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RESPONSE OF TABLE OLIVE (Aggizi cultivar) TO DIFFERENT AMOUNTS OF IRRIGATION IN SANDY SOIL

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ABSTRACT

Worldwide, olive is well known as an important economic and social crop. Egypt is one of the major producers of olive under arid and semi-arid conditions. Water scarcity is the most severe problem for the sustainability of agricultural production in Egypt. Therefore, it is important to evaluate irrigation strategies tending to reduce irrigation water without affecting production. A field experiment was conducted on drip irrigated table olive trees (Aggizi cultivar) in a private farm representing the newly reclaimed sandy soil of west Nile Delta region, Egypt 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 (WCU), olive fruit yield and some physical parameters, water use efficiency (WUE), water productivity (WP), electric energy used, and farm income. Also, to develop a local table olive coefficient (Kc) and yield response factor (Ky). The experiment was laid out in a randomized complete blocks design with four replicates. Results revealed that, the average reference evapotranspiration values varied between 1.16 mm day^{-1} in January and 5.35 mm day^{-1} in July. Results indicated also that, the 2–year average AIW values were 9952 (14.94 m^3 tree^{-1} yr.$^{-1}$), 8484 (12.74 m^3 tree^{-1} yr.$^{-1}$), 6971 (10.71 m^3 tree^{-1} yr.$^{-1}$), 5480 (8.23 m^3 tree^{-1} yr.$^{-1}$), and 14747 m^3 ha^{-1} (21.61 m^3 tree^{-1} yr.$^{-1}$) for the 120, 100, 80, and 60% ETo treatments and farmer practice, respectively. While, the WCU values varied from 7817 m^3 ha^{-1} (11.7 m^3 tree^{-1} yr.$^{-1}$) to 3359 m^3 ha^{-1} (5.0 m^3 tree^{-1} yr.$^{-1}$) for the 120 and 60% ETo treatments, and 11437 m^3 ha^{-1} (17.2 m^3 tree^{-1} yr.$^{-1}$) for farmer practice. Olive fruit yields and physical parameters were significantly affected by the tested treatments. The highest fruit yield of 17.08 and 14.6 t ha^{-1} were recorded for the 120% ETo treatment, while the lowest yield of 11.12 and 9.66 t ha^{-1} was obtained from the 60% ETo treatment in the 1st and 2nd seasons, respectively. The highest 2-year average WUE of 3.09 kg / m^{-3} consumed water was recorded for the 60% ETo treatment, while the lowest value of 1.0 kg m^{-3} consumed water was obtained from farmer practice. The WP values of the same treatments were 1.9 and 0.8 kg fruits m^{-3} applied water. Aggizi olive cultivar, a seasonal average Kc value of 0.77 was recorded. An average yield response factor (Ky) of 0.836 was obtained indicating its moderate tolerance to water stress. The 2-year average consumed energy values varied from 32.5% for the 120% ETo to 62% for the 60% ETo treatments less than farmer practice. Average net income values for the 120%, 100%, and 80% ETo treatments were 47.6, 18.1 and 8.2% higher than farmer practice. From the obtained results it could be concluded that, irrigating table olive trees (Aggizi cultivar) in sandy soils with 120% ETo will save 32.5% of applied irrigation water and energy used for irrigation, achieve WUE of 2.02 kg fruits m^{-3} of consumed water and WP of 1.6 kg fruits and 17.98 LE m^{-3} of applied water, as well as 47.6% higher net income when compared with farmer practice. In case of water shortage, it is recommended to apply the 80% ETo treatment, since it will save water and energy, and achieve higher net income and water productivity than farmer practice. It is also recommended to conveying the achieved results to the farmers in the region and similar areas by the extension authorities.

(Keywords:Applied water, water consumption, water use efficiency, water productivity, crop coefficient, yield response factor, energy saving, net income)

INTRODUCTION

Olive is well known as an important economic and social crop. The world's olive production is estimated at 1.7 million tons of table olives and approximately 3 million tons of olive oil, produced from 12 million tons of olives. The worldwide olive tree cultivated area is approximately 10 million hectares, of which more than 90% is located in the Mediterranean Basin. Due to the growing demand for high-quality commercial olive yields, the need for cultivated areas is also increasing (Fraga *et al.*, 2021 and Anonymous, 2018).

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Egypt is one of the major worldwide producers of olive, and it is one of the leaders in growing olive under arid and semi-arid conditions. Egypt's production of olive is about 912,549 tons from an area of 81,523 ha (Anonymous, 2018).

The availability of irrigation water is a considerable constraint in olive production. The improvement of water use efficiency is an issue of vital importance, with direct environmental and economic consequences. Therefore, it is important to determine the water requirements of olive tree and to evaluate irrigation strategies tending to reduce irrigation water supplies without affecting production and quality. To optimize water use in olive growing in several countries in the Mediterranean Basin, strategies using controlled water deficit (DI) and regulated deficit irrigation (RDI) have been proposed (Grattan *et al.*, 2006; Pérez-López *et al.*, 2007). The aims of these strategies are to apply the optimum irrigation amount below the crop water needs but in a rational way, to keep the crop productivity as close as possible to its maximum potential (Pérez-López *et al.*, 2008; Rousseaux *et al.*, 2008). Some works have evaluated the effects of RDI on productivity and classical quality parameters of olive oil (Romero *et al.*, 2002; Grattan *et al.*, 2006; Lavee *et al.*, 2007; Servili *et al.*, 2007). Several studies have shown that irrigation has a large effect on the productivity of olive farms and an ideal water supply to olive farms is fundamental to ensure the growth processes and tree production (Girona *et al.*, 2002, and Anabela *et al.*, 2010). In arid region with an annual reference evapotranspiration (ETo) of around 1200 mm, resulting in a high water demand by crops and near daily irrigation in the summer, the sustainability of olive production in such region requires improved irrigation water productivity (WP), with deficit irrigation (DI) management being advocated as a way to better yields, oil quality, and economic returns of newly commercial orchards (Santos *et al.*, 2007 and Ramos *et al.*, 2009). Zelek *et al.* (2012) investigated the effect of three irrigation regimes, rainfed, R (0% ETc); deficit, D (50% ETc); and irrigated, I (100% ETc) on olive oil content and physical quality parameters of fruits. Results indicated that both D (50% ETc) and I (100% ETc) increased the fruit size of three of the varieties, but had no effect on oil contents compared to rainfed, R (0% ETc) while irrigation water saving was 35% for rainfed, R (0% ETc) treatments compared with the I treatment and the D treatment which resulted in 17.5% water saving with minor effects on fruit size, timing of maturity and oil content. Santos (2018), in southern Portugal, showed that mature drip-irrigated olive orchards with planting densities of around 300 trees ha^{-1} require between 3500 and 4000 m^3 ha^{-1} (350 to 400 mm) to satisfy irrigation needs for full irrigation (FI).

In Egypt, water scarcity is the most severe problem for the sustainability of agricultural production. The intensity of this problem is increasing in most cultivated areas due to increasing population, competition with other sectors, and the negative impact of climate change. The availability of fresh water is limited, while the demand for this important resource is continuously on the rise. Little information is known about the influence of controlled water deficit (DI) on olive performance and production in different areas in Egypt. Khattab *et al.* (2009) carried out a field experiment on the Picual olive cultivar in mid North Sinai Governorate to evaluate the effect of three levels of irrigation (100% or 75% or 50% of the actual calculated needs of water requirements) on fruit quality of this cultivar. Results indicated that fruit weight, volume, length, diameter and flesh thickness and moisture increased under the 100% irrigation level. Abd El-All *et al.* (2016) tested the effect of traditional (TI) and deficit irrigation (DI) treatments on the productivity of Koroniki olive variety. Their results indicated for TI treatment that, the amount of applied water as 7899 m^3 ha^{-1} yr^{-1}, fruit yield was 2.7 t ha^{-1}, and water productivity was 2.62 kg m^{-3}. While for the DI treatment, the respective values were 5924 m^3 ha^{-1} $yr.^{-1}$, 17.8 t ha^{-1}, and 2.99 kg m^{-3}. El-Taweel and Farag (2016) conducted a field experiment to study the effect of different irrigation levels, irrigation methods and olive cultivars on plant growth and yield of olive trees (*Olea europara*, L.). Treatments were: a- three irrigation levels: 10434 m^3 ha^{-1} (100%), 8901 m^3 ha^{-1} (85%) and 7352 m^3 ha^{-1} (70%); b- two drip irrigation methods: on-line surface irrigation and in-line sub surface irrigation and c- two olive cultivars, Picual and Manzanillo. Results revealed that using 85% irrigation level gave the highest growth and yield compared with other treatments. The highest WUE was found in 70% treatment with subsurface irrigation combined with Manzanillo cultivar.

Little information are available on the impact of adequate and deficit irrigation on table olive yield and its physical parameters. Therefore, the aims 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 (kg $tree^{-1}$ and t ha^{-1}) and its physical parameters (20 fruit weight, fruit length, and fruit width),water use efficiency, water productivity, electric energy used for irrigation, farm net income and to develop a local table olive coefficient (Kc) and yield response factor (Ky) under the experimental conditions.

MATERIALS AND METHODS

Experimental site description

Location

A field experiment was conducted on table olive trees (Aggizi cultivar) 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

Disturbed and undisturbed samples from the upper 60 cm soil surface were collected at 15 cm interval 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 available NPK macronutrients. Soil available nitrogen was detected by alkaline permanganate method (Hussain and Malik, 1985), available phosphorus was determined by Olsen method, and available potassium was determined in soil using ammonium acetate extractable by flame photometer according to Pansu and Gautheyrou (2006). The values of available soil N, P, and K nutrients were 16, 5.4, and 62.3 mg kg^{-1}, respectively.

Samples from irrigation water were also collected and analyzed. The obtained values are presented in Table 1.

Table 1. Physical, hydro-physical, and 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	45-60
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
Textural class		Sand	sand	sand	sand
Bulk density, g cm^{-3}		1.58	1.68	1.74	1.77
Field capacity, % v/v		17.30	16.65	14.70	13.65
Permanent wilting point, % v/v		5.60	5.35	4.80	4.40
Available soil moisture, %v/v		11.70	11.30	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+}		14.60	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
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^{+}	22.28				
K^{+}	0.21				
Soluble anions, meq l^{-1}					
CO_3^{2-}	nd*				
HCO_3^{-}	1.56				
Cl^{-}	27.12				
SO_4^{2-}	23.43				

*nd: not detected

Agro-meteorological data

A 2-year (2018 and 2019) monthly average agro-meteorological data obtained from a nearby METOS weather station were used in this study (Table 2). The station measures rainfall, air temperature, air humidity, solar radiation, and wind speed and direction. The obtained data were used to calculate reference evapotranspiration (ETo) values by applying the FAO-56 Penman-Monteith equation (Allen *et al*., 1998) in the CROPWAT 8 model.

Table 2. Monthly average agro-meteorological data used at the experimental site

Month	Air temperature (°C)			Relative humidity (%)			Wind speed ($m\ sec^{-1}$)	Solar radiation $MJ\ m^{-2}\ d^{-1}$
	Tmin	Tmax	Tmean	RHmin	RHmax	RHmean		
January	5.36	18.51	11.93	40.15	94.68	67.41	2.96	14.79
February	8.38	21.95	15.17	34.10	96.66	65.38	2.72	19.44
March	13.59	24.99	19.29	29.79	90.98	60.39	2.81	34.58
April	13.95	29.62	21.78	24.08	97.65	60.87	2.98	34.01
May	18.38	32.21	25.29	23.19	89.82	56.51	3.25	44.57
June	22.62	35.90	29.26	23.40	89.92	56.66	2.88	44.91
July	24.59	36.14	30.37	27.01	89.25	58.13	3.14	46.08
August	23.05	35.35	29.20	32.01	92.37	62.19	3.03	34.89
September	19.40	33.48	26.44	31.27	94.17	62.72	2.96	26.53
October	17.31	29.77	23.54	36.35	97.02	66.69	1.97	16.43
November	12.58	25.07	18.82	41.35	98.03	69.69	1.73	11.49
December	8.77	20.57	14.67	47.68	97.95	72.81	2.20	9.75
Average	15.67	28.63	22.15	32.53	94.04	63.29	2.72	28.12

Experimental design and tested treatments

The field experiment was laid out in a randomized complete block 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 at harvest time on the 25th and 20th of September 2020 and 2021 seasons, respectively. Irrigation event was practiced by the researchers and the farmer every 3 days. During the off-season (October to mid-February), the farmer does not irrigate while, minimum amounts of irrigation water (0.4 ETo) were weekly applied to the experimental plots. The farmer practiced irrigation and fertilization without any interference from the researchers.

Cultural practices

5-years old olive orchard (Aggizi cultivar) planted in rows 6 m apart, at a tree spacing of 2.5 m, with a plantation density of 666 plants ha^{-1}. The trees were irrigated via a surface drip irrigation system and groundwater was the source of irrigation water.

The drip system consists of:

1- Irrigation pump (60 hp) with discharge rate of 100 $m^3\ h^{-1}$.

2- Sand and screen filters and a venturi fertilizer injector. Fertilizers were applied in 80% of irrigation time through irrigation water (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 were connected to the sub-sub-main line. The trees were drip-irrigated by two drippers $tree^{-1}$, each with a flow rate of 8 l h^{-1}, connected to a single drip line. Each lateral had a 16 mm PE valve to control the application of irrigation water and mineral fertilizers.

Fertilization (macro- and micro-nutrients)

Ammonium nitrate (33.5% N) was added at the rate of 325 kg N ha^{-1}, potassium sulfate was added at the rate of 315 kg K_2O ha^{-1}. Phosphorus was added at rate of 90 kg P_2O_5 ha^{-1} as phosphoric acid (85%) in three doses: the first, 30 days before flowering, the second during fruit formation, and the third was added during the mid of August (one month before harvest). Micro-nutrients, i.e. Fe, Zn and Mn (EDTA, 13%), were also added at the rate of 600:600:600 g ha^{-1} during flowering stage using 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)

A calibrated Time Domain Reflectometry (TDR) was used to measure volumetric soil moisture contents in the surface 60 cm depth of the soil at the experimental site. The measured values were used to determine water consumptive use (WCU), or crop evapotranspiration (ETc), values according to Israelsen and Hansen (1962) using the following equation:

$$WCU = \sum_{i=1}^{i=4} \left(\frac{\theta 2 - 1\theta}{100} \times d\right)$$

where:

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

i = number of soil layer.

$è_2$ = soil moisture content after irrigation, (%, by volume).

$è_1$ = 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 (mm d^{-1}).

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).

Crop coefficient (Kc)

The local crop coefficient values for table olive trees (Aggizi cultivar.) were estimated according to Allen *et al.* (1998) as follows:

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

where:

ETc = crop evapotranspiration (mm d^{-1}) H" water consumptive use (WCU).

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

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^{-1}).

Y_m = maximum yield (t ha^{-1}).

AIW_a = actual amount of applied irrigation water (m^3 ha^{-1}). 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^{-1}). The AIW for 120% ETo treatment was used.

Water use efficiency (WUE)

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

$$WUE = \frac{\text{Olive fruit yield, Y (kg ha}^{-1})}{\text{Consumed Water, WCU (m}^3\text{ ha}^{-1})}$$

where:

Y = Table olive 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:

$$WP = \frac{\text{Olive fruit yield, Y (kg ha}^{-1})}{\text{Applied Irrigation Water, AIW (m}^3\text{ ha}^{-1})}$$

Yield and yield components

At harvest time, trees of the five treatments were manually harvested and their fresh fruits were weighed in the field and averaged to obtain the final yield (kg $tree^{-1}$), and (t ha^{-1}) per treatment. Also, fruit samples from each tree were collected to determine 20-fruit-weight, length (mm), and width (mm).

Energy saving (ES, %)

Energy saving (%): 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 table olive production at farm gate (Anonymous, 2021).The net income values were calculated using the following formula:

$$\text{Net income} = \text{Total profits} - \text{Total costs}$$

Statistical analysis

All obtained data were statistically analyzed according to (MSTAT-C) computer software package. Least significant differences (LSD) method was used to test the differences between treatments' means at 5% level of probability as described 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 (2020) and Taha and Khalifa (2022), 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 d^{-1}) values calculated by the CROPWAT 8 model are illustrated in Fig. 1. Results indicated that, the ETo value for irrigation season was 1160 mm. Results presented in this figure show that, the highest mean ETo values were 5.38 and 5.08 mm d^{-1} during July and August, respectively. The lowest ETo mean values were 1.23 and 1.16 mm d^{-1} during the winter months of December and January, respectively. It is clear from the obtained results that, changes in ETo magnitudes are attributed to the combined effects of changes in agrometeorological parameters used for calculations.

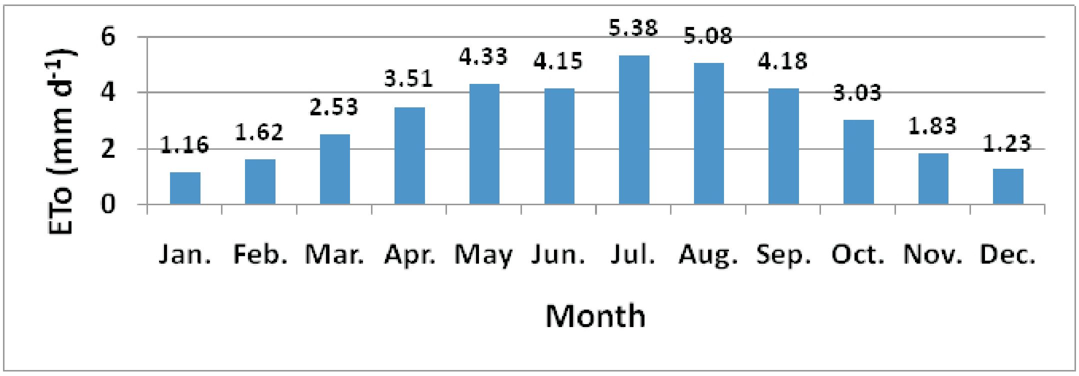

Figure 1. The 2-year daily average reference evapotranspiration values at the experimental site

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

Results in Table 3 shows the effect of tested treatments on depths (mm), amounts (m^3 ha^{-1}) and the savings (%) in applied irrigation water. The 2-year average AIW values were 9952 m^3 ha^{-1} (14.94 m^3 tree^{-1} season^{-1}), 8484 m^3 ha^{-1} (12.74 m^3 tree^{-1} season^{-1}), 6971 m^3 ha^{-1} (10.47 m^3 tree^{-1} season^{-1}), 5480 m^3 ha^{-1} (8.23 m^3 tree^{-1} season^{-1}), and 14747 m^3 ha^{-1} (21.64 m^3 tree^{-1} season^{-1}) for the 120, 100, 80, 60% ETo, and farmer treatments, respectively. Results revealed for the proposed treatments that, the amounts of AIW in the 1st season were higher than the amounts in the 2nd season due to the early harvest (20 September) compared to the 25 September in the first season. Due to increasing the temperature in the 2nd season, the farmer applied more irrigation water (15080 m^3 ha^{-1}) than the 1st season (14414 m^3 ha^{-1}). Results also showed that, the applied irrigation water by the farmer exceeded the other tested treatments by amounts varied from 30.4 to 61.9% in the 1st season and from 34.5 to 63.8% in the 2nd season, which reflects the need of extension services to the growing table olives farmers in the newly cultivated areas to avoid over irrigation, reduce the cost of fertilizers added and energy used for pumping from the groundwater, and to alleviate the negative effect on crop yield. The results of this study were in close agreement with depths of water needed to irrigate olive trees and obtain optimum yield. The reported depths were 800-1000 mm (Baratta *et al.,* 1986), > 777 mm to avoid water stress (Beede and Goldhamer, 1994), 600 to 1000 mm (Nuberg and Yunusa, 2003), and 592-790 mm (Abel-All *et al*., 2016). 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. Results in Table 3 showed that, actual water consumed by table olive trees increased with increasing the applied irrigation water. The 2-year average consumptive water use values were 7817 m^3 ha^{-1} (11.7 m^3 $tree^{-1}$ $yr.^{-1}$), 6005 m^3 ha^{-1} (9.0 m^3 $tree^{-1}$ $yr.^{-1}$), 4358 m^3 ha^{-1} (6.5 m^3 $tree^{-1}$ $yr.^{-1}$), 3359 m^3 ha^{-1} (5.0 m^3 $tree^{-1}$ $yr.^{-1}$), and 11437 m^3 ha^{-1} (17.2 m^3 $tree^{-1}$ $yr.^{-1}$) for the 120, 100, 80, and 60% ETo irrigation treatments, and farmer practice, respectively.

Table 3. Effect of tested treatments on the depths and amounts of applied irrigation water (AIW), water saved (%), and water consumption (WCU) by table olive trees during 2020 and 2021 seasons

	2020			2021		
Irrigation treatment	AIW (mm, m^3ha^{-1})	Saving in AIW(%)	WCU(m^3ha^{-1})	AIW (mm, m^3ha^{-1})	Saving in AIW(%)	WCU (m^3ha^{-1})
120 % ETo	1002.5 (10025)	30.4	7959	988 (9880)	34.5	7675
100% ETo	853.8 (8538)	40.8	6138	843 (8430)	44.1	5871
80% ETo	700.7 (7007)	51.4	4374	693.5 (6935)	54.0	4341
60% ETo	549.8 (5498)	61.9	3365	546.2 (5462)	63.8	3353
Farmer	1441.4 (14414)	----	11357	1508 (15080)	----	11516

Olive yield and its components

Results in Table 4 indicate that, there is a significant effect of irrigation treatments on tested traits (weight of 20 fruits (g), fruit length and width (mm), fruit yield $tree^{-1}$ (kg), and total fruit yield (t ha^{-1})) in the two growing seasons. The highest fruit yields of 17.08 t ha^{-1} (25.39 kg $tree^{-1}$) and 14.6 t ha^{-1} (21.9 kg $tree^{-1}$) were recorded for the 120% ETo treatment, while the lowest values of 11.12 t ha^{-1} (16.7 kg $tree^{-1}$) and 9.66 t ha^{-1} (14.5 kg $tree^{-1}$) were recorded for the 60% ETo treatment in the 1st and 2nd seasons, respectively. Farmer practice resulted in 11.99 t ha^{-1} (18 kg $tree^{-1}$) and 10.33 t ha^{-1} (15.15 kg $tree^{-1}$) in the same respective seasons. There were no significant differences between fruit yields recorded for farmer practice, 60 and 80% ETo treatments. This result indicates that over irrigation (i.e., farmer practice) and water stress treatments will result in yield reduction. Results revealed that, increasing the AIW resulted in more water availability to the trees with direct negative effect on the yield. Yield reduction in farmer treatment as compared to the 120% ETo treatment could be due to leaching most of the applied fertilizers. The results are in agreement with what reported by Iniesta *et al.* (2009), who stated that olive yield increased with the increasing applied irrigation water. The obtained yields in this study were close to those reported by Teresa *et al.* (2019), who reported that average olive yield varied from 14 to 18 t ha^{-1}. Results also showed that, table olive yields in the 2nd season were 17, 17.3, 15.9, 15.1, and 16.1% lower than yields of the 1st season for the 120, 100, 80, and 60% ETo and farmer treatments, respectively. This result was due to the heat waves and increasing air temperatures that occurred during summer season (Fig. 2). It is clear from Figure 2 that maximum air temperature (Tmax) exceeded 30 °C from early June to the end of the growing season and Tmax reached 40 °C several times during the season.

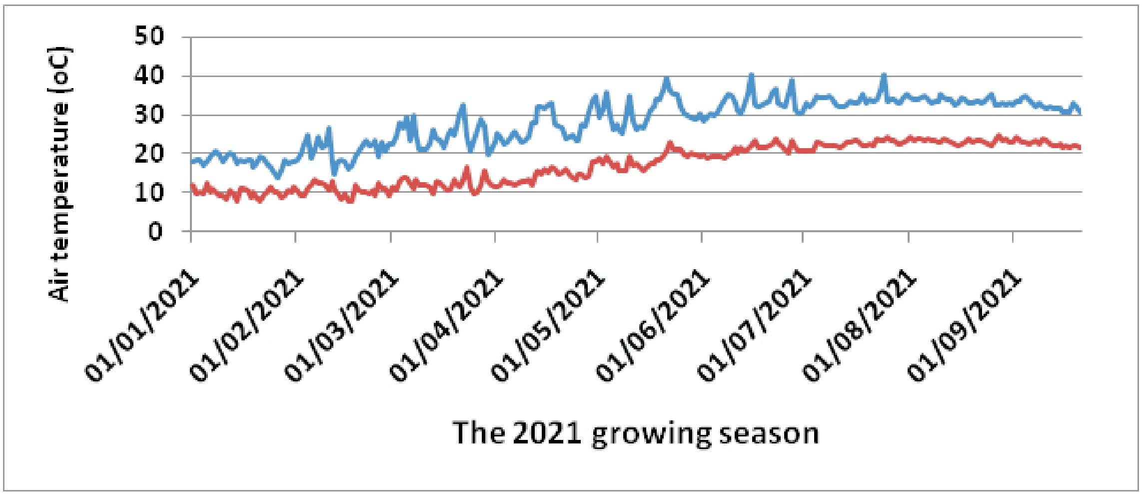

Figure 2. Maximum (blue) and minimum (red) air temperatures (°C) during 2021 growing season

The obtained results are in line with those reported by Palliotti *et al.* (1996); Koubouris *et al.* (2009); Mancuso *et al.* (2013; and Moriondo *et al.* (2013). They stated that, an olive tree typically cannot withstand temperatures below -8 ^{o}C for more than one week and very high summer temperatures may also limit its yield performances, namely, maximum temperatures higher than ~30 ^{o}C and its photosynthetic rate when exceeding 40 ^{o}C. They also stated that, a comprehensive climatological analysis over the Mediterranean Basin indicated that olive cultivation areas are constrained by temperatures of the coldest (mean monthly temperature of January is centered on ~7 ^{o}C) and warmest months (mean monthly temperature of July is centered on ~25 ^{o}C).

A linear regression analysis was run to develop a relationship between table olive yield (t ha^{-1}) and the amounts of applied irrigation water (m^{3} ha^{-1} yr.$^{-1}$) for the 120, 100, 80, and 60% ETo treatments. The obtained linear Yield – AIW relation is illustrated in Figure 3 and expressed as:

$$\text{Yield } \left(\text{t ha}^{-1}\right) = 0.0012 \text{ AIW } (\text{m}^3\text{ha}^{-1}) + 3.54, \quad r^2 = 0.63$$

The coefficient of determination value (r^2 = 0.63) indicates that, there is a reasonable accepted relation between AIW and fruit yield. Also, table olive yield is linearly related to the amounts of applied irrigation water (i.e., 5462 d" AIW d" 10025 m^{3} ha^{-1} yr.$^{-1}$) and the developed relation can be reasonably used to predict the yield under the experimental conditions and similar areas.

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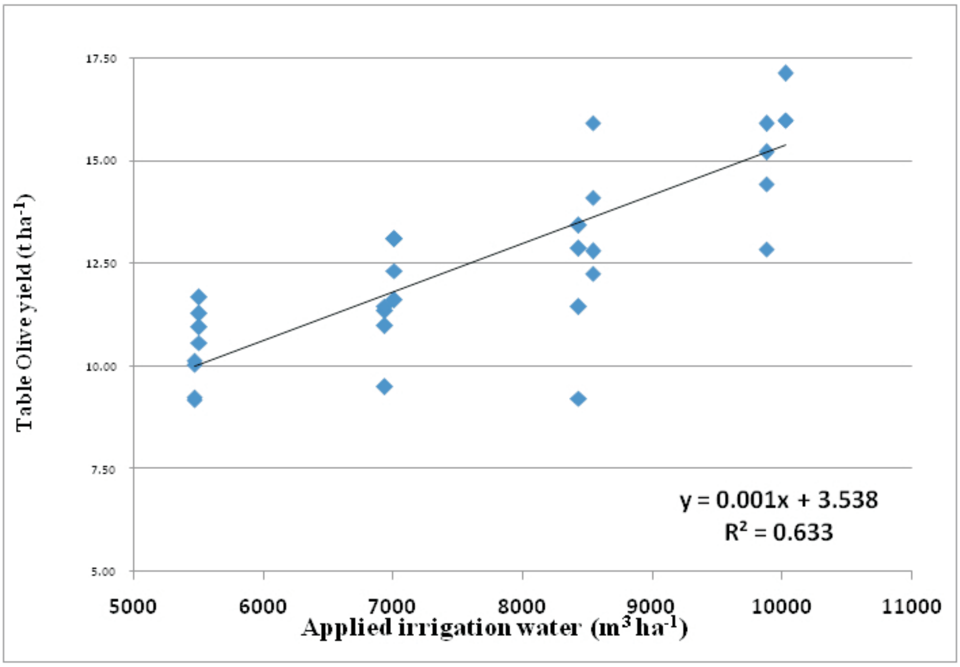

Figure 3. Linear relation between applied irrigation water and table olive yield

Results in Table 4 showed that, the tested treatments had significant effect on the tested yield and size parameters. The 2-year average 20 fruit weight values were 260, 217.7, 179.6, 148.2, and 170.8 g for the 120, 100, 80, 60% ETo and farmer practice treatments, respectively. The 2-year average fruit length values were 26.2, 23.8, 24.5, 19.8, and 21.1 mm for the same respective treatments. As for fruit width, the 2-year average values were 23.9, 22, 21.3, 18, and 20 mm for the respective treatments. It is also clear that, the tested olive yields (t ha^{-1}, kg tree^{-1}, and 20-fruit weight) decreased in 2nd season as compared to the 1st season under all irrigation treatments due to increasing the temperature during a long period of the growing season. The obtained results were in close agreement with those reported by Omran (2021). His results showed that Aggizi yield varied from 19 to 39.5 kg tree^{-1}, fruit weight varied from 6.1 to 6.2 g, and fruit length varied from 25.9 to 27.1 mm. The reported results were also in line with those reported by Ali *et al.* (2022). They reported that Aggizi yield varied from 23.4 to 43.1 kg tree^{-1} and fruit weight varied between 9.4 and 10.1 g.

Table 4. Effect of irrigation treatments on fruit yield (t ha^{-1} and g tree^{-1}), twenty fruit weight (g), fruit length (mm), and fruit width (mm) in 2020 and 2021 seasons

Trait	Yield (t ha^{-1})		Yield (kg tree^{-1})		Twenty fruit weight (g)		Fruit length) (mm)		Fruit width (mm)	
Treatment	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
120% ETo	17.08 A	14.60 A	25.39 A	21.92 A	280.0 A	240.0 A	24.20 AB	28.12 A	22.03 AB	25.70 A A
100% ETo	13.77 B	11.74 B	20.66 B	17.58 B	235.0 B	200.3 B	23.61 AB	24.00 B	20.16 AB	23.75 B
80%ETo	12.54 BC	10.82 BC	18.83 BC	16.25 BC	198.8 C	160.3 CD	27.18 A	21.89 BC	23.68 A	19.01 C
60% ETo	11.12 C	9.66 C	16.70 D	14.50 C	158.8 D	137.5 D	19.33 B	20.26 CD	17.91 B	18.01 C
Farmer	11.99 C	10.33 BC	17.99 CD	15.15 C	172.5 C	169.0 C	22.96 AB	19.26 D	21.04 AB	19.00 C
LSD 0.05	1.545	1.552	1.853	2.235	16.89	26.37	5.284	2.418	4.162	1.575

Crop coefficient (Kc)

The monthly Kc values were calculated for 120% ETo treatment (which recorded the highest yield) in the two seasons (Fig. 4). The 2-year average monthly values were 0.14, 0.28, 0.56, 0.66, 0.76, 0.82, 0.99, 0.96, 0.63, 0.24, 0.20, and 0.17 for the period from January to December, respectively. A local seasonal Kc value of 0.77 is recommended for table olive (Aggizi cultivar) at the experimental site. This value represents average Kc values from March to September to avoid the effect of high temperature on the amount of irrigation water. The obtained results were close to those reported by Tombesi *et al.* (1996), who indicated that the calculated olive crop coefficient varied from 0.5 to 0.85. Also, the results were in line with the values given by Fernandez *et al.* (2006), who reported that the crop coefficient of table olive ranged from 0.63 to 0.77, based on growth stages. Also, Rousseaux *et al.* (2009) reported Kc values of about 0.65–0.70 and 0.85–0.90 for either moderately or excessively irrigated olive plots, respectively.

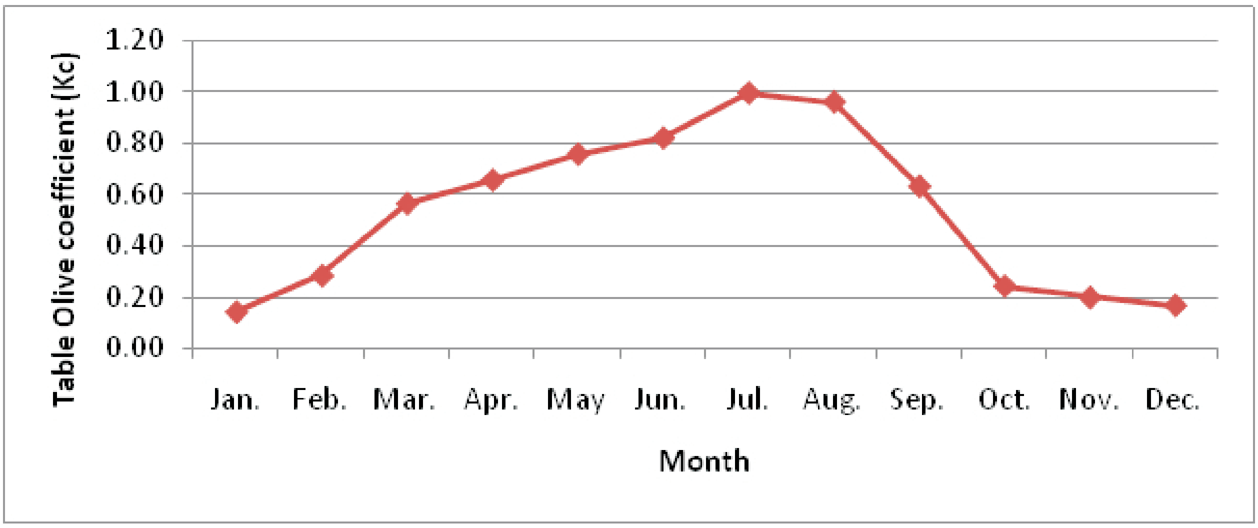

Figure 4. Table olive (Aggizi cultivar.) crop coefficient (Kc)

Yield response factor (Ky)

Table olive (Aggizi cultivar.) 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 (Fig. 5). The equation representing this relation can be expressed as:

$$Y = 0.836\ X,\ r^2 = 0.90$$

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.

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 AIWa represents the applied irrigation water for 100, 80, and 60% ETo treatments.

The constant 0.836 represents the crop response factor (K_y) that relates relative yield reduction of the table olive crop (Aggizi cultivar.) grown under the experimental conditions to the relative decrease in applied irrigation water. The coefficient of determination (r^2) value of 0.90 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 locations with similar conditions. The results indicated that, since Ky value was less than 1.0, the table olive(Aggizi cultivar) was moderately tolerant to deficit irrigation and the relative reduction in yield is less than the relative reduction in applied water.

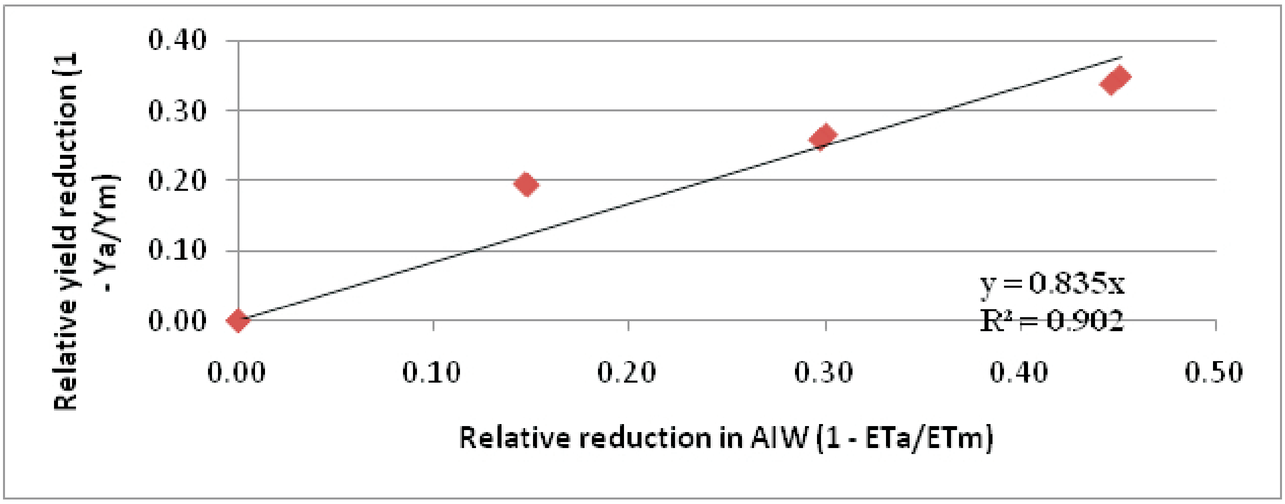

Figure 5. Table olive (Aggizi cultivar) yield response factor (Ky) at the experimental site

Consumed electric energy

Results in Table 5 indicated that the highest 2-yr. average value of consumed electric energy of 7535 kW was recorded for farmer treatment, while the lowest average value of 2795 kW was recorded for the 60% ETo treatment. The application of irrigation treatments reduced the consumed electric energy by values varied from 30.4 to 61.9% in the 1st season and from 34.7 to 63.9% in the 2nd season for the120 to 60% ETo treatments as compared with farmer practice. Energy saved was a direct result of using the proposed irrigation treatments which reduced the number of hours used to operate the irrigation pump. The results of this study were in same trend with those reported by Taha and Khalifa (2022), who indicated that 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 to farmer practice.

Table 5. 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	5113	30.4	5039	34.7
100% ETo	4353	40.8	4298	44.3
80% ETo	3574	51.4	3537	54.2
60% ETo	2804	61.9	2786	63.9
Farmer	7351	—	—	—

Economic analyses

Results in Table 6 indicated that, the 2-yr. average net income values were 178798, 143091, 131163, 116749, and 121222 LE for the 120, 100, 80% and 60% ETo, and farmer practice, respectively. Results also revealed that, the net income values for the 120, 100 and 80% ETo irrigation treatments were 47.6, 18.1 and 8.2% higher than that of the farmer, while the 60% ETo treatment was3.7% less than the farmer practice. The high net income from the 120, 100, and 80% ETo treatments in both seasons can be attributed to the increase in fruit yields resulted from optimizing the amounts of applied water, and the efficient use of applied fertilizer through adopting the fertigation practice. The obtained results were similar with those reported by Taha and Khalifa (2022), who indicated that the net income values for the 120 and 100% ETo irrigation treatments were higher than that of the farmer, while the 60% ETo treatment was less than the farmer practice.

Results indicated also that, irrigation, fertilization, Integrated Pest Management (IPM), pruning, and harvesting, which represent the main cultural practices, represented 65.1, 10.5, 5.2, 7.7 and 11.5% of the total costs of farmer practice, while they represented 55.7, 13.3, 6.6, 9.8, and 14.6% of the total costs of the 120% ETo treatment, respectively. From the obtained results it could be concluded that, applying the 120% 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.

Table 6. Net income as affected by the adopted irrigation treatments in the two growing seasons

Irrigation treatments	Cost elements (le) Irri.	Fert.	IPM	Prun.	Harv.	Total cost	Benefits Yield ($t\ ha^{-1}$)	Local price ($LE\ t^{-1}$)	Total Benefits (LE)	Net Income (LE)
2020										
Farmer	6984	1150	570	800	1170	10674	11.98	10000	119800	109126
120%	4857	1150	570	800	1170	8547	17.05	10000	170500	161953
100%	4135	1150	570	800	1170	7825	13.77	10000	137700	129875
80%	3395	1150	570	800	1170	7085	12.54	10000	125400	118315
60%	2664	1150	570	800	1170	6354	11.12	10000	111200	104846
2021										
Farmer	7332	1150	570	900	1350	11302	10.33	14000	144620	133318
120%	4787	1150	570	900	1350	8757	14.6	14000	204400	195643
100%	4083	1150	570	900	1350	8053	11.74	14000	164360	156307
80%	3360	1150	570	900	1350	7330	10.81	14000	151620	144010
60%	2646	1150	570	900	1350	6616	9.662	14000	135268	128652

*Kilowatt (kW) price = 0.95 LE

** 1 Dollar (USA) price = 15.76 LE in the first season

***1 Dollar (USA) price = 18.70 LE in the second season

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

The results regarding effect of irrigation treatments on water use efficiency and water productivity values are presented in Table 7. Results indicated, in general, that WUE values increased with decreasing the amounts of applied water. The trend was obtained for the WP values except for the 100% ETo treatment. The highest WUE (3.3 and 2.88 kg fruits m^{-3} consumed water) and WP values (2.02 and 1.77 kg fruits m^{-3} applied water) were recorded for the 60% ETo treatment in the 1st and 2nd seasons, respectively. While, the lowest WUE values (1.06 and 0.90 kg fruits/m^3 consumed water) and WP values (0.83 and 0.69 kg fruits m^{-3} applied water) were obtained from the farmer treatment in the two respective seasons. Since the yield of 120% ETo treatment was significantly higher than all other treatments, it is recommended to use its WUE and WP values instead of the higher values reported for the other treatments under this experimental condition. Considering water productivity based on the net income, results showed that WP (LE m^{-3} applied water) values for all tested treatments were higher than those obtained from farmer practice. The 2-yr. average WP values were 17.98, 16.88, 18.83, 21.31, and 8.21 LE m^{-3} applied water for the 120, 100, 80, 60% ETo, and farmer treatments, respectively.

From the obtained results it could be concluded that, irrigating table olive trees (Aggizi cultivar.) in sandy soils with 120% ETo will save 32.5% of applied water and energy used for irrigation, achieve WUE of 2.02 kg fruits/$m^3$of consumed water and WP values of 1.6 kg fruits and 17.98 LE m^{-3} of applied water, as well as 47.6% higher net income as compared to farmer practice. In case of water shortage, it is recommended to apply the 80% ETo treatment, since it will save water, and energy, higher net income and water productivity than farmer practice. It is also recommended to conveying the achieved results to the farmers in the region and similar areas by the extension authorities.

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

Irrigation treatments	WUE			WP					
	(kg m^{-3} consumed water)			(kg m^{-3} applied water)			(LE m^{-3} applied water)		
	2020	2021	2-yr. average	2020	2021	2-yr. average	2020	2021	2-yr. average
120% ETo	2.15	1.90	2.02	1.70	1.48	1.6	16.15	19.80	17.98
100% ETo	2.24	2.02	2.12	1.61	1.39	1.5	15.21	18.54	16.88
80% ETo	2.87	2.49	2.68	1.79	1.56	1.7	16.89	20.77	18.83
60% ETo	3.30	2.88	3.09	2.02	1.77	1.9	19.07	23.55	21.31
Farmer (control)	1.06	0.90	0.98	0.83	0.69	0.76	7.57	8.84	8.21

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