

# On-Farm Water Management and its Impacts on Productivity and Quality of Cactus Pear (*Opuntia ficus-indica*)

Maha Elbana<sup>1</sup>, Mahmoud Elwakeel<sup>2</sup>, Mohamed Rashad<sup>3</sup>

## ABSTRACT

*Opuntia ficus-indica* was planted under three irrigation water regimes during 2019-2020 in the north west of Alexandria, Egypt. The objective was to study the influence of applied irrigation regimes on fruit quality, total yield, and water use efficiency (WUE). The first irrigation treatment (T1) was 12 liters of water per plant week<sup>-1</sup>. The second and third irrigation treatments (T2 and T3) only applied when soil moisture content in the effective root zone reached below 35% and 30% of field capacity ( $\Theta_{fc}$ ), respectively to be filled up to 40% of  $\Theta_{fc}$  again. The obtained results indicated that the highest WUE was in T3 (0.59 - 0.61 kg ha<sup>-1</sup>mm<sup>-1</sup>) followed by T2 (0.52 - 0.60 kg ha<sup>-1</sup>mm<sup>-1</sup>) and the lowest was in T1 (0.06 - 0.31 kg ha<sup>-1</sup> mm<sup>-1</sup>) for (2019-2020), respectively. Very good quality fruits were produced for commercialization taking into account fruit shape, pH, total soluble solids, vitamin C content, and color index. Fruits produced under T1 had a significant higher total sugars' content than those produced under irrigation regime T2 and T3. Fruits produced under T3 had higher nutritional value with a significant higher concentration of antioxidants than T1 and T2. In conclusion, applying irrigation water when soil moisture content falls below 30% of field capacity produced higher fruit quality and saved more irrigation water. It is recommended that the obtained results be confirmed with third plantation season before dissemination to farmers and stakeholders.

**Keywords:** antioxidant, fruit quality, Irrigation regime, Prickly pear, vitamin C, water use efficiency

## INTRODUCTION

Water is the foremost pillar for agriculture and food security, especially in arid areas and marginalized lands (Daccache et al., 2016). Egypt is located in arid region within the Nile basin and facing serious challenges related to water scarcity, development and agricultural sustainability (Hassan and Mohmd, 2018). In addition, urbanization and concrete sprout on agricultural lands are high threat to food security and ecosystem (FAO and Plan Bleu, 2018). According to the most recent study conducted by FAO and IHE Delft (2020) about water accounting in the Nile river basin, water use due

to actual evapotranspiration is higher than the amount received by precipitation. The study reported that the majority of this water loss is because of the natural land cover evapotranspiration which result in no benefit from the agricultural point of view. The attempt to replace the natural land cover with dominant plant to the Nile basin ecosystem would have a positive impact on reducing non-beneficial water loss by actual evapotranspiration. It would play a relevant role in establishing new agri-food communities. Yet, it should be studied carefully to avoid any possible negative impact on the ecosystem or limited available water. On this context, attention was given to marginal lands with and/or without natural plant covers to revitalize the ecosystem and reduce non-beneficial water loss due to actual evapotranspiration or evaporation. Generally, marginal lands in Egypt are characterized by severe water scarcity with low and irregular rainfall intensity, high temperature, low soil fertility, and degraded soils. Therefore, the introduced crops, in marginal lands, should bear these harsh conditions and do not compete with strategic crops in the region increasing pressure on limited water resources.

Cactus pear (*Opuntia ficus-indica*) is one of the most adopted crops to such fragile ecosystems in marginal and arid areas (Butera et al., 2002). It has great capacity to conserve much water in its tissue (GAAC, 2012). Its roots are capable to absorb huge amount of water in short time (Inglese et al., 2017). These characteristics can benefit scarce and irregular rainfall in Egypt especially, during winter season. The economic value of cactus pear was increasing recently; thanks to its nutritional and pharmaceutical values (Piga, 2004). It is rich in vitamin C, dietary fibers,  $\beta$ -carotene (Albano et al., 2015), calcium, phosphorus, magnesium, potassium, sodium, iron (GAAC, 2012), and antioxidants (Sumaya-Martinez et al, 2011). The fruits are normally consumed fresh or processed as jams, juices, dried fruits, etc. (Cassano et al., 2010). Its fruit is sugary and juicy with thin skin (Barbera et al., 1992). Promoting *Opuntia ficus-indica* plantation in marginal lands with limited

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<sup>1</sup> Soil and Water Science Department, Faculty of Agriculture, Beni-Suef University, Beni-Suef 62511, Egypt

<sup>2</sup>Food Science Department, Faculty of Agriculture, Beni-Suef University, Beni-Suef 62511, Egypt

<sup>3</sup>Land and Water Technologies Department, Arid Lands Cultivation Research Institute, City of Scientific Research and Technological Applications (SRTA-City), New Borg Elarab, Alexandria, Egypt

\* Corresponding author: maha.elbana@agr.bsu.edu.eg

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water resources in Egypt would significantly revitalize the agri-food system in these areas and open new agri-food market and job opportunities beside its nutritional and pharmaceutical values. Nevertheless, few studies were conducted on this crop in Egyptian marginal lands to understand the best on-farm water management practices to benefit scarce rainfall and produce high quality fruits especially, under extreme long water deficit period. The present study aims are: 1- to understand and evaluate the impact of different applied irrigation regimes including extreme water deficit conditions in effective root zone on cactus pear fruit yield and water use efficiency; 2- to secure good fruit quality for commercialization; 3- to assist in the revitalization plan for marginal lands' ecosystems in arid regions by promoting cactus pear plantation with the lowest water consumption.

## MATERIAL AND METHODS

### Experimental layout

Cactus pear (*Opuntia ficus-indica*) was planted in the experimental farm of the City of Scientific Research and Technological Applications (SRTA-City), Alexandria, Egypt. The farm is located at 30°53'33.17" North and 29°22'46" East. It belongs to semi-arid marginal land with common Mediterranean arid climate conditions. Annual rainfall values were 213 and 256 mm in 2019 and 2020 (until November 11<sup>th</sup>, 2020), respectively. Average reference evapotranspiration ( $ET_0$ ) during summer was 4 mm day<sup>-1</sup>. In winter, average  $ET_0$  was 0.8 mm day<sup>-1</sup>. Mean minimum and maximum temperature were 15.7°C and 25.8°C, respectively. Cactus cladodes were planted in the field on March 24<sup>th</sup>, 2019. Before plantation, the far end of the cladodes was soaked in 1 g l<sup>-1</sup> solution of copper oxychloride and subjected to well air-dried shadow place for 4 weeks. This treatment was recommended by the Egyptian Ministry of Agriculture and Land Reclamation (MALR) to prevent potential infections to the cladodes (CAAES, 2005). Land was prepared and the experimental field was divided into three plots with 0.1 ha of each. The distance between plots was 8 m to avoid lateral flow of irrigation water between treatments. Furrows were formed and prepared in each plot from north to south direction at 4 m distance. A cubic hole with dimensions (0.5m×0.5m×0.5m) was dug along the furrow on 3 m spacing. Each hole was filled with a mixture of organic compost (12 kg), agricultural sulfur (0.5 kg), ammonium sulfate (0.5 kg, 21% N), and 0.5 kg of super phosphate fertilizer (15.5% P<sub>2</sub>O<sub>5</sub>). Treated cladodes were inserted into the soil vertically leaving one third of the cladode above soil surface facing the sun from east to west.

Drip irrigation system was installed in each plot with separate valves to control water flow and irrigation duration. Emitters' flow rate was 4 l h<sup>-1</sup>. Three irrigation regime treatments were applied to test their effect on fruit yield and quality as well as water use efficiency. Each treatment was applied in a separate plot with three replicates following a strip plot statistical design. SAS program was used for statistical analysis. Results were checked at 95% degree of confidence. The first irrigation treatment (T1) was irrigating the plant following MALR recommendation (CAAES, 2005) with 12 l plant<sup>-1</sup> week<sup>-1</sup>. The second (T2) and third (T3) irrigation treatments were extreme water deficit irrigation scheduling application. They received irrigation water based on soil moisture content (SMC) in effective root zone. Treatment T2 was applied only when SMC was lower than 35% of field capacity ( $\Theta_{fc}$ ). Treatment T3 received irrigation when SMC dropped below 30% of  $\Theta_{fc}$ . Irrigation period in T2 and T3 depended mainly on the time that SMC took to reach 40% of  $\Theta_{fc}$  in effective root zone. At the beginning of the experiment all treatments received the same amount of water (12 liters per plant) to ensure similar initial conditions and stablish of cladodes.

Soil moisture content (SMC) was determined on weekly basis using the traditional gravimetric method described in Estefan et al. (2013). Soil samples were collected at two depths (0-25 and 25-50 cm), weighed and put to dry in the oven for 24 h at 105°C. After that they left to cool in desiccator and weighed again. SMC was measured following the equation:

$$SMC = \left( \frac{\text{weight of wet soil} - \text{weight of dry soil}}{\text{weight of dry soil}} \right) \times 100$$

SMC at saturation, field capacity, wilting point, EC, and pH were measured in soil baste following Black (1965). Soil texture and bulk density were determined as well at the beginning of the experiment.

Water use efficiency for each applied irrigation treatment was determined following Castro et al. (2020) by dividing total fruit yield by water depth as follows:

$$WUE = \frac{Y_f}{I + R}$$

Where

WUE = water use efficiency in kg ha<sup>-1</sup> mm<sup>-1</sup>, Y<sub>f</sub> = total fruit yield in kg ha<sup>-1</sup>, I = total applied irrigation depth in mm, and R = accumulated rainfall in mm.

Digital image processing was used to estimate canopy cover (CC) development during the experiment run following Elbana et al. (2020). Analysis was conducted using ImageJ Java image processing program (ImageJ 1.52p, National Institutes of Health, USA).

Analysis of Variance (ANOVA) was applied to study the significant difference in canopy cover and water depth (irrigation + rainfall) among applied treatments. Results were checked at 95% degree of confidence.

### Fruit quality and phytochemical characterization

The fruit physical properties were determined including fruit and pulp weight, diameter, length, and peel thickness. Fruit shape index was measured by dividing fruit width by its length. According to Mashope (2007), the resulted index revealed the standard fruit shape being "oblong" when ranged between 0.05 to 0.55. Elliptic shape was assigned to an index from 0.56 to 0.69. Shape index from 0.70 to 0.79 indicated "ovoid" shape and from 0.80 to 0.89 was for "round" shape. Total soluble solids (TSS) were determined using Abbe refractometer at 20°C and expressed as °Brix following method of AOAC (2005).

In order to conduct the required analyses, only fruits without external injuries were selected, washed and manually peeled. Juice extraction was prepared through stirring the pulp with blender (38BL52 LBC10, Waring Commercial, USA). Seeds were removed by passing the juice through strainer. Five ml of juice was added to 50 ml of 50% methanol and extracted for 24 h at room temperature with magnetically stirring. The produced suspension was centrifuged at 4500X g for 10 min. The supernatant was filtered through a cheese cloth followed by 0.45 µm microbial filter. The extract was then stored in a dark bottle at 4°C for analyses.

The total phenolic content (TPC) was assessed according to Folin-Ciocalteu method (Zarroug et al., 2015). Total flavonoid content (TFC) was determined in the juice extract using spectrophotometer based on the formation of complex flavonoid-aluminum (Djeridane et al., 2006). The free radical scavenging activity of *Opuntia* extract was analyzed using 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical according to Kivrak (2015). The extract solutions with different concentrations (50, 100 and 150 µl) and methanolic solution (120 µl) containing DPPH radicals (0.4 mM) were incubated at room temperature in darkness for 30 min. Absorbance was measured at 517 nm using UV-VIS Shimadzu (UV-1601, PC) spectrophotometer using microplate reader and µmol Trolox equivalents per liter of pulp were obtained. Vitamin C content in the juice was determined following the technique used by Durust et al. (1997) who used ascorbic acid as a reference standard and results were expressed in mg ascorbic acid per liter of juice (mg AA l<sup>-1</sup>).

Color was measured using a Hunter Lab colorimeter (MiniScan XE™, Hunter Associates Laboratory Inc., Reston, Virginia, USA), using the D65 illuminant with an angle of observation of 10. Juice sample of 50 ml was tempered to 20°C before analysis. Color was recorded using the CIE L/a/b/ values, where L/ indicates lightness (L/ = 0 or 100 indicate black and white respectively); a\* the axis of chromaticity between green (-) to red (+), and b/ the axis between blue (-) to yellow (+). Numerical values of L\*, a\* and b/ were used to obtain chroma ( $C = [a^2 + b^2]^{1/2}$ ) and color index ( $CI = ab/L$ ) (Domínguez 1992). Amount of 5 ml of juice sample were centrifuged at 3400 rpm for 10 min at 20.0 ± 0.5°C (6500, Hamilton Bell, New Jersey, USA). Cloud index was measured according to Baker and Cameron, (1999). The concentration of total, reducing, and non-reducing sugars were determined in 100 ml fruit juice using the Nelson Somogyi method (Nelson, 1944; Somogyi, 1952).

## RESULTS AND DISCUSSION

### Soil properties and applied water depth

Soil properties at the beginning of the experiment are presented in

Table I. Soil analysis revealed sandy loam texture (65.3% sand and 18.7% clay). Soil EC and pH were determined in soil baste. Soil pH is elevated indicating alkali soil according to Richards (1954) classification. Soil bulk density of the experimental farm was 1.56 g cm<sup>-3</sup>. It is a good indicator for root ability to easily develop and grow in the root zone. Smith et al. (2001) reported reduction of ~60% in root depth when soil bulk density increased from 1.6 g cm<sup>-3</sup> to 1.8 g cm<sup>-3</sup> for *Corymbia* tree. However, other studies found that despite high soil bulk density could affect root depth and its vertical development, it could encourage its horizontal and lateral expansion (Mósená and Dillenburg, 2004). Ola et al. (2018) explained the lateral growth of root system in soil when increasing its bulk density to the soil capacity to hold more water and keep moisture in acceptable level for longer time. Richards (1954) indicated that soil bulk density in range of 1.0 to 1.8 g cm<sup>-3</sup> is very good for the majority of cultivated plants.

The total applied water depth (WD) in T1, as sum of applied irrigation water depth (I) + rainfall depth (R), was the highest compared to T2 and T3. Total WD in T1 was 239 mm and 1038 mm during season 1 and season 2, respectively. WD for T2 and T3 was 37.2 and 36.9 mm for season 1 and 344 and 337 mm for season 2.

**Table 1. Soil characteristics at the beginning of the experiment**

Parameter	Unit	Value
EC	dS m <sup>-1</sup>	2.70
pH	(1:2.5, W:V)	8.45
Bulk density	g cm <sup>-3</sup>	1.56
Hydraulic conductivity	cm h <sup>-1</sup>	2.14
Water content at saturation	%	42.80
Water content at field capacity	%	22.70
Water content at wilting point	%	13.40
Sand content	%	65.30
Clay Content	%	18.70

The noticed increase in total WD in season 2 compared to season 1 was mainly due to: (i) season 1 duration was shorter (4 months) than season 2 (14 months) and (ii) Rainfall contribution to WD during season one was very low (23 mm) in comparison with season 2 (~330 mm). The total WD for T2 and T3 in the two seasons were relatively lower than T1. This was mainly due to their application dependence on SMC in effective root zone. Therefore, irrigation was mostly conducted in summer since rainfall contributed to keeping SMC at the minimum required levels in effective root zone during winter.

#### Plant canopy, fruit yield, and water use efficiency

Cactus pear canopy cover development and added water depth to soil by irrigation (I) and rainfall (R) during the two growing seasons 2019-2020 are shown in Fig.1 No significant difference ( $P \leq 0.05$ ) was observed in CC among the applied irrigation treatments along the two growing seasons. However, mean CC was higher in T1 than T2 and T3. This might be due to the significantly higher applied WD in T1 than T2 and T3.

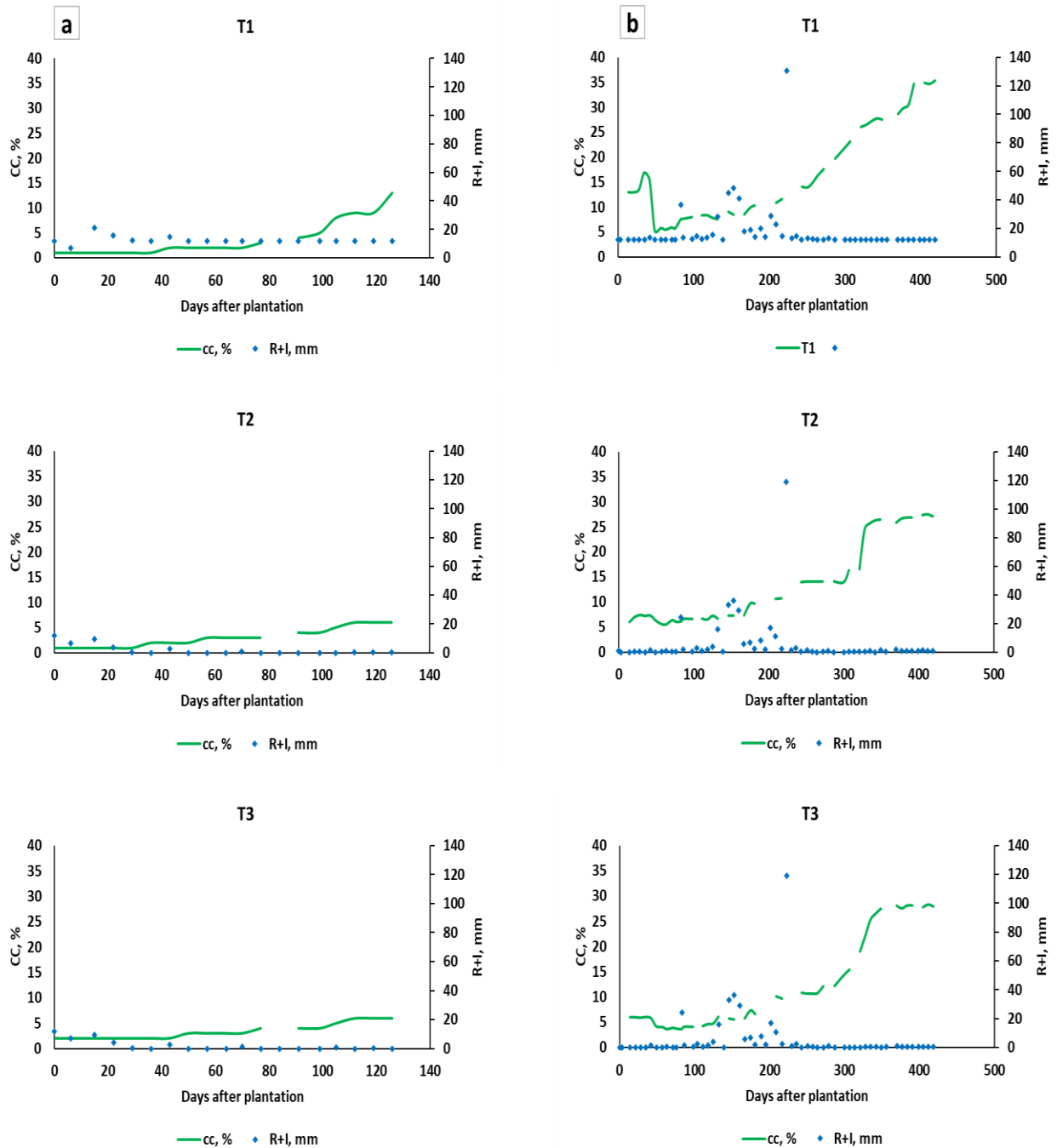
Cactus pear fruits were harvested on August 4<sup>th</sup>, 2019 for the first season and on September 27<sup>th</sup>, 2020 for the second season. Total yield and water use efficiency per each treatment during first and second seasons are presented in Fig.2. Fruit yield was relatively low during the first season where 15 kg ha<sup>-1</sup> were harvested in T1, 19 kg ha<sup>-1</sup> in T2, and 22 kg ha<sup>-1</sup> in T3. For the second season, the total yield was significantly increased ( $P \leq 0.05$ ) to 327 kg ha<sup>-1</sup> for T1, 207 kg ha<sup>-1</sup> for T2 and 206 kg ha<sup>-1</sup> for T3. Yet, no significant difference was found in yield among the applied irrigation treatments.

Water use efficiency was higher in T3 than T2 and T1 during the two growing seasons. WUE for season 1 was 0.06, 0.52, and 0.59 kg ha<sup>-1</sup> mm<sup>-1</sup> for T1, T2, and T3. This was increased to 0.31, 0.60, and 0.61 kg ha<sup>-1</sup> mm<sup>-1</sup> for T1, T2, and T3 respectively in season 2. No significant difference was found in WUE between seasons and among the applied treatments.

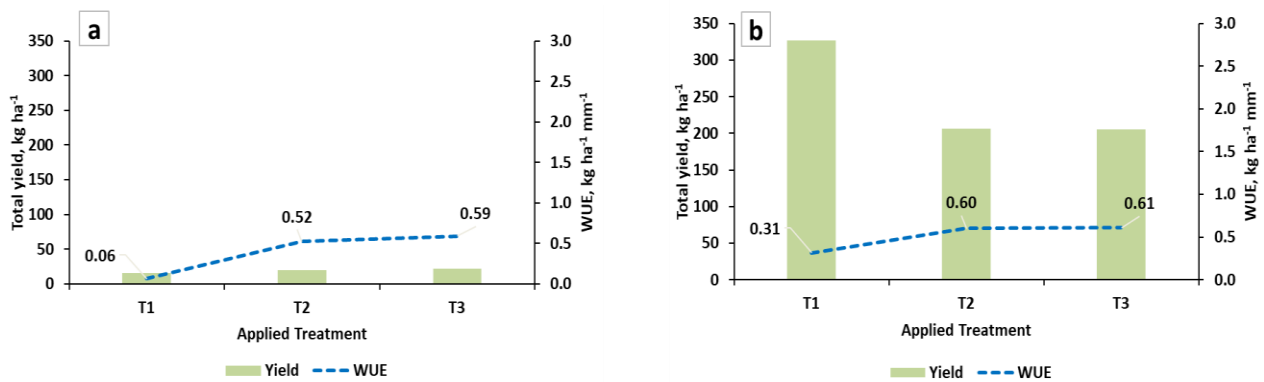
The observed lower yield in season 1 than season 2 was expected since cactus pear fruits normally start to produce ~3-5 years after plantation (CAAES, 2005). In addition, season 1 was relatively shorter than season 2. The observed increase in total yield during season 2 would be also thanks to the expansion of the shoot system and plant canopy as well (Fig.1).

In addition, the higher amount of applied WD in T1 might encouraged the crop for vegetative growth instead of fruit production. Inglese et al. (1994) found that the relationship between cladodes and fruits in cactus pear varied depending on the developing stages. They indicated that young developed cladodes normally compete with fruits in favor to cladodes production. In further development stages, cladodes become a relevant carbohydrate source for the fruit. This is opposing what was observed by Snyman (2004) who recorded significant decrease in cactus pear root system when plant received fewer amount of irrigation water than 11.664 l plant<sup>-1</sup>. However, the experimental conditions of Snyman (2004) were conducted in pots under greenhouse environment where root development is restricted to the pot size while the current study was conducted in an open field on-farm level where better chance for root system development was provided.

However, due to the circumstances of Covid-19 spread disease and the quarantine period in Egypt during 2020, there was a lack in receiving fund on time and apply proper on-farm management as same as first season. Therefore, no herbal control was conducted during the quarantine period and no fertilization processes was applied during season 2. This put the plant under fertility stress that was completely different from the first season. Fruits were of different quality during second season indicating lower sugar content and smaller size. Therefore, the current study will focus on the impact of the applied on-farm irrigation water treatment during the first season on fruit quality. The impact of severe deficit of water and fertilization on cactus pear productivity and fruit quality will be assessed in further study. The third season during 2020-2021 is running to confirm the results.



**Fig. 1. Canopy cover development (%) of cactus pear and total added water depth to soil (R+I) under each applied irrigation regime during season 1 (a) and season 2 (b). Where R is rainfall and I is irrigation in mm**



**Fig. 2.** Harvested total fruit yield in kg ha<sup>-1</sup> and water use efficiency (WUE) in kg ha<sup>-1</sup> mm<sup>-1</sup> of cactus pear for each applied irrigation treatment during season 1 (a) and season 2 (b)

## Fruit quality

### Physical properties and nutritional characterization

The physical properties and nutritional characterization of *Opuntia ficus-indica* fruit during 2019 season are shown in Table 2. Low pH values play significant role in expanding fruit shelf life (Mert, 2010). The pH value for the fruit juice significantly ( $P \leq 0.05$ ) varied from 6.35 in T1 to 6.11 in T2 and T3. The pH value for the produced juice for all treatments falls within the acceptable range (5.3:7.1) indicated by Saenz (2000). Cloud index was significantly lower in T1 compared to T2 and T3. The stability of the cloud is an important quality parameter in juice. Its positivity and negativity are directly affected by consumer

perception. For clarified juice, an unstable cloud or turbidity is unacceptable to be marketed as clarified juice (Sin et al., 2006). Cloud indices for T2 and T3 were identical.

No significant difference in fruit shape index was found as well among the three irrigation regime treatments. Yet, it showed an elliptic fruit shape in T1 and T3, whereas it was ovoid shape in T2 (Mashope, 2007). In cactus pear, it was reported that oval and/or barrel-shaped fruits were easier to handle than elongated fruits and undergo less damage to the stem end during harvesting (Cantwell, 1991). This indicates that the obtained fruit yield from all treatments is well qualified for commercialization.

**Table 2.** Physical properties and nutritional characterization of *Opuntia ficus-indica* fruit harvested in 2019 season for each applied irrigation treatment

Parameter	T1	T2	T3
pH	6.35±0.03 <sup>a</sup>	6.11±0.03 <sup>b</sup>	6.11±0.02 <sup>c</sup>
Cloud index	15±0.03 <sup>b</sup>	16±0.03 <sup>a</sup>	16±0.03 <sup>a</sup>
TSS, %	12.83±1.04 <sup>a</sup>	9.33±0.2 <sup>b</sup>	12.66±0.5 <sup>a</sup>
Shape index	0.61±0.03 <sup>a</sup>	0.7±0.09 <sup>a</sup>	0.65±0.08 <sup>a</sup>
<b>Sugar content</b>			
Total, g 100g <sup>-1</sup>	6.52±0.03 <sup>a</sup>	5.75±0.03 <sup>b</sup>	5.67±0.02 <sup>b</sup>
Reducing, g100g <sup>-1</sup>	5.87±0.06 <sup>a</sup>	5.11±0.05 <sup>b</sup>	5.06±0.04 <sup>b</sup>
Non reducing, g100g <sup>-1</sup>	0.65±0.06 <sup>a</sup>	0.64±0.04 <sup>a</sup>	0.61±0.04 <sup>b</sup>
<b>Color</b>			
a*	44.66±2.3 <sup>a</sup>	46.33±2.5 <sup>a</sup>	41.33±4.5 <sup>a</sup>
L*	2.33±1.5 <sup>a</sup>	2.33±2.3 <sup>a</sup>	3.66±2.0 <sup>a</sup>
B*	42.0±1.7 <sup>a</sup>	41.66±4.0 <sup>a</sup>	38.66±4.1 <sup>a</sup>
Color index	805.03±12.5 <sup>a</sup>	828.37±5.5 <sup>ab</sup>	436.56±7.5 <sup>b</sup>
Chroma	61.31±3.5 <sup>a</sup>	62.3±4.5 <sup>a</sup>	56.59±8.4 <sup>b</sup>

Data are presented as means ± SDM (n=3) and Means within a column with different letters are significantly different at ( $P \leq 0.05$ ).

The obtained results revealed no significant differences among samples under study of different treatments with regard to the hardness of the fruit. The total soluble solids (TSS) measured as °Brix is an indicator to sugar content. Sugar content is an important criterion of fruit quality for consumers since they prefer sweet fruits (Inglese et al., 2002). In general, the results revealed that as fruits ripen, levels of soluble solids in the cell vacuoles increased as acidity decreased. No significant difference in TSS content was found between T1 (12.83%) and T3 (12.66%). TSS for T2 was significantly the lowest (9.33%). The obtained TSS levels compared well with that recommended for cactus fruits by El-Gharras et al. (2006).

The total sugar was significantly higher (6.52 g 100g<sup>-1</sup>) in T1 than T2 (5.75 g 100g<sup>-1</sup>) and T3 (5.67 g 100g<sup>-1</sup>). No significant differences were found in total sugar content between T2 and T3. Salim et al. (2009) reported that the total sugars in cactus pear fruit varied from 6.26 to 11.45 g 100g<sup>-1</sup>. Reducing sugars' values were approximate between T2 and T3 reaching 5.11 and 5.06 g 100g<sup>-1</sup>, respectively, while T1 was higher value and recorded 5.87 g 100g<sup>-1</sup>. Non-reducing sugars for T3 was significantly lower (0.61 g 100g<sup>-1</sup>) than T2 (0.64 g 100 g<sup>-1</sup>) and T1 (0.65 g 100g<sup>-1</sup>). The sugar in fruit pulp consisted of glucose and fructose in roughly equal amounts. Generally, fructose is sweeter in taste than glucose while the last is a rapid energy source available for nerve cells and brain (Abd El-Razek and Hasasan, 2011).

On the other hands, color is an important indicator for juice value as it contributes to consumer acceptability. Cavitation may provoke fruit color to change due to speeding up chemical reactions, raising diffusion rate, and particles breakdown (Sala et al., 1995). Color parameters (L, a, b, CI, and C) are presented in Table 2. No significant difference in color index (CI) among the three applied irrigation treatments was observed. Higher Chroma value was observed for T2 (62.3) than T1 (61.3) and T3 (56.59). Chroma is an indicator to color saturation level and visual intensity. It is defined as the level of deviation between gray to a pure chromatic color (Zhao et al., 2004). Therefore, the higher the values of Chroma, the higher the color saturation.

### Content of antioxidants and vitamin C

Fruit content of antioxidants and vitamin C for each applied irrigation treatment during 2019 season are presented in Table 3. Vitamin C (ascorbic acid) is a good indicator of commercial maturity of the fruit and is an important antioxidant nutrient (Selli et al., 2002).

No significant difference was found in vitamin C concentration among the tested irrigation treatments in the produced fruit juice (Table 3). However, the obtained concentration of vitamin C indicated good fruit commercial maturity for all treatments (Sumaya-Martínez et al., 2011).

In addition, existence of antioxidant compounds such as the phenolics in food plays a positive role in human health protection (Stintzing et al., 2005). A significant difference was found in total phenolic contents (TPC) and total flavonoid content (TFC) among the three applied treatments (P<0.05). TPC in the pulp ranged from 82.33 to 92.33 mg GAE 100 ml<sup>-1</sup> being the lowest for T1 and the highest for T3, respectively. TFC concentration in *O.ficus indica* juice significantly varied from 0.96 GAE mg 100 ml<sup>-1</sup> for T1 to 1.14 GAE mg 100 ml<sup>-1</sup> for T2 and 1.38 GAE mg 100 ml<sup>-1</sup> for T3. The literature also revealed that the majority of tested cactus pear presented significant amounts of flavonoids, such as isorhamnetin, quercetin, and luteolin (Osuna-Martínez et al., 2014).

**Table 3. Antioxidant concentration (±stander error) in *O.ficus indica* fruit juice per each irrigation treatment during 2019 season**

Treatment	TPC, GAE mg 100 ml <sup>-1</sup>	TFC, GAE mg 100 ml <sup>-1</sup>	Vit. C, g AA kg <sup>-1</sup>
T1	82.54±1.54 <sup>c</sup>	0.96±0.02 <sup>c</sup>	4.32±0.6 <sup>a</sup>
T2	89.51±1.08 <sup>b</sup>	1.14±0.1 <sup>b</sup>	4.43±0.02 <sup>a</sup>
T3	92.34±0.75 <sup>a</sup>	1.38±0.04 <sup>a</sup>	4.51±0.3 <sup>a</sup>

\* Different a, b, and c letters indicate significant difference between treatments (P<0.05). TPC: total phenolics content. TFC: total flavonoid content, and Vit.C is vitamin C content.

*O.ficus indica* fruit content of DPPH obtained under each irrigation treatment is presented in Table 4. The antioxidant activity of assured foods depends on the content of a combination of antioxidants with diverse mechanisms of actions i.e., synergistic interactions. For this reason, it is essential to unite several methods to decide in vitro antioxidant capacity of food (Perez-Jimenez et al., 2008). The pulp of *O.ficus-indica* had higher antioxidant values measured by DPPH 2,2-Diphenyl-1-picrylhydrazyl in T3 than in T2 and T1. Pulp of *O.ficus-indica* in T3 exhibited higher levels compared to T2 and T1 in all concentrations. This coincides with what was observed by Zafra-Rojas et al. (2013) who found convergence results in all treatments in antioxidant compounds.

**Table 4. Content of DPPH ( $\pm$ stander error) in *O.ficus-indica* as influenced by each applied irrigation treatment at different concentrations of extract solution**

Extraction solution, $\mu$ l	T1	T2	T3
50	62.91 $\pm$ 0.2 <sup>c</sup>	73.81 $\pm$ 0.5 <sup>c</sup>	82.64 $\pm$ 0.3 <sup>c</sup>
100	66.87 $\pm$ 0.4 <sup>b</sup>	77.54 $\pm$ 0.3 <sup>b</sup>	86.93 $\pm$ 0.4 <sup>b</sup>
150	70.81 $\pm$ 0.3 <sup>a</sup>	80.34 $\pm$ 0.3 <sup>a</sup>	88.53 $\pm$ 0.3 <sup>a</sup>

\* Different letters indicate significant difference between treatments for the same concentration of extract solution

## CONCLUSIONS

It can be concluded that cactus pear (*Opuntia ficus-indica*) is a very adapted plant for cultivation in marginal lands in arid zones. Irrigation scheduling based on soil moisture content contributed in improving crop water use efficiency and maximizing rain water as relevant source for water input in root zone. Irrigation regime affected *Opuntia ficus-indica* fruit quality. Maintaining a minimum of 30% of soil field capacity in effective root zone for *O.ficus-indica* production secured very good fruit quality and quantity suitable for commercialization.

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## REFERENCES

Abd El-Razek, F.H. and A.A. Hassan. 2011. Nutritional value and hypoglycemic effect of prickly cactus pear (*Opuntia Ficus-Indica*) fruit juice in alloxan-induced diabetic rats. Aust. J. Basic Appl. Sci. 5 (10):356-377.

Albano, B., C. Negro, N. Tommasi, C. Gerardi, G. Mita, A. Miceli, L. De Bellis and F. Blando. 2015. Betalains, phenols and antioxidant capacity in cactus pear (*Opuntia ficus-indica* (L.) Mill). Fruit from Apulia (South Italy) genotypes. Antioxidants. 4 (2): 269-280. doi:10.3390/antiox4020269.

AOAC. 2005. Official methods of analysis. 18th eds., Association of Official Analysis Chemists, Inc. USA.

Baker, R.A. and R.G. Cameron. 1999. Clouds of citrus juices and juice drink, Food Technol. 53 (1): 64-69.

Barbera, G., G. Carimi and P. Inglese. 1992. Past and present role of the Indian-fig prickly pear (*Opuntia ficus-indica* (L.) Miller, Cactaceae) in the agriculture of Sicily. Econ. Bot. 46 (1):10-20.

Black, C. 1965. Methods of soil analysis Part 1: Physical and mineralogical properties, including statistics of measurement and sampling. Am. Soc. Agron. Inc., Publisher Wisconsin. USA.

Butera, D., L. Tesoriere and F. Di Gaudio. 2002. Antioxidant activities of Sicilian prickly pear (*Opuntia ficus indica*) fruit extracts and reducing properties of its betalains: betanin and indicaxanthin. J. Agric. Food Chem. 50: 6895-6901.

CAAES. 2005. Cultivation and production of cactus pear. Central Administration for Agricultural Extension Services, Ministry of Agriculture and Land Reclamation, Report no.993/2005. Cairo.

Cantwell, M. 1991. Quality and post-harvest physiology of nopalitos and tunas. In: Proceedings of the Second Annual Texas Prickly Pear Conference, McAllen, Texas. USA.

Cassano, A., C. Conidi and E. Drioli. 2010. Physico-chemical parameters of cactus pear (*Opuntia ficus-indica*) juice clarified by microfiltration and ultrafiltration process. Desalination. 250 (3): 1101-1104.

Castro, I.N., S.R. Santos, M.K. Kondo, V.M. Maia and C.C.R. Santos. 2020. Agronomic performance and water use efficiency of irrigated cactus pear cultivars. Revista Caatinga. 33(2): 529-540. <http://dx.doi.org/10.1590/1983-21252020v33n225rc>.

Daccache, A., M. Elbana, A. Fouial, F. Karajeh, R. Khadra, N. Lamaddalena, R. Saliba, A. Scardigno, P. Steduto and M. Todorovic. 2016. Management of water resources. In: Mediterra. 2016. Zero waste in Mediterranean natural resources: Food and Knowledge. International Center for Advanced Mediterranean Agronomic Studies (CIHEAM) and Food and Agriculture Organization of the United Nations (FAO), Paris, Presses de Sciences Po.

Djeridane, A., M. Yousfi, B. Nadjemi, D. Boutassouna, P. Stocker and N. Vidal. 2006. Antioxidant activity of some Algerian medicinal plants extracts containing phenols compounds. Food Chem. 97 (4): 654-660. <https://doi.org/10.1016/j.foodchem.2005.04.028>.

Domínguez, T.J.J. 1992. Effects on the incidence of freezing damage on the physiology and quality of prickly pear fruits (*Opuntia amyclaea* T). Master Degree Theses, Colegio de Posgraduados, México (In Spanish).

Durust, N., D. Sumengen and Y. Durust. 1997. Ascorbic acid and element contents of foods of Trabzon (Turkey). J. Agric. Food Chem. 45 (6): 2085-2087. <https://doi.org/10.1021/jf9606159>.

Elbana M, E.H. El-Gamal, A.E. Mohamed, A.L. Fernando, L. Pari, A. Outzourhit, M. Elwakeel, W.E.A. El-Sheikh, M. Rashad. 2020. Effect of irrigation scheduling on canopy cover development and crop-water management related parameters of *O.ficus-indica* under prolonged drought conditions. Sci. J. Agr. Sci. 2(2):113-122. 10.21608/sjas.2020.50551.1061

El-Gharras, H., A. Hasib, A. Jaouad and A. El-Bouadili. 2006. Chemical and physical characterization of three cultivars of Moroccan yellow prickly pears (*Opuntia ficus-indica*) at three stages of maturity. Cienc. Tecnol. Aliment. 5 (2):93-99. <https://doi.org/10.1080/11358120609487677>.



- Estefan, G., R. Sommer and J. Ryan. 2013. Methods of soil, plant, and water analysis: A manual for the west Asia and north Africa region. Third edition. International Center for Agric. Res. Dry Areas (ICARDA). Lebanon.
- FAO and IHE Delft. 2020. Water accounting in the Nile basin. FAO WaPOR water accounting reports. Food and Agriculture Organization of the United Nations and IHE Delft Institute for Water and Education. Rome, Italy. <https://doi.org/10.4060/ca9895en>.
- FAO and Plan Bleu. 2018. State of Mediterranean forests. Food and Agriculture Organization of the United Nations, Rome and Plan Bleu, Marseille.
- GAAC. 2012. Cultivation and production of cactus pear. General Administration of Agrarian Culture, Ministry of Agriculture and Land Reclamation, Technical Report number 7/2012. Cairo.
- Hassan, H.B.A. and E.S.O. Mohmd. 2018. Egyptian water security in view of the risks emerged by the construction of the Renaissance Dam. Middle East J. Agri. Res. 7 (3): 836-846.
- Inglese, P., C. Mondragon, A. Nefzaoui and C. Sáenz . 2017. Crop ecology, cultivation and uses of cactus pear. IX International Congress on Cactus Pear and Cochineal: CAM crops for a hotter and drier world. The Food and Agriculture Organization of the United Nations (FAO) and the International Center for Agricultural Research in the Dry Areas (ICARDA), Rome, Italy.
- Inglese, P., F. Basile and M. Schirra. 2002. Cactus pear fruit production. In: Nobel, P.S., (Ed.), Cacti: Biology and Uses: 163-183. University of California Press, California, USA.
- Inglese, P., A.I. Israel and P.S. Nobel. 1994. Growth and CO<sub>2</sub> uptake for cladodes and fruit of the Crassulacean acid metabolism species *Opuntia ficus-indica* during fruit development. *Physiol. Plantarum*. 91 (4): 708-714. <https://doi.org/10.1111/j.1399-3054.1994.tb03009.x>.
- Kivrak, I. 2015. Analytical methods applied to assess chemical composition, nutritional value and in vitro bioactivities of *Terfezia Olbiensis* and *Terfezia Claverya* from Turkey. *Food Anal. Method.* 8 (5):1279-1293. <https://doi.org/10.1007/s12161-014-0009-2>.
- Mashope, B.K. 2007. Characterization of cactus pear germplasm in South Africa, Department of Plant Sciences, University of Free State, South Africa, Ph.D.
- Mert, M. 2010. Effect of high hydrostatic pressure on microbial load and quality parameters of grape juice (M.S. thesis). Ankara, Turkey: Department of Food Engineering, Middle East Technical University.
- Mósená, M. and L.R. Dillenburg. 2004. Early growth of Brazilian Pine (*Araucaria angustifolia* [Bertol.] Kuntze) in response to soil compaction and drought. *Plant Soil* 258:293-306. <https://doi.org/10.1023/B:PLSO.0000016559.47135.21>
- Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. *J. Biol. Chem.* 153:375-380.
- Ola, A., S. Schmidt and C.E. Lovelock. 2018. The effect of heterogeneous soil bulk density on root growth of field-grown mangrove species. *Plant Soil.* 432: 91-105. [doi.org/10.1007/s11104-018-3784-5](https://doi.org/10.1007/s11104-018-3784-5).
- Osuna-Martínez, U., J. Reyes-Esparza and L. Rodríguez-Fragoso. 2014. Cactus (*Opuntia ficus-indica*): a review on its antioxidant properties and potential pharmacological use in chronic diseases. *Nat. Prod. Chem. Res.* 2 (6):1-8. [doi:10.4172/2329-6836.1000153](https://doi.org/10.4172/2329-6836.1000153).
- Perez-Jimenez, J., S. Arranz, M. Taberner, M.E. Diaz-Rubio, J. Serrano, I. Goni and F. Saura-Calixto. 2008. Updated methodology to determine antioxidant capacity in plant foods, oils and beverages: extraction, measurement and expression of results, *Food Res. Int.* 41 (3): 274-285. <https://doi.org/10.1016/j.foodres.2007.12.004>.
- Piga, A. 2004. Cactus pear: A fruit of nutraceutical and functional importance. *J. PACD.* 6: 9-22.
- Richards, L.A. 1954. Diagnosis and Improvement of Saline Akali Soils: Agriculture, Handbook No.60. US Department of Agriculture, Washington DC.
- Saenz, C. 2000. Processing technologies: an alternative for cactus pear (*Opuntia spp.*) fruits and cladodes. *J. Arid Environ.* 46 (3): 209-225. <https://doi.org/10.1006/jare.2000.0676>
- Sala, F.J., J. Burgos, S. Condon, P. Lopez and J. Raso. 1995. Effect of heat and ultrasound on microorganisms and enzymes, in: Gould, G.W., (Ed.), *New Methods of Food Preparation*, Unilever Research Laboratory Press, London. 176-204.
- Salim, N., C. Abdelwaheb, C. Rabah and B. Ahcene. 2009. Chemical composition of *Opuntia ficus-indica* (L.) fruit. *Afr. J. Biotechnol.* 8 (8):1623-1624.
- Selli, S., A. Canbas and Ü. Ünal. 2002. Effect of bottle colour and storage conditions on browning of orange wine, *Nahrung.* 46 (2): 64-67.
- Sin, H.N., S. Yusof, N.S. Abdul Hamid and R. Abd Rahman. 2006. Optimization of enzymatic clarification of sapidilla juice using response surface methodology. *J. Food Eng.* 73 (4): 313-319. <https://doi.org/10.1016/j.jfoodeng.2005.01.031>.
- Smith, K.D., P.B. May and G.M. Moore. 2001. The influence of compaction and soil strength on the establishment of four Australian landscape trees. *J. Arboriculture.* 27 (1): 1-7.
- Snyman, H.A. 2004. Effect of various water application strategies on root development of *Opuntia ficus-indica* and *O. robusta* under greenhouse growth conditions. *J. Prof. Assoc. Cactus.* 6: 35-61.
- Somogyi, M. 1952. Notes on sugar determination. *J. Biolog. Chemi.* 195:19-23.
- Stintzing, F.C., K.M. Herbach, M.R. Mosshammer, R. Carle, W. Yi, S. Sellappan, C.C. Akoh, R. Bunch and P. Felker. 2005. Color, betalain pattern, and antioxidant properties of cactus pear (*Opuntia spp.*) clones. *J. Agric. Food Chem.* 53 (2): 442-451. <https://doi.org/10.1021/jf048751y>

- Sumaya-Martinez, M.T., S. Cruz-Jaime, E. Madrigal-Santillán, J.D. García-Paredes, R. Cariño-Cortés, N. Cruz-Cansino, C. Valadez-Vega, L. Martínez-Cárdenas and E. Alanís-García. 2011. Betalain, acid ascorbic, phenolic contents and antioxidant properties of purple, red, yellow and white cactus pears. *Int. J. Mol. Sci.* 12 (10): 6152-6168. <https://dx.doi.org/10.3390%2Fijms12106452>
- Zafra-Rojas, Q.Y., N. Cruz-Cansino, E. Ramirez-Moreno, L. Delgado-Olivares, J. Villanueva-Sanchez and E. Alanís-García. 2013. Effects of ultrasound treatment in purple cactus pear (*Opuntia ficus-indica*) juice. *Ultrason. Sonochem.* 20 (5): 1283-1288. <https://doi.org/10.1016/j.ultsonch.2013.01.021>.
- Zarroug, M.B., G. Baraket, L. Zourgui, S. Souid and A.S. Hannachi. 2015. Genetic diversity and phylogenetic relationship about Tunisian cactus species (*Opuntia*) as revealed by random amplified microsatellite polymorphism markers. *Genet. Mol. Res.* 14(1):1423-1433. <https://doi.org/10.4238/2015.february.13.21>.
- Zhao, C., M.M. Giusti, M. Malik, M.P. Moyer and B.A. Magnuson. 2004. Effects of commercial anthocyanin-rich extracts on colonic cancer and nontumorigenic colonic cell growth. *J. Agric. Food Chem.* 52 (20): 6122-6128. doi: 10.1021/jf049517a.

## الملخص العربي

### إدارة الماء على مستوى المزرعة وتأثيراته على إنتاجية وجودة نبات التين الشوكي

مها البناء، محمود الوكيل ، محمد رشاد

ذات جودة جيدة جدًا للتسويق من حيث شكل الثمرة ودرجة الحموضة والمحتوى من المواد الصلبة الذائبة الكلية ومحتوى فيتامين ج ومؤشر اللون. تحتوي الفواكه المنتجة تحت T1 على محتوى سكري إجمالي أعلى معنويًا من تلك المنتجة في T2 و T3. كانت الثمار المنتجة تحت T3 ذات قيمة غذائية أعلى ومرتفعة التركيز من مضادات الأكسدة مقارنة مع T1 و T2. وأخيرًا، فإن استخدام مياه الري فقط عندما ينخفض المحتوى الرطوبي للتربة إلى أقل من 30% من السعة الحقلية ينتج فاكهة عالية الجودة ويوفر المزيد من مياه الري. يوصى بتأكيد النتائج التي تم الحصول عليها مع موسم الزراعة الثالث قبل مشاركة النتائج على نطاق واسع مع المزارعين.

الكلمات الدالة: مضادات الأكسدة، جودة الثمار، جدولة الري، التين الشوكي، فيتامين ج، كفاءة استخدام الماء.

تمت زراعة نبات التين الشوكي (*Opuntia ficus-indica*) تحت ثلاث معاملات ري خلال الفترة 2019-2020 في شمال غرب الإسكندرية، مصر بهدف دراسة تأثير معاملات الري المطبقة على إنتاجية الثمار وجودتها وكذلك كفاءة استخدام المياه. استقبلت معاملة الري الأولى (T1) 12 لترًا لكل نبات أسبوعيًا. تم تطبيق المعاملتين الثانية والثالثة (T2 و T3) فقط عندما انخفض المحتوى الرطوبي في التربة في منطقة الجذور الفعالة إلى أقل من 35% و 30% من السعة الحقلية ( $\Theta_{fc}$ )، على التوالي واستمرت كل رية حتى الوصول إلى 40% من السعة الحقلية مرة أخرى. أشارت النتائج إلى ارتفاع كفاءة استخدام المياه في T3 (0.59-0.61 كجم هكتار<sup>-1</sup>) بالمقارنة مع T2 (0.52-0.60 كجم هكتار<sup>-1</sup>) و T1 (0.31-0.06 كجم هكتار<sup>-1</sup>) لعامي (2019-2020) على التوالي. كانت جميع الثمار المنتجة