capacity, % v/v	17.3	16.6	14.7	13.6
Permanent wilting point, % v/v	5.60	5.35	4.80	4.40
Available soil moisture, %	11.7	11.3	9.90	9.25
pH (1:2.5)	7.98	7.95	8.10	8.12
Average ECe, soil paste extract, dS m^{-1}	4.85			
Soluble cations, meq L^{-1}				
Ca^{2+}	14.6	10.1	15.2	10.6
Mg^{2+}	6.80	4.30	6.10	4.10
Na^{+}	46.5	23.5	28.2	20.3
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^{-}	65.4	36.5	46.0	31.8
SO_4^{2-}	3.20	2.20	4.20	3.90
IRRIGATION WATER ANALYSIS				
pH	6.70			
EC, dS m^{-1}	5.28			
Soluble cations, meq L^{-1}				
Ca^{2+}	16.1			
Mg^{2+}	13.6			
Na^{+}	22.3			
K^{+}	0.21			
Soluble anions, meq L^{-1}				
CO_3^{2-}	nd*			
HCO_3^{-}	1.56			
Cl^{-}	27.1			
SO_4^{2-}	23.4			

**nd: not detected.*

Table 2: Average monthly agro-meteorological data used at the experimental site

Month	Air temperature (°C)			Relative humidity (%)			Wind speed (m/sec)	Solar radiation (MJ/m^2)
	Tmin	Tmax	Tmean	RHmin	RHmax	RHmean		
January	5.36	18.5	11.9	40.1	94.7	67.4	2.96	14.8
February	8.38	21.9	15.2	34.1	96.7	65.4	2.72	19.4
March	13.6	25.0	19.3	29.8	91.0	60.4	2.81	34.6
April	13.9	29.6	21.8	24.1	97.6	60.9	2.98	34.0
May	18.4	32.2	25.3	23.2	89.8	56.5	3.25	44.6
June	22.6	35.9	29.3	23.4	89.9	56.7	2.88	44.9
July	24.6	36.1	30.4	27.0	89.2	58.1	3.14	46.1
August	23.0	35.3	29.2	32.0	92.4	62.2	3.03	34.9
September	19.4	33.5	26.4	31.3	94.2	62.7	2.96	26.5
October	17.3	29.8	23.5	36.3	97.0	66.7	1.97	16.4
November	12.6	25.1	18.8	41.3	98.0	69.7	1.73	11.5
December	8.77	20.6	14.7	47.7	97.9	72.8	2.20	9.75
Average	15.7	28.6	22.1	32.5	94.0	63.3	2.72	28.1

Experimental design and tested treatments

The field experiment was laid out in a strip plot design with four replicates. Each replicate consists of three trees. Five irrigation treatments, namely I_1: 120% ETo, I_2: 100 % ETo, I_3: 80% ETo, I_4: 60% ETo and I_5: represented the farmer practice (control treatment),were tested in this study.

Irrigation treatments started in the second week of February and stopped after harvest by the end of October 2020 and 25 September 2021 with an irrigation interval every 3 days. Minimum amounts of irrigation water were applied during the rest of the season.

The farmer practiced irrigation and fertilization without interference from the researchers.

Cultural practices

Six years old date palm trees (Barhi variety) were planted in 8 m × 8 m spacing, with total planting density of 156 trees ha^{-1},and irrigated via a surface drip irrigation system. Groundwater was the source of irrigation water.

The drip system consists of:

- Irrigation pump (60 hp) with discharge rate of 100 m^3 h^{-1}.
- Sand and screen filters and a venturi fertilizer injector. Fertilizers were applied in 80% of irrigation time through irrigation water (fertigation).

The conveying pipeline system consists of:

- 160 mm PVC main line.
- 110 mm PVC sub-main line.
- 50.8 mm PVC sub-sub-main line.
- The drip lateral lines of 16 mm diameter are connected to the sub-sub-main line. The irrigation water was applied through the drip lateral line in a circle consisting of 12 drippers. The drip line has GR inline emitters spaced at 0.5 m with 4 l/h discharge rate. Each lateral has a 16 mm PE valve to control the application of irrigation water and mineral fertilizers.

Fertilization (macro- and micro-nutrients)

Two sources of solid N-fertilizer were used. Ammonium nitrate (33.5 % N) was added at the rate of 55 kg N/ha and calcium nitrate (15.5 %N) was added at the rate of 497 kg N/ha. Potassium sulfate was added at the rate of 365 kg K_2O/ha. Magnesium sulfate was added at the rate of 300 kg $MgSO_4.7H_2O$/ha. Sulfuric acid (98%) was added at the rate of 80 kg H_2SO_4/ha. Nitric acid (72%) was added at the rate of 140 kg HNO_3/ha. Phosphoric acid (85%) was added 15 days from flowering and during flowering stage at the rate of 180 kg P_2O_5/ha. Micronutrients, i.e. Fe, Zn and Mn (EDTA, 13%), were also added at the rate of 800:800:800 g/ha during flowering stage by a regular hand sprayer.

All other cultural practices were done as recommended by the Ministry of Agriculture and Land Reclamation in Egypt.

Irrigation water measurements and crop-water relations

Distribution uniformity (DU)

The water distribution uniformity (DU) of the drip system was measured in the field at the beginning of applying irrigation treatments on February of 2020 and 2021 seasons. The DU values were calculated by the equation developed by Keller and Bliesner (1990) as:

$$DU = \frac{Qn}{Qa} \times 100$$

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)

Water consumptive use (WCU), or actual evapotranspiration (ETc), values were measured by Time Domain Reflectometry (TDR) sensor which determines the volumetric soil moisture contents in the surface 60 cm depth of soil before and after each irrigation. The seasonal WCU values were calculated according to Israelsen and Hansen (1962) using the following equation:

$$WCU = \sum_{i=1}^{i=4} \frac{\theta2 - \theta1}{100} \times d$$

where:

WCU = water consumptive use or actual evapotranspiration, ETa (mm).

i = number of soil layer.

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

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

d = depth of soil layer (mm).

Applied irrigation water (AIW)

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

$$AIW = \frac{ETo\ X\ Kr\ X\ A\ X\ Iinterval}{Ea\ (1 - LR)}$$

where:

AIW = applied irrigation water (m^3).

ETo = reference crop evapotranspiration (m/d).

Kr = ground cover reduction factor (= 0.7 according to Keller and Karmeli, 1975).

$I_{interval}$ = irrigation interval (3 days under experimental conditions).

A = irrigated area (m^2)

Ea = irrigation efficiency = K1 x K2

where:

K1 = emitter distribution uniformity (= 0.89 and 0.91 in the 1st and 2nd seasons, respectively),

K2 = drip irrigation system efficiency (= 0.90 at the experimental site).

LR = leaching requirements (was not considered in this study to avoid the effect of excess leaching water on the stress irrigation treatments).

Crop coefficient (Kc)

The local crop coefficient values for date palm trees were estimated according to Allen *et al.* (1998) as follows:

$$Kc = \frac{ETc}{ETo}$$

where:

ETc = crop evapotranspiration (mm/d) ≈ water consumptive use (WCU).

ETo = reference evapotranspiration (mm/d).

Yield response factor (Ky)

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

$$Ky = [(1 - \frac{Ya}{Ym})/(1 - \frac{AIWa}{AIWm})]$$

where:

K_y = yield response factor.

Y_a = actual yield (t/ha).

Y_m = maximum yield (t/ha).

AIW_a = actual amount of applied irrigation water (m^3/ha). In this study, the AIW values for 100, 80, and 60% ETo were used.

AIW_m = maximum amount of applied irrigation water (m^3/ha). The AIW for 120% ETo treatment was used.

Water use efficiency (WUE)

Water use efficiency values were calculated according to Stanhill (1986) equation as:

$$WCU = \frac{Date\ palm\ yield, Y\ (\frac{kg}{ha})}{Consumed\ Water, WCU\ (\frac{m^3}{ha})}$$

where:

Y = Date palm yield (kg/ha).

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

Crop water productivity (WP)

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

$$WP = \frac{Date\ palm\ yield, Y\ (\frac{kg}{ha})}{Applied\ Irrigation\ Water, AIW\ (\frac{m^3}{ha})}$$

Yield and yield components

At harvest time, the number and weight of each bunch per tree were recorded. Fruit yield (kg/tree and t/ha) was calculated by multiplying the mean bunch weight by the total bunches per tree and the total yield was obtained by multiplying tree yield by no. of trees/ha.

Physical fruit parameters

At harvest time, samples of 20 fruits were collected from each tree and the following measurements were carried out: fruit weight (g), length (cm), and diameter (cm).

Fruit chemical parameters

- Carbohydrate (%)was determined according to AOAC (1985).
- Fructose content (%) was determined according to Daniel and George (1972).
- Glucose content (%) was determined according to Daniel and George (1972).

Energy saving (ES, %)

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

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

Economic analysis

Economic analysis was performed to evaluate the economic return due to 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 treatment that achieves the highest net return. The income profits were calculated based on the actual prices of average date palm production (18 L.E. per kg at farm gate, Bulletin of Statistical Cost Production and Net Return, 2019).The net income values were calculated using the following formula:

Statistical analysis

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

RESULTS AND DISCUSSION

Distribution uniformity (DU)

The calculated water distribution uniformity (DU) values, conducted in February of the 1st and 2nd seasons, were 89 and 91%, respectively. The obtained results showed a small increase in DU values in the 2nd season as compared to 1st season. This trend of results was close to that reported by El-Tomy (2008), who stated that the distribution uniformity values for drip lateral lengths of 20, 40 and 60 m were 99, 98 and 97%, respectively. The obtained results were similar with those reported by Taha (2018), who indicated that, the DU values for drip lateral length of 24 m were 89 and 90%in the 1st and 2nd seasons, respectively.

Reference crop evapotranspiration (ETo)

The 2-year mean daily ETo (mm/day) values calculated by the METOS weather station and used at the experimental site are illustrated in Figure 1. The peak values were recorded from June to August in the summer months. Results presented in this figure showed that the highest mean values of ETo were 8.99, 9.85 and 7.92 mm/day during the summer months of June, July, and August, respectively. The lowest mean values of ETo were 1.67, 1.26, and 1.8 mm/day during the winter months of November, December, and January, respectively. It is clear from the obtained results that, changes in ETo magnitudes are attributed to combine effects of changes in temperature, sunshine hours during different months, radiation effects, wind speed records, and humidity rates.

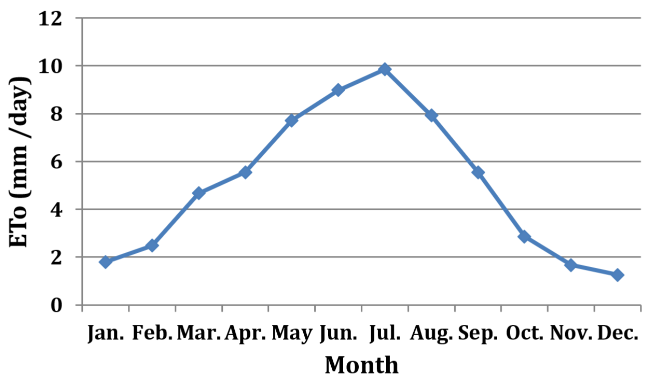

Figure 1: The 2-year average monthly reference evapotranspiration values

Applied irrigation water (AIW) and water consumption (CU)

Results in Table 3 indicated that depths of applied irrigation water were 1783 mm (114 m^3/tree/yr.), 1493 mm (95.7 m^3/tree/yr.), 1202 mm (77.1 m^3/tree/yr.), 911 mm (58.4 m^3/tree/yr.), and 2486 mm (159 m^3/tree/yr.) in 1st season and were 1692 mm (108.4 m^3/tree/yr.), 1416 mm (90.8 m^3/tree/yr.), 1141 mm (73.1 m^3/tree/yr.), 865 mm (55.5 m^3/tree/yr.) and 2450 mm (157.1 m^3/tree/yr.) in 2nd season for the 120, 100, 80, 60 % ETo and farmer treatments, respectively. Results revealed that the amounts of AIW in the 1st season were higher than the amounts in the 2nd season due to the early harvest (25 September) compared to the end of October in the first season. Results showed also that farmer irrigation practice exceeded the other tested treatments by amounts varied from 28 to 63 % in the 1st season and from 31 to 65 % in the 2nd season, which reflects the need of extension services to the growing date palms farmers in the newly cultivated areas to avoid over irrigation, reduce the cost of fertilizers added and energy used for pumping the groundwater, and to alleviate the negative effect on crop yield and quality. The results of this study were in close agreement with those reported by FAO (2008) indicating that annual growth water use varied between 10280 and 14880 m^3/ha or from 86 to 124 m^3/tree/yr. and by Mazahrih *et al.* (2012) indicating that annual applied water varies between 133 and 199 m^3/tree/yr. Also, the obtained results agreed well with the recommendation by Al-Humaid and Kassem (2005), who found that the seasonal gross irrigation requirements for date palm offshoots were 2191 m^3/ha/yr., while the farmer applied 19960 m^3/ha/yr. The farmers added irrigation water nine times as much as the actual gross irrigation requirements. Also, Kassem (2007) indicated that there is an urgent need to improve our knowledge concerning the water use and response to drought of the main perennial vegetation types such as date palm and fruit trees. Results were also 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, depletion of irrigation water from the aquifer and the significant loss of energy used to lift irrigation water.

Table 3: Effect of tested treatments on the depths and amounts of applied irrigation water (AIW), water saved (%) and water consumption (CU) by date palm trees during 2020 and 2021 seasons

Irrigation treatment	2020			2021		
	AIW (mm, m^{3}ha^{-1})	Saving (%)	CU (m^{3}ha^{-1})	AIW (mm, m^{3}ha^{-1})	Saving (%)	CU (m^{3}ha^{-1})
120 % ETo	1783 (17835)	+28.3	14944	1692 (16918)	+30.9	13963
100% ETo	1493 (14928)	+40.0	12178	1416 (14164)	+42.2	11420
80% ETo	1202 (12021)	+51.6	9757	1141 (11409)	+53.4	9027
60% ETo	911 (9114)	+63.3	7266	865 (8655)	+64.7	6856
Farmer	2486 (24860)	-----	21338	2450 (24500)	-----	20970

Results in Table 3 showed that actual water consumed by date palm trees increased with increasing the applied irrigation water. The 2-year average consumptive water use values were 14454 m^3/ha (93 m^3/tree/yr.), 11799 m^3/ha (76 m^3/tree/yr.), 9392 m^3/ha (60 m^3/tree/yr.), 7061 m^3/ha (45 m^3/tree/yr.) and 21154 m^3/ha (136 m^3/tree/yr.) for the 120, 100, 80, and 60 % ETo irrigation treatments and farmer practice, respectively. The obtained results were close to those reported by Alamoud *et al.* (2012), indicating that the actual date palm water use ranged from 59.4 to 80.0 m^3 per tree per season.

Date palm yield and its components

Results in Table 4 indicated that there is a significant effect of the tested irrigation treatments on weight of 20 fruits (g), no. of bunches/tree, fruit yield/tree (kg) and total fruit yield (t/ha) in the two growing seasons. The 2-yr. average total fruit yield values were 39.2, 33.1, 25.1, 15.2 and 30.2 t/ha for the 120, 100, 80, and 60% ETo and farmer treatments, respectively. It is clear from the results that increasing the amounts of applied irrigation water from 60% to 120% ETo significantly increased date palm yield. Results indicated that the obtained yields from the 120% ETo irrigation treatment (40.0 and 38.4 t/ha) were significantly higher than the yields obtained from all other treatments in the two growing seasons. Also, there were no significant differences between the yields of 100% ETo and farmers treatments with saving of about 40% of irrigation water. The lowest yields (15.6 and 14.8 t/ha) were recorded for the 60% ETo treatments. Increasing the AIW resulted in more water availability to the trees with direct effect on the yield. Yield reduction in farmer treatment as compared to the 120 and 100% ETo treatments could be due to leaching most of the applied fertilizers. Results showed also that date palm yields in the 2nd season were 4.2, 3.5, 8.1, 5.4, and 3.1% lower than the 1st season for the 120, 100, 80, and 60% ETo and farmer treatments, respectively. This result was due to a heat wave and increasing air temperatures that shortened the second season by almost one month. The small changes in the yields assure the fact that date palm trees are tolerant to high temperatures. The obtained results are in agreement with those reported by Brouk and Fishman (2016) who stated that date palm is well adapted to the desert environment as it can withstand high temperatures.

A linear regression analysis was run to develop a relationship between date palm yield (t/ha) and the amounts of applied irrigation water (m^3/ha/yr.) from the 120, 100, 80 and 60% ETo treatments. The obtained linear Yield – AIW relation is illustrated in Figure 2 and expressed as:

$$Yield\left(\frac{t}{ha}\right) = 0.003\ AIW\left(\frac{m^3}{ha}\right) - 8.74, \quad r^2 = 0.92$$

The high coefficient of determination value ($r^2 = 0.92$) indicates that date palm yield is linearly related to the amounts of applied irrigation water (i.e., 8655 ≤ AIW ≤ 17835 m^3/ha/yr.) and the developed relation can be reasonably used to predict the yield under the experimental conditions and similar areas. The obtained result indicates that the 120 and 100% ETo treatments could be used to obtain high date palm yields in the newly reclaimed lands at the west Nile delta region.

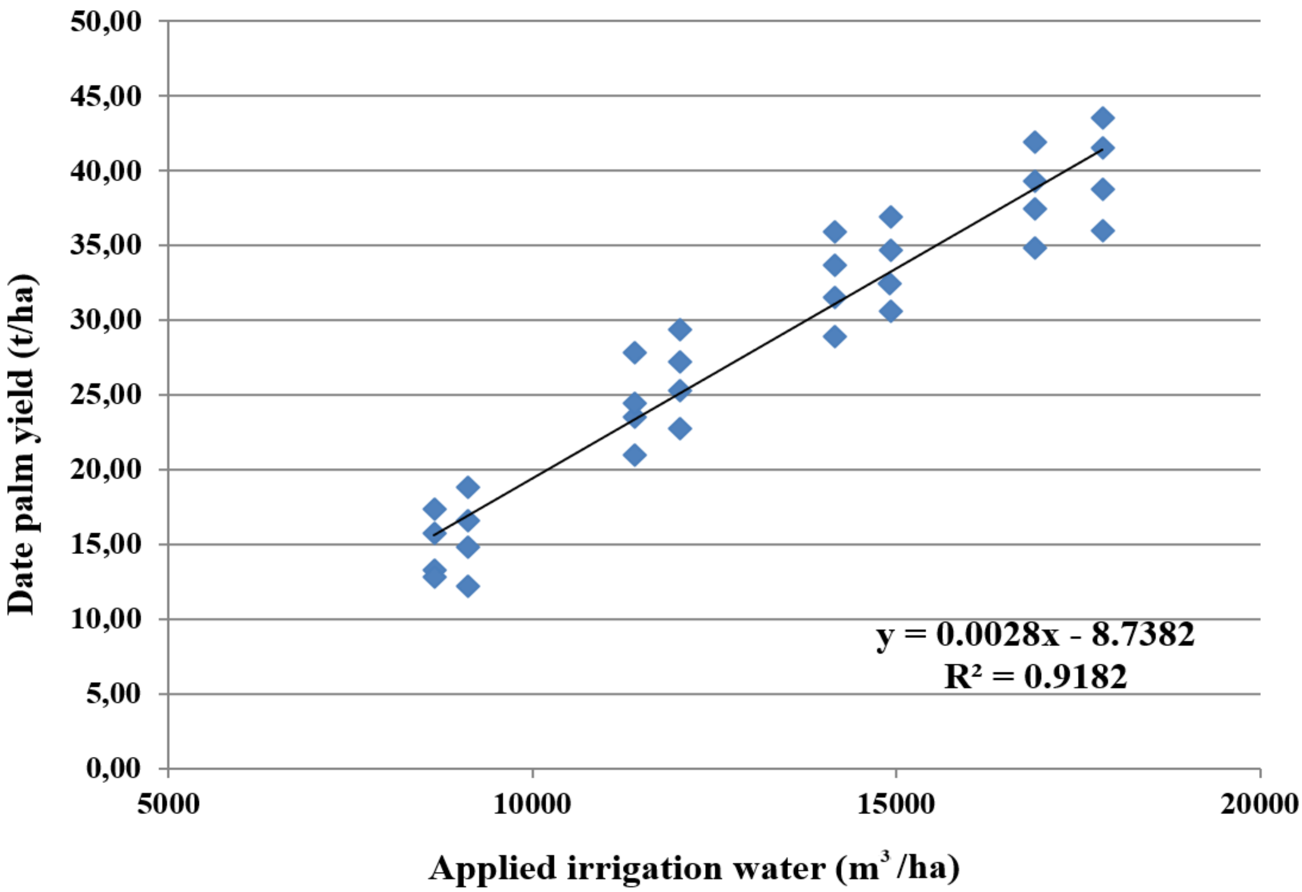

Figure 2: Linear relation between applied irrigation water and date palm yield

Results in Table 4 showed that the highest 20 fruit weight values of 362 and 346 g were recorded for the 120% ETo irrigation treatment, while the lowest values of 280 and 265 g were recorded for the 60% ETo irrigation treatments in the 1st and 2nd seasons, respectively. Results revealed also that there were no significant differences between no. of bunches/tree for the 120% ETo and farmer practice treatments. The lowest no. of bunches/tree were recorded for the 60% ETo treatment. The values of fruit yield/tree were significantly affected by tested irrigation treatments. The highest values (256.2 and 245.8 kg/tree) were produced from the irrigation with 120% ETo treatment as compared with the other treatments. Meanwhile, the lowest values (100.5 and 94.9 kg/tree) were recorded for the 60% ETo treatment. Fruit yield/tree decreased slightly in 2nd season as compared to the 1st season under all irrigation treatments due to increasing the temperature during the ripening.

Date palm physical properties

In general, results indicated that there was a significant effect of the irrigation treatments on physical properties of date palm (Table 5). Fruits of the 120 and 100% ETo treatments were significantly (13.1 and 10.4%) longer than the other treatments. The 2-year average fruit length values were 38.4, 37.5, 34.3, 33.6, and 34.0 mm for the 120, 100, 80, and 60% ETo treatments and farmer practice, respectively. Results revealed also that the 2-yr. average fruit width of the 120% ETo treatment (27.8 mm) was significantly higher than the other treatments. The smallest width (24.8 mm) was recorded for the 60% ETo water stress treatment. As for fruit weight, results showed that the highest values were recorded for the 120% ETo treatment (17.8 g) followed by farmer practice (16.3 g), while the lowest value of 13.6 g was recorded for the 60% ETo treatment. The obtained results are due to the adequate water and fertilizer availability to the growing plants with increasing amounts of applied irrigation water.

Date palm chemical properties

Results in Table 6 showed no significant effect of the tested treatments on the studied traits. Generally, increasing amounts of applied water decreased the values of carbohydrate, fructose, and glucose chemical properties. The 2-year average carbohydrate values of 57.1, 57.5, 57.8, 58.3, and 56.8 g/100 g were obtained from the 120, 100, 80, and 60% ETo treatments and farmer practice, respectively. Results showed that the highest fructose value of 27.9 g/100 g was recorded for the 60% ETo treatment,

Table 4: Effect of irrigation treatments on twenty fruits weight(g), numbers of bunches/tree, fruit yield/tree (kg), and total yield (t/ha) in 2020 and 2021 seasons

Irrigation treatments	20 fruits weight (g)		No. of bunches/tree		Fruit yield/tree (kg)		Total fruit yield (t ha^{-1})	
	2020	2021	2020	2021	2020	2021	2020	2021
120% ETo	362 a	346 a	12.0 a	10.5 a	256 a	246 a	40.0 a	38.3 a
100% ETo	326 b	313 ab	10.0 b	9.5 ab	217 b	209 b	33.6 b	32.5 b
80%ETo	310 b	288 bc	8.5 b	8.5 b	167 c	155 c	26.1 c	24.1 c
60% ETo	280 c	265 c	6.5 c	6.25 c	100 d	94.9 d	15.6 d	14.8 d
Farmer	333 b	323 a	12.0 a	11.2 a	197 b	191 b	30.7 b	29.8 b
LSD 0.05	24.5	33.4	1.84	1.99	21.5	23.2	4.24	4.01

Table 5: Effect of different levels of irrigation on fruit length (mm), width (mm) and weight (g) in 2020 and 2021 seasons

Irrigation treatments	Length (mm)		Width (mm)		Weight (g)	
	2020	2021	2020	2021	2020	2021
120 %ETo	39.2 a	37.6 a	28.3 a	27.3 a	18.2 a	17.4 a
100%ETo	39.2 ab	35.8 a	27.3 b	26.3 ab	16.4 ab	15.7 c
80 %ETo	35.6 b	33.0 b	26.5 c	24.6 b	15.5 bc	14.4 d
60%ETo	34.4 b	32.7 b	25.4 d	24.1 b	14.0 c	13.2 e
Farmer	34.4 b	33.5 b	25.3 d	24.5 b	16.6 ab	16.1 b
LSD 0.05	3.34	1.95	0.330	2.69	2.02	0.228

Table 6: Effect of different levels of irrigation on total carbohydrate (g/100 g), fructose (g/100 g) and total glucose (g/100 g) of date palm fruits in 2020 and 2021 seasons

Irrigation treatment	Carbohydrate (g/100 g)		Fructose (g/100 g)		Glucose (g/100 g)	
	2020	2021	2020	2021	2020	2021
120 %ETo	58.2 bc	56.0 a	28.1 a	26.9 a	30.2 a	28.9 a
100%ETo	58.7 ab	56.3 a	28.2 a	27.0 a	30.4 a	29.3 a
80 %ETo	59.0 ab	56.7 a	28.4 a	27.1 a	30.6 a	29.4 a
60%ETo	59.3 a	57.2 a	28.6 a	27.1 a	31.0 a	29.6 a
Farmer	57.8 c	55.8 a	27.9 a	26.4 a	30.1 a	28.9 a
LSD 0.05	0.851	2.30	2.03	1.86	1.86	1.73

while the lowest value of 27.2 g/100 g was recorded for farmer practice. The same trend was reported for glucose content. The 2-year average values of 30.3 and 29.5 g/100 g were recorded for the 60% ETo treatment and farmer practice, respectively. The obtained results were also similar to the results reported by Khattab *et al.* (2011) who stated that total soluble solids, total sugars and total anthocyanin were gradually decreased with increasing irrigation level.

Water use efficiency and water productivity

The effect of irrigation treatments on water use efficiency and water productivity values is presented in Table 7. Results indicated that WUE values increased with increasing the amounts of applied water except for farmer treatment. The highest WUE values (2.76 and 2.85 kg/m^3 consumed water) and (2.67 and 2.75 kg/m^3 consumed water) were recorded for the 100 and 120% ETo treatments in the 1st and 2nd seasons, respectively. The lowest values of 1.44 and 1.42 kg/m^3 consumed water were obtained from the farmer treatment in the two respective seasons.

Results showed that the 2-yr. average WP values were 2.25, 2.27, 2.14, 1.71, and 1.23 kg fruits/m^3 applied irrigation water for the 120, 100, 80, and 60% ETo and farmer treatments, respectively. The lowest WP values were recorded for the sever stress (60% ETo) and the over irrigation (farmer) treatments. The obtained results were close to the range of water productivity values (2.28 – 3.31 kg/m^3) reported by FAO (2008).

Crop coefficient (Kc)

The monthly Kc values were calculated for 120% ETo treatment (which recorded the highest yield) in the two seasons (Figure 3). The 2-year average monthly values were 0.58, 0.67, 0.7, 0.74, 0.77, 0.84, 1.06, 0.9, 0.83, 0.66, 0.61 and 0.56 for the period from January to December, respectively. A local seasonal Kc value of 0.74 is recommended for date palm (Barhi var.) at the experimental site. The obtained results were close to those reported by Ismail *et al.* (2014), who indicated that the calculated crop coefficient was 0.56 in January, 0.72 in February, 0.77 in March–June and 0.72 from July to December.

Table 7: Water use efficiency (WUE) and water productivity (WP) of date palm trees as affected by irrigation treatments during the 2020 and 2021 growing seasons

Irrigation treatments	WUE (kg m^{-3} consumed water)		WP (kg m^{-3} applied water)	
	2020	2021	2020	2021
120% ETo	2.67	2.75	2.24	2.27
100% ETo	2.76	2.85	2.25	2.29
80% ETo	2.68	2.68	2.17	2.12
60% ETo	2.15	2.16	1.71	1.71
Farmer (control)	1.44	1.42	1.23	1.22

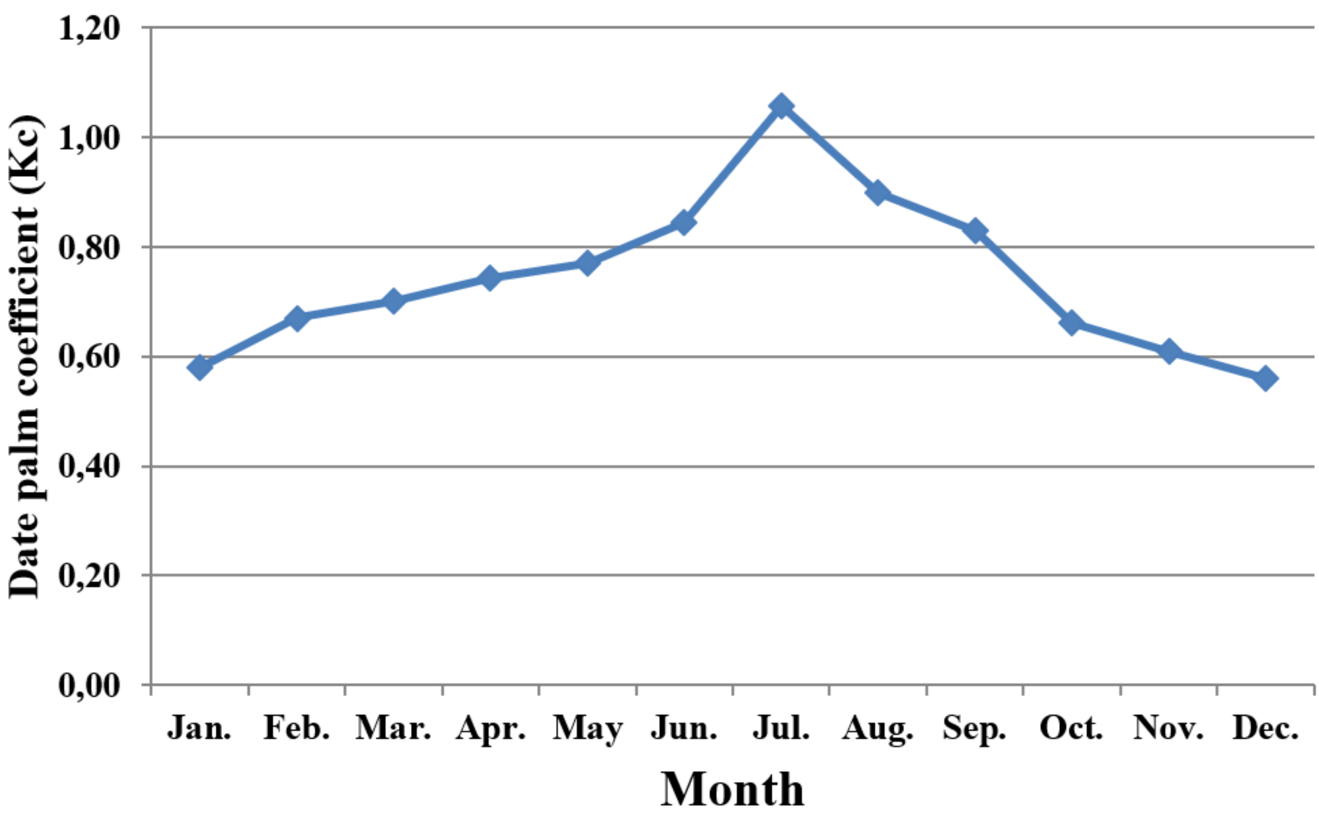

Figure 3: Date palm (Barhi var.) coefficient (Kc) for the 120% ETo treatment

Also, the results were in line with the values given by Mazahrih *et al.* (2012), who's crop coefficients of date palm ranged from 0.5 to 1.18, based on growth stages.

Figure 4 illustrates different date palm (Barhi var.) maturity stages at the experimental site.

Yield response factor (Ky)

Date palm yield response data from the tested irrigation treatments were fitted to the linear equation relating the relative yield decrease to the relative decrease in applied irrigation water (Figure 5). The equation representing this relation can be expressed as:

$$Y = 1.187\,X, \quad r^2 = 0.98$$

where:

Y: represents relative yield reduction ($1 - Y_a/Y_m$). In this study, Ym represents the yields obtained from 120% ETo treatment, while Ya represents the yields obtained from 100, 80, and 60% ETo treatments.

Figure 4: Date palm fruits maturity stages at the experimental farm: (a) Pollination, (b) Hababouk, (c) Kimri, (d) Pre-Khalad, (e) Khalad and (f) Harvest

X: represents relative reduction in applied irrigation water ($1 - AIW_a/AIW_m$). The AIWm represents the applied irrigation water for 120% ETo treatment while AIW represents the applied irrigation water for 100, 80 and 60% ETo treatments.

The constant 1.187 represents the crop response factor (K_y) that relates relative yield reduction of the date palm crop grown under the experimental conditions to the relative decrease in applied irrigation water. The coefficient of determination (r^2) value of 0.98 indicates that the developed relation can predict with high confidence level the relative yield reduction due to relative reduction in applied irrigation water at the experimental site and other sites with similar conditions. The results indicated that since Ky value is more than 1.0, date palm (Barhi variety) is sensitive to deficit irrigation and the relative reduction in yield is more than the relative reduction in applied water. Results revealed also that the obtained yield response factor of 1.187 is higher than 0.8 that reported by FAO (2002). The difference in Ky values between the experimental data and FAO could be due to the Barhi variety has soft fruits which is sensitive to water stress as compared with date palm dry varieties. From the obtained results, it could be concluded that local Ky values should be developed considering locations and crop varieties.

Consumed electric energy

Results in Table 8 indicated that the highest 2-yr. average value of consumed electric energy of12587 kilowatts was recorded for farmer treatment, while the lowest average value of 4531 kilowatt was recorded for the 60% ETo treatment. The application of irrigation treatments reduced the consumed electric energy by values varied from 29.6 to 64 % for the 120 to 60% ETo treatments as compared with farmer practice. Energy saving was a direct result of using deficit irrigation technique which reduced the number of hours used to operate the irrigation pump in all proposed irrigation treatments.

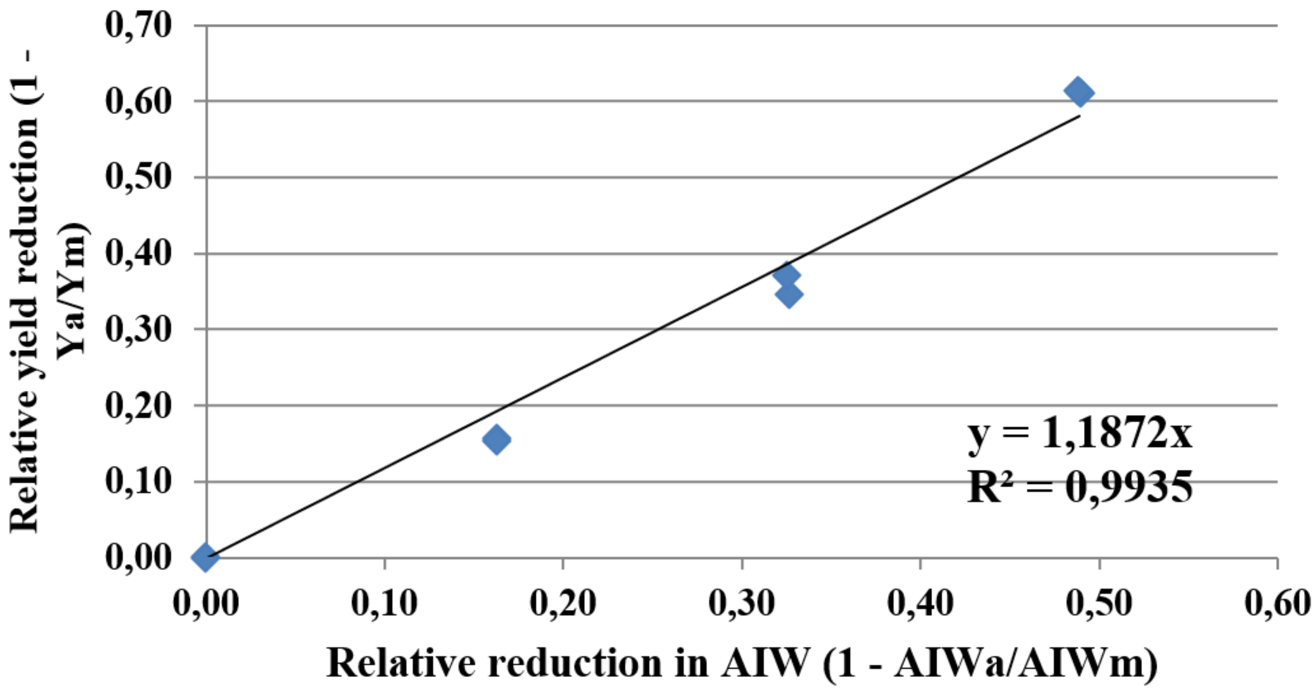

Figure 5: Date palm (Barhi variety) response factor (Ky) at the experimental site

Table 8: Effect of irrigation treatments on the consumed electric energy in the two growing seasons

Irrigation treatments	2020		2021	
	Energy consumed (kW)	Saving (%)	Energy consumed (kW)	Saving (%)
120% ETo	9096	28.3	8628	30.8
100% ETo	7613	40.0	7224	42.2
80% ETo	6131	57.6	5819	53.4
60% ETo	4648	63.6	4414	64.7
Farmer	12679	-----	12495	----

Cost-Benefit analyses

Results in Table 9 indicated that the 2-yr. average net income values were 680 331, 572 263, 430 624, 253 256, and 516 233 LE for the 120, 100, 80% and 60% ETo and farmer practice, respectively. Results revealed also that the net income values for the 120 and 100% ETo irrigation treatments were 31.8 and 10.9 % higher than that of the farmer, while the 80 and 60% ETo treatments were 16.6 and 50.9% less than the farmer practice. The high net income from the 120 and 100% ETo treatments in both seasons can be attributed to the increase in fruit yields resulting from optimizing the amounts of applied water and the efficient use of applied fertilizer through adopting the fertigation practice. Results indicated also that irrigation, fertilization, IMP, pollination and other cultural practices represented 42.7, 46.4, 2.5 and 8.4 % of the total costs of farmer practice, while they represented 34.4, 53.2, 2.9, and 9.6 % of the total costs of the 120% ETo treatment, respectively. From the obtained results it could be concluded that applying either 120 or 100% ETo irrigation treatment can achieve higher net income, save irrigation water and energy as compared to farmer practice. Also, an extension message should be conveyed to the farmers in the area to follow the results achieved by this applied research.

CONCLUSIONS

The CU values varied from 14 454 m^3/ha (93 m^3/tree/yr.) to 7 061 m^3/ha (45 m^3/tree/yr.) for the 120 and 60% ETo treatments and 21 154 m^3/ha (136 m^3/tree/yr.) for farmer practice. Total fruit yields and yield components were significantly affected by the tested treatments.

The seasonal average Kc value of 0.74 was obtained for the 120% ETo treatment.

From the obtained results it could be concluded that:

- The 2–year average AIW values were 17 377 m^3/ha (111 m^3/tree/yr.), 14 546 (93 m^3/tree/yr.), 11 715 (75 m^3/tree/yr.), 8 885 (57 m^3/tree/yr.), and 24 680 (158 m^3/tree/yr.) for the 120, 100, 80 and 60% ETo treatments and farmer practice, respectively.
- There was a significant effect of the tested irrigation levels on date palm physical and some chemical parameters and on total fruit yield.
- The highest fruit yield of 39.2 t/ha was recorded for the 120% ETo treatment, while the lowest yield of 15.2 t/ha was obtained from the 60% ETo treatment.
- The highest 2-year average WUE of 2.8 kg/m^3 consumed water was recorded for the 100% ETo treatment, while the lowest value of 1.43 kg/m^3 consumed water was obtained from farmer practice. The WP values of the same treatments were 2.27 and 1.23 kg fruits/m^3 applied water.
- The 2-year seasonal average Kc value of 0.74 was obtained for the date palm (Barhi var.) under experimental condition. The obtained values can be used under similar conditions. The date palm response factor (Ky) of 1.187 is obtained for the Barhi var. indicating its sensitivity to water stress.
- The consumed energy values varied from 28.9 for the 120 % ETo to 64.7 % for the 60% ETo treatments less than farmer practice.
- Average net income values for the 120 % and 100 % ETo treatments were 31.8 and 10.9 % higher than farmer practice.
- Irrigating date palm trees (Barhi var.) in sandy soils with 120% ETo will save 29.6 % of applied irrigation water and 29.0 % of the energy used for irrigation, achieve WUE of 2.71 kg fruits/m^3 of consumed water and WP of 2.25 kg fruits/m^3 of applied water, as well as 31.8 % higher net income as compared with farmer practice.
- To benefit from this applied research, results should be conveyed by the extension agents to the farmers in the region and similar areas.

Table 9: Net income as affected by the adopted irrigation treatments in the two growing seasons

Irrigation treatments	COST ELEMENTS (1000 LE)					BENEFITS (1000 LE)			Net Income (1000 LE)
	Irrigation	Fertilizer	IPM	Palm Pollination	Total cost	Local market: Yield (t/ha)	Local market: Price (LE/t)	Total benefits	
2020									
Farmer	12,045	13,000	0.7	2,340	28,085	30.7	18,000	552,600	524,515
120%	8,641	13,000	0.7	2,340	24,681	40.0	18,000	719,280	694,599
100%	7,233	13,000	0.7	2,340	23,273	33.6	18,000	605,700	582,427
80%	5,824	13,000	0.7	2,340	21,864	26.1	18,000	469,980	448,116
60%	4,416	13,000	0.7	2,340	20,456	15.6	18,000	280,800	260,344
2021									
Farmer	11,870	13,000	0.7	2,340	27,910	29.8	18,000	535,860	507,950
120%	8,197	13,000	0.7	2,340	24,237	38.3	18,000	690,300	666,063
100%	6,862	13,000	0.7	2,340	22,902	32.5	18,000	585,000	562,098
80%	5,528	13,000	0.7	2,340	21,568	24.1	18,000	434,700	413,132
60%	4,193	13,000	0.7	2,340	20,233	14.8	18,000	266,400	246,167

Kilowatt (kw) price = 0.95 LE

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