J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 15 (7):183 - 191, 2024

Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

Influence of Irrigation Regime on Total Yield of Tomato Crop and Water Productivity under Drip Irrigation System

Abd El-baki, M. S.[1*]; M. M. Ibrahim[1]; S. E. M. El-Sayed[2] and Nadia G. A. Daoud[1]

[1] Agricultural Engineering Department, Faculty of Agriculture, Mansoura University
[2] Environmental studies and Research Institute, University of Sadat City

Cross Mark

ABSTRACT

Water scarcity remains a significant challenge for global agriculture. Deficit irrigation has emerged as a strategy to optimize water productivity without compromising crop yield. This study aimed to assess the impact of deficit irrigation on tomato yield and water productivity (WP). Two field experiments were conducted over consecutive seasons of 2022 and 2023 using drip irrigation. Three irrigation regimes were employed: 100% (T100), 75% (T75), and 50% (T50) of the full irrigation requirements. Crop stress indicators, including fresh biomass weight (FB), dry-biomass weight (DB), canopy water content (CWC), soil moisture content (SMC), and relative chlorophyll content (SPAD measures) were evaluated. The results showed that the highest values of FB, DB, CWC, SMC, and yield were achieved under T100, followed by T75, while the lowest values were observed at T50. The highest SPAD values were obtained under T75, followed by T100 and T50 for both seasons. The results further showed that the highest WP values were observed with T100 (27.37 kg/m^3), followed by T75 (25.96 kg/m^3). The lowest WP value was 21.58 kg/m^3 at T50. The application of T75 and T50 led to saving 22.29% and 44.57% of the irrigation water applied compared to T100 in both seasons, respectively. In conclusion, this study proves that applying moderate deficit irrigation at T75 is considered to be a feasible technique for tomato production.

***Keywords*:** Deficit irrigation, Tomato yield, Water productivity, Crop stress indicators, Drip irrigation.

INTRODUCTION

Tomato crop is one of the most commonly grown vegetables worldwide. Global production has increased by roughly 10% in recent years (Shalaby and El-Banna, 2013). Tomatoes are the second most significant crop in terms of cultivated area, after potatoes (Mehdizadeh et al., 2013). Egypt is the world's sixth-largest producer, as the area cultivated with tomatoes amounted to about 143,618 hectares, with a total production of about 6.28 million tons (FAOSTAT, 2022).

Tomato plants are significantly affected by water stress, as there is a strong connection between the water needs of the crops and their overall yield (Zinkernagel et al., 2020). It is imperative to improve water consumption efficiency given Egypt's limited water supply and growing use of irrigation, as revealed by Morillo et al. (2015). In this context, deficit irrigation, in conjunction with effective irrigation techniques like drip irrigation, has drawn interest as a potential strategy to address these challenges. Deficit irrigation is an alternative water conservation strategy without remarkable reductions in crop yield and quality (Afzal et al., 2017).

To accurately determine crop water requirements and establish irrigation schedules, irrigation water management programs can be employed, utilizing weather station data or information from website applications (Gabr, 2022). Khan et al. (2019) found that the CROPWAT program proved to be the most effective for farmers in understanding the optimal timing and amount of water required for their tomato fields, accounting for changes in climatic conditions.

Understanding how plants respond to water stress is crucial for determining the optimal timing and amount of irrigation, as pointed out by Morillo et al. (2015). When soil water content decreases, plants close their stomata to minimize water loss. However, prolonged stomatal closure can lead to a reduction in chlorophyll content, thereby inhibiting photosynthesis Tembe et al. (2017). Crop productivity is significantly influenced by photosynthetic activity. Koech and Langat (2018) emphasized that chlorophyll, the primary pigment responsible for the greenness of leaves, is essential for plant functioning to rapidly and cost-effectively assess chlorophyll regimes. SPAD chlorophyll meters are commonly employed and effectively used to measure chlorophyll (Filek et al. 2015).

Ragab et al. (2018) used several deficit irrigation regimes to investigate its effects on tomato plants and found that the maximum FB and DB were found with 100% of the full irrigation treatment (FIT), positively affecting flowering and tomato yield. El-Labad et al. (2019) and Sarker et al. (2020) conducted studies on the impact of varying irrigation regimes (100%, 80%, and 60%) of the FIT on tomato yield and water productivity, considering indicators such as FB, DB, CWC, SMC, and SPAD. Their results showed that applying 80% of the FIT yielded the highest values for all stress indicators, followed by 100% of the FIT. Moderate water deficit application led to increased water productivity without significant reduction in yield, while severe water deficit had a detrimental effect on tomato yield (Zhang et al. 2017 and Abd-Elhakim et al. 2021). These findings point out that moderate deficit irrigation can effectively optimize water productivity in tomato crops.

This study's objective is to assess the impacts of three different irrigation regimes (100, 75, and 50% of the full irrigation treatment) on various measured parameters, including fresh biomass weight (FB), dry biomass weight

[*] **Corresponding author.**
E-mail address: mohamedsalah@mans.edu.eg
DOI: 10.21608/jssae.2024.298525.1234

(DB), canopy water content (CWC), soil moisture content (SMC), relative chlorophyll content (SPAD), as well as yield and water productivity (WP) of tomato crop. The study also aimed to determine the optimal irrigation regime for tomato cultivation, balancing water savings and yield.

MATERIALS AND METHODS

1. Study area

Field trials were carried out over two consecutive spring growing seasons of 2022 and 2023 at a private farm located in Talkha, Dakahlia province, Egypt. The precise coordinates of the farm are 31.09° N latitude and 31.38° E longitude, with an elevation of 17 meters. The experimental soil classified as a sandy clay texture, and its maximum rain infiltration rate was determined as 30 mm per day. The daily meteorological parameters, including maximum and minimum temperature, average air humidity, average wind speed, and rainfall, were sourced from the website: https:// power. larc.nasa.gov/data-access-viewer/ , according to Power (2022).

2. Soil and water data analysis

The physical and chemical characteristics of soil samples were taken from various soil profile depths are listed in Table 1. The chemical and hydrophysical characteristics of water samples taken from the irrigation source are displayed in Table 2. These samples were evaluated to assess specific properties.

Table 1. Some physical and chemical properties of soil in the experimental site

Depth, cm	Soil particle size distribution, %			Texture	F.C %	P.W.P %	BD (gm/cm^3)	pH
	Sand	Clay	Silt					
0-20	56.04	32.17	11.79	Sandy Clay Loam	28.11	14	1.13	8.28
20-40	46.77	43.46	9.78	Sandy Clay	31.07	15	1.12	8.34
40-60	48.57	35.02	16.41	Sandy Clay	30.6	14.8	1.08	8.32

Where, F.C: Field Capacity%, P.W.P: Permanent Wilting Point were determined as percentages in weight%, BD: Bulk density.

Table 2. Some irrigation water's chemical analysis.

pH	ECw (dS/m)	Available nutrients (mg/l)			Soluble cations (mg/l)
		Nitrogen (N)	Phosphorus (P)	Potassium (K)	(Sodium) Na$^+$
7.21	0.83	363.64	0	3.01	28.11

Where, ECe: Electrical conductivity of the irrigation water.

3. Crop Data

The hybrid tomato seeds 'Gs12 F1' were planted in plastic seedling trays on January 19th, 2022, and January 27th, 2023, for the two respective growing seasons. In the first season, the transplanting process began on February 23rd, followed by a 35-day initial growth stage. The harvest took place on June 17th. For the second season, transplanting commenced on March 3rd, and the harvest was completed on June 25th. The entire growing season for the tomato plants lasted for 150 days, which was divided into four stages: initial (35 days), developmental (39 days), middle (46 days), and late (30 days). According to Noreldin et al. (2014), the crop coefficients (K_c) for different stages were: 0.38 for the initial stage, 1.10 for the developmental stage, 1.10 for the middle stage, and 0.65 for the late stage.

4. Experimental Design and Procedures

Experimental irrigation system

The drip irrigation system's layout is shown in Figure 1. The control head, includes: a centrifugal water pump (diameter: 80 mm; capacity: 1050 L/min; power: 4.8 hp) to supply water; a disk filter to remove impurities; a pressure gauge to monitor the pressure of the system; control valves to control the desired pressure at different parts of the system; and a Venturi-type injector to inject water-soluble fertilizers into the irrigation network. The main line was 75 mm in diameter from polyethylene (P.E.) pipes, and the sub-main line was P.E. pipes with a 63 mm diameter. Laterals with a 16 mm diameter, P.E., a built-in emitters were used with an average discharge rate of 6 lit/h at 1 bar operating pressure. The beginning of each lateral was provided with a T-shaped 16 mm plastic valve to control the irrigation depth at the desired level for each treatment separately.

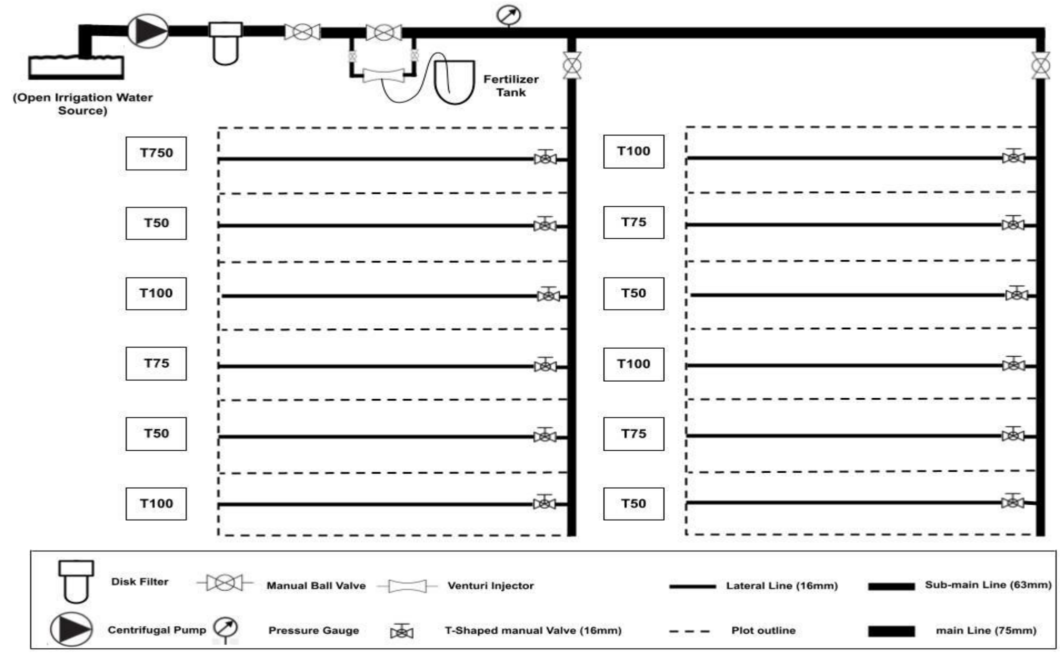

Fig. 1. The layout of experimental design for the different irrigation treatments

The end of each lateral was closed by an end cap. A drip irrigation system was constructed and tested before being used in the experimental location using equation (1), according to Ella et al. (2013). The distribution uniformity (DU) was estimated to be 92%.

$$\mathbf{DU} = \frac{\textbf{average of the lowest quartile}}{\textbf{the average of all readings}} * \mathbf{100\%} \quad \ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

Planting and water regime treatments

Tomato plants were irrigated using a drip irrigation system. In order to reduce the effect of spatial heterogeneity, a randomized complete block with four replicates was used for the experiment. The distance between plants within the same row was 0.4 meters. The spacing between lateral lines was set at 1.2 meters. Each plot had an area of 10.8 m^2, measuring 9 meters in length and 1.2 meters in width.

Irrigation treatments started after 15 days of transplanting to ensure the survival rate of the seedlings. After that, the irrigation treatments were applied for the rest of the growing season, except for the last 10 days before harvest, when irrigation was stopped. Three irrigation regimes were applied to the tomato plants: 100% (T100), 75% (T75), and 50% (T50) of the full irrigation treatment.

Fertilizer requirements were determined based on the recommendations provided by the Egyptian Ministry of Agriculture. All treatment groups received 357 kg/ha of nitrogen (N) in the form of urea (46.5% N), 60 kg/ha of phosphorus (P) in the form of phosphoric acid (85% P_2O_5), and 238 kg/ha of potassium (K) in the form of potassium sulphate (50% K_2O). These fertilizers were applied through the drip irrigation system using a venturi meter injector throughout the two growing seasons.

5. Measurements of crop stress indicators

The measurements were conducted on the selected plants under different irrigation treatments at the same time. The following measurements were calculated based on the respective formulas utilized:

Soil moisture content (SMC):

According to Zotarelli et al. (2009b), the 0–15 cm soil layer contained approximately 70–75% of the root density. Therefore, soil samples were specifically taken within this range. The SMC was determined using the gravimetric method as described by Paltineanu and Starr (1997) and Evett et al. (2002). This method involves drying soil samples for 24 hours at 105 °C in an oven. The laboratory analysis involved weighing the soil samples before and after drying, and the SMC was estimated using equation (2).

$$\mathbf{SMC}\ (\%) = \left(\frac{\mathbf{M_{wet} - M_{dry}}}{\mathbf{M_{wet}}}\right) * \mathbf{100\%} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\textbf{(2)}$$

Where: $\mathbf{M_{wet}}$**: Weight of container with moist soil, gm.**
$\mathbf{M_{dry}}$**: Weight of container with oven dry soil, gm.**

Fresh and Dry Biomass Weights

The estimation of FB and DB were evaluated by adopting the procedures outlined by Semananda et al. (2016). Four plants were cut above the ground for each treatment during the flowering stage, 67 days after transplanting (DAT) for the first season and 68 DAT for the second season. The FB was recorded by gram per plant, and after that, the samples were subsequently dried at 105 °C in a forced-air oven for approximately 24 hours. Then, the DB was recorded by gram per plant.

Canopy Water Content (CWC)

The CWC is the percentage of water stored in the plant's canopy, which reflects the plant's water status and transpiration rate. CWC was calculated by adopting the procedures outlined by Semananda et al. (2016) using the following equation:

$$\mathbf{CWC} = \left(\frac{\mathbf{FB - DB}}{\mathbf{FB}}\right) * \mathbf{100\%} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3)}$$

Relative Chlorophyll Content (SPAD)

The SPAD-502 chlorophyll meter, as explained in Figure 2, was utilized to determine the relative chlorophyll content. This instrument operates by measuring the leaf absorbance in the red and near-infrared regions. It employs two LEDs with peak wavelengths of 650 nm and 940 nm to emit light. The measuring area of the SPAD-502 is 2 x 3 mm, offering a high level of precision with an accuracy of ± 1.0 (Ding and Zhang, 2020). Following the methodology outlined by Bai et al. (2018), the SPAD readings were taken on the newest fully expanded leaf of all plant samples, specifically at a point approximately halfway between the leaf edge and the midpoint of the leaf. To determine the relative chlorophyll content, four leaves were measured for each plant. The values for the four leaves were averaged to represent each plant. Subsequently, for each treatment, the values obtained from the four replicates were averaged to represent each treatment combination.

Fig. 2. Portable chlorophyll meter SPAD-502 for measuring relative chlorophyll content

6. Calculations of water requirements

Total available soil water (TAW)

The TAW was estimated for (0–40) cm depth by equation (4), according to Philipova et al. (2012).

$$\mathbf{TAW} = (\theta_{\mathbf{FC}} - \theta_{\mathbf{PWP}}) * \frac{\boldsymbol{\gamma}_{\mathbf{d}}}{\boldsymbol{\gamma}_{\mathbf{w}}} * \mathbf{10} \quad \ldots\ldots\ldots\ldots \textbf{(4)}$$

Where: TAW: Total available soil water, mm/m.
$\theta_{\mathbf{FC}}$**: Field capacity by weight, %.**
$\theta_{\mathbf{PWP}}$**: Wilting point by weight, %.**
$\boldsymbol{\gamma}_{\mathbf{d}}$**: Bulk density of soil, g/cm^3.**
$\boldsymbol{\gamma}_{\mathbf{w}}$**: Density of water, g/cm^3.**

Crop Evapotranspiration (ET$_c$)

Reference evapotranspiration (ET$_o$) values were calculated on a daily basis using the "FAO Penman-Monteith" equation (5) of the CROWAT program, as described by Halimi and Ashebir (2019) and Gabr (2022). Also, the ET$_c$ values were calculated by multiplying the ET$_o$ by the crop coefficient (K$_c$) for each growth stage using equation (6).

$$\mathbf{ETo} = \frac{\mathbf{0.408\Delta(R_n - G) + \gamma(\frac{900}{T + 273}) * U_2(e_a - e_d)}}{\mathbf{[\Delta + \gamma(1 + 0.34U_2)]}} \ldots\ldots\textbf{(5)}$$

Where: ETo: Reference evapotranspiration (mm/day); $\mathbf{R_n}$: Net radiation at crop surface (MJ/m^2.day); G: Soil heat flux (MJ/m^2.day); T: Average temperature (°C); $\mathbf{U_2}$: Wind speed measured at 2 m above ground (m/s); $\mathbf{e_a - e_d}$: Vapor pressure deficit (kpa); Δ: Slope vapor pressure curve (kpa/°C); γ: Sychometric constant (kpa/°C).

$$\mathbf{ETc = ETo * K_c} \quad \text{……………………} \quad \mathbf{(6)}$$

Where: **K_c: Crop coefficient (dimensionless).**

Effective root zone depth (Z_r)

The effective root zone depth (Z_r) was calculated using the equations (7 and 8), according to Salman et al. (2021). The specific values utilized for the following equations in relation to the tomato crop were sourced from Machado and Oliveira (2005).

$$\mathbf{Z_r = Z_0 + (Z_x - Z_0)\sqrt[n]{\frac{t - \frac{t_0}{2}}{t_x - \frac{t_0}{2}}}} \quad \text{…………………} \quad \mathbf{(7)}$$

$$\mathbf{Z_0 = \frac{Z_n}{2}} \quad \text{……………………….} \quad \mathbf{(8)}$$

Where: Z_r= effective rooting depth at time t, m; Z_0 = Starting depth of the root zone, m; Z_x= maximum effective rooting depth, m (0.4 m); n = shape factor describing root zone expansion, (1.5); t=time after planting, day; t_0 = time to reach 90 % of crop emergence, day (7 days); t_x = time after planting when Z_x is reached, day (39 days); Z_n = the minimum effective rooting depth, m (0.1 m).

Net Irrigation Depth (d_n)

The net depth required through drip irrigation was estimated, according to Allen et al. (1998), by the following equation:

$$\mathbf{d_n = TAW * \frac{MAD}{100} * Z_r} \quad \text{………………} \quad \mathbf{(9)}$$

Where:

d_n: Net irrigation depth, mm.

TAW: Total available soil water, mm/m.

MAD: Maximum allowable depletion (%), 40% for tomato crops, according to Allen et al. (1998).

Z_r: Effective root depth (m).

Irrigation Scheduling

The irrigation schedule was determined based on the ET_C at different stages of the growing period and the total available water in the soil. The CROPWAT program was utilized for irrigation scheduling, which provides various options for determining when and how much water to apply. In this study, the irrigation scheduling was set at 40% of the critical depletion level. The irrigation application option chosen was to refill the soil to its field capacity, which corresponds to 100% soil moisture level. Furthermore, the efficiency of the drip irrigation system used in the study was reported as 90%.

Irrigation Water Applied (IWA)

The leaching requirement (LR) refers to the quantity of water required to enable the leaching of salts from the root zone. In this work, the LR specifically for a drip irrigation system was determined using equation (10) as described by Doorenbos (1977). However, the leaching requirement was disregarded due to its estimated value being 0.032, which falls below the threshold of 0.1. Therefore, the need for additional water for salt leaching was deemed unnecessary based on the obtained LR value.

$$\mathbf{LR = \frac{EC_w}{2MaxEC_e}} \quad \text{…………………………} \quad \mathbf{(10)}$$

Where: EC_w: Electrical conductivity of irrigation water was measured to be 0.83 ds/m based on the physical and chemical properties of the samples.

$MaxEC_e$: Maximum tolerable electrical conductivity of the soil saturation extract was 13 ds/m for a tomato crop, as mentioned by Savva and Frenken (2002).

The irrigation water applied (IWA) is determined as the quantity required to replenish the crop water consumed to reach field capacity. The calculation of IWA for the three treatments (T100, T75, and T50) was conducted using equation (11) as specified by Abdulhadi and Alwan (2021). The IWA in the three treatments was based on percentages of the full irrigation treatment, with 100%, 75%, and 50% utilized for T100, T75, and T50, respectively.

$$\mathbf{IWA = \frac{d_n * S_e * S_m * K_r}{E_a}} \quad \text{………………} \quad \mathbf{(11)}$$

d_n: The net depth computed using CROPWAT8.0 for the full irrigation treatment, mm.

S_e: Lateral spacing along the sub-main, m.

S_m: Dripper spacing along the lateral, m.

E_a: Irrigation application efficiency (90%).

K_r: wetted area factor was estimated to be 0.33 using equation (12), according to YILDIRIM and BAHAR (2017):

$$\mathbf{K_r = \frac{S_e}{S_m}} \quad \text{…………………………} \quad \mathbf{(12)}$$

7. Yield and Water Productivity

Eight plants for each treatment were chosen randomly and given labels. The yield from each pick was measured in order to gather yield statistics for these plants. Ripe fruits were manually picked from each replicate. There were two fruit picks, one at 109 and 115 days after transplanting (DAT) and the other at 107 and 115 DAT, in 2022 and 2023, respectively. The average weight of four replicates was used to determine the total fruit production for each treatment, which was then expressed in tons per hectare.

Water productivity (WP) was computed as the ratio of fruit yield to the total amount of IWA during the season. The WP was estimated using equation (13), as outlined by Ali and Talukder (2008).

$$\mathbf{WP = \frac{yield\ (kg/hectare)}{Total\ irrigation\ water\ applied(m^3/hectare)}} \text{…………}\mathbf{(13)}$$

8. Yield Reduction and Water Saving

The reduction in tomato yield was determined using equation (14), according to Ismail (2010).

$$\mathbf{Reduction\ in\ yield, (\%) = 100 - (\frac{yield\ of\ T50\ or\ T75}{yield\ of\ T100} * 100)} \quad \text{…}\mathbf{(14)}$$

Water saving (WS) was calculated using equation (15), according to Ismail (2010).

$$\mathbf{WS, (\%) = 100 - (\frac{seasonl\ IWA\ \ of\ T50\ or\ T75}{seasonal\ IWA\ of\ T100} * 100)} \text{……..}\mathbf{(15)}$$

9. Statistical Analysis

The experiment was laid out in a randomized complete block design (RCBD) with four replicates. All collected data were subjected to analysis of variance (ANOVA) in order to examine the response of plant stress indicators to different irrigation treatments. SPSS statistical software package version 28.0 was used to analyze the data. Significantly different means were separated using Duncan's multiple range test at the P ≤ 0.05 level of probability. The relationships between plant stress indicators and tomato yield were fitted by linear regression using Excel 2016 (v14.0).

RESULTS AND DISCUSSION

1. Climatic Data

The climate data collected during the field experiment is presented in Figure 3. The data includes measurements of mean daily maximum and minimum temperatures (°C), humidity (%), and wind speed (m/sec). These data show variations between the two growing seasons. On average, the daily maximum temperature was 46.1 °C and 42.3 °C, while the daily minimum temperature was 7.2 °C and 9.3 °C for both tested seasons, respectively. The mean relative humidity reached its highest values at 79.3% and 68.5% in the two seasons, with the lowest values of 35% and 25.9% respectively. In terms of rainfall, the second growing season had a higher amount of precipitation, with 24.20 mm, compared to the first growing season, which recorded 20.0 mm.

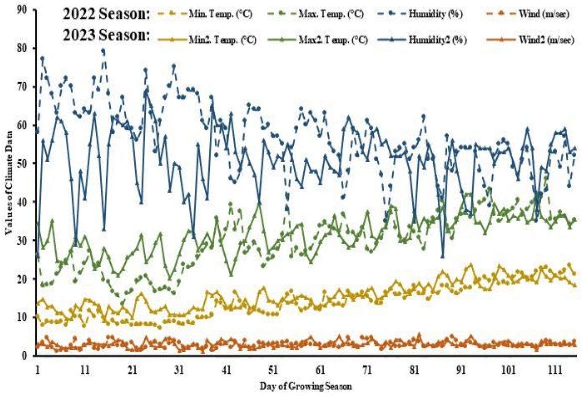

Fig. 3. Daily climatic data for tomato growing seasons of 2022 and 2023.

2. Irrigation water applied

In the two seasons under study, the ET_o exhibited a difference, with season 2023 showing a higher value of 789.63 mm compared to season 2022, which recorded 711.79 mm. Regarding the ET_c, the second season had the highest value of 841.0 mm, while the first season had the lowest value of 753.1 mm. These results are in close agreement with those published by Kizza et al. (2016) and Çetin and Uygan (2008). Previous researches showed that there was a broad range of ideal irrigation requirements (532 to 905 mm) for having high tomato yields EL-MARAZKY (2018) and Attia et al. (2019). These studies demonstrate a diverse array of irrigation requirements to reach optimum yields, and how the irrigation water management is important for enhancing crop productivity.

In this study, the irrigation scheduling for tomato crop in both seasons was calculated by the CROPWAT program, as shown in Figures 4 and 5. Before starting the irrigation treatments, 78.9 and 108.1 mm of water were added equally to each treatment in the first and second seasons, respectively. The total gross irrigation depths during the first season, corresponding to T100, T75, and T50, were recorded as 792.5, 614.1, and 435.7 mm, respectively, with 31 irrigation events. But in the second season, the total gross irrigation depths reached 918.3, 715.75, and 513.2 mm, for T100, T75, and T50, respectively, with 37 irrigation events. These results are close to those of EL-MARAZKY (2018) and Attia et al. (2019).

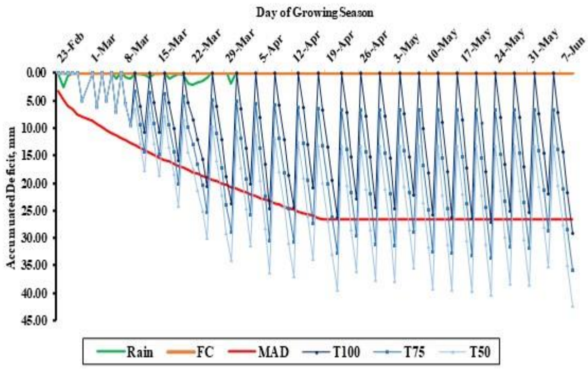

Fig. 4. Tomato crop irrigation scheduling for 2022 season at different irrigation treatments

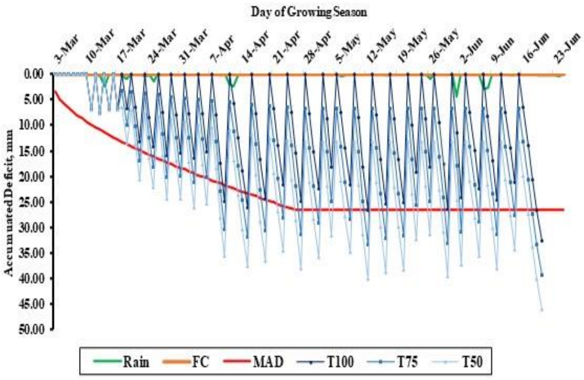

Fig. 5. Tomato crop irrigation scheduling for 2023 season at different irrigation treatments

The irrigation water applied for the tomato crop during the 2022 season was 2615.25, 2026.53, and 1437.81 m^3/ha for the T100, T75, and T50, respectively. In season 2023, the values were 3030.39, 2361.98, and 1693.56 m^3/ha for the same treatments. These results are close to those of Soussa (2010). The largest amount of water applied was recorded with T100, while the least amount was observed with T50 in both seasons. The variation in irrigation levels can be attributed to the differences in climatic parameters during both seasons, as depicted in Figure 3.

3. Effect of Irrigation Regimes on crop stress indicators:

Tomatoes, being one of the most widely cultivated vegetables, exhibit sensitivity to soil moisture stress, primarily due to its shallow root systems (Zotarelli et al., 2009). This characteristic highlights the importance of comprehending the impact of soil moisture on tomato plants. By understanding these effects, effective irrigation management strategies can be developed. Maintaining optimal soil moisture conditions is essential to maximize returns and water productivity in tomato production, particularly when implementing deficit irrigation techniques.

Soil Moisture Content (SMC)

The statistical analysis shows a highly significant impact due to irrigation regimes on soil moisture content (SMC) ($p < 0.05$), as indicated in Table 3. A comparison of different irrigation regimes with SMC revealed that reducing the amount of applied water leads to a decrease in SMC. These results are in line with Al-Ghobari and Dewidar (2018). Table 3 details the variation in SMC for the different irrigation regimes. The highest and lowest values of SMC in both seasons were observed with T100 and T50, respectively.

Fresh and Dry Biomass Weight

The statistical analysis conducted at different irrigation regimes revealed highly significant effects on the FB and DB of tomatoes throughout both seasons ($p < 0.05$), as shown in Table 3. For both seasons, T100 has the greatest average FB values (17.59 tons per hectare). These outcomes can be explained by the fact that plants in the T100 received the optimal amount of water. In the T75, the FB decreased by 24.81% and 25.89%, while in the T50, it decreased by 59.94% and 60.61% compared to the T100 during the first and second seasons, respectively.

The trend of DB followed a similar pattern as FB, as shown in Table 3. The highest DB, averaging 2.18 tons per hectare, were observed in T100 for both seasons. This outcome can be attributed to the robust vegetative growth, due to good photosynthesis and subsequent accumulation of dry matter. In T75, the DB decreased by 17.57% and 18.78%, while in T50, the decrease was 44.00% and 45.80% compared to T100 in the first and second seasons respectively. These findings suggest that water stress has a highly detrimental effect on both FB and DB. The results concerning FB and DB align with the findings of Zhang et al. (2017), Al-Ghobari and Dewidar (2018), and El-Labad et al. (2019), who reported that the full irrigation treatment produced the greatest FB and DB for tomato crops compared to other deficit irrigation treatments.

Canopy Water Wontent (CWC)

The statistical analysis conducted at different irrigation regimes revealed highly significant effects on the canopy water content (CWC) of tomatoes throughout both seasons ($p < 0.05$), as shown in Table 3. Comparing different irrigation regimes with canopy water content shows that reducing the amount of irrigation water applied reduces CWC, as shown in Table 3. These findings align with the results obtained by Ihuoma and Madramootoo (2020) and Alordzinu et al. (2021). We observed the highest CWC at T100 during both growing seasons, and the lowest value at T50. While the T75 had a slight reduction compared to the T100, Generally, water-stressed plants within T50 and T75 have a lower CWC than non-stressed plants within T100. So, scientists have used CWC to indicate plant water stress and schedule irrigation.

Table 3. The Effect of Irrigation Regimes on Stress Indicator for Tomato Crops.

Crop Stress Indicators	Treatment	First Season	Second Season
SMC, (%)	T100	21.36±0.27a	28.02±0.20a
	T75	16.81±0.41b	24.23±0.56b
	T50	12.51±0.13c	20.08±0.13c
CWC, (%)	T100	87.69±0.60a	87.58±0.35a
	T75	86.53±0.57b	86.40±0.24b
	T50	82.83±0.63c	82.92±0.39c
FB, (ton/hectare)	T100	17.72±1.57a	17.46±0.59a
	T75	13.33±0.38b	12.94±0.74b
	T50	7.10±0.32c	6.88±0.31c
DB, (ton/hectare)	T100	2.18±0.15a	2.17±0.09a
	T75	1.80±0.09b	1.76±0.12b
	T50	1.22±0.09c	1.17±0.06c
SPAD	T100	54.11±0.70b	53.50±2.02b
	T75	56.07±0.95a	55.88±0.82a
	T50	46.75±1.76c	45.93±0.81c

Means having the different alphabetical letter (s) are significantly differ at 0.05 level according to Duncan's multiple range test ($P \leq 0.05$).

Relative Chlorophyll Content (SPAD)

The numerical SPAD value specifies the relative chlorophyll content within the leaf samples. In this study, a significant variation in SPAD values for tomato plants at different irrigation regimes during both seasons were observed in Table 3. The highest SPAD values were 55. 98 at T75 as a mean for both seasons, followed by 53.87 at T100 and 46.34 at T50. Water stress can affect chlorophyll, the primary pigment responsible for photosynthesis. Stressed plants may experience a decrease in chlorophyll content due to the detrimental effects of severely reduced CWC, as demonstrated by the enigmatic T50. On the other hand, a slight reduction in CWC can make chlorophyll content more concentrated in certain areas of the leaf. These changes in pigment distribution can lead to higher SPAD values, such as T75. These results are consistent with those of Sarker et al. (2020) and Sivakumar and Srividhya (2016).

4. Effect of Irrigation regimes on Crop yield

The statistical analysis of the tomato yield data demonstrated a highly significant variation due to difference in irrigation regimes ($p < 0.05$). The tomato yield values for both seasons can be found in Table 4. The highest average tomato yield was 76.83 tons per hectare in T100, followed by T75 with an average yield of 56.44 tons per hectare. However, the lowest average yield of 33.55 tons per hectare was found with T50. T75 resulted in a yield decrease of 23.44% and 29.66% in the two investigated seasons, respectively. Similarly, T50 led to a yield decrease of 56.30% and 56.38% in both seasons, respectively, compared to T100. These results are consistent with those of Etissa et al. (2016), Djurović et al. (2016), and El-Labad et al. (2019), who observed that increased watering application positively influenced vegetable growth, improved flowering, and ultimately increased tomato yield.

5. Water productivity and water saving

Water productivity exhibited statistical significance among different irrigation regimes ($p < 0.05$), except for T75 and T100 during the first season, as indicated in Table 4. The highest and lowest values of WP were observed in tomatoes grown under T100 and T50, with average values of 27.37 kg/m^3 and 21.58 kg/m^3, respectively. In terms of water saving, T50 and T75 saved approximately 44.57% and 22.29% of the IWA, with average amounts of 1257.14 m^3/hectare and 628.57 m^3/hectare in both seasons compared to T100. These results align with the Nangare et al. (2016) and Abd-Elhakim et al. (2021).

Table 4. The effect of irrigation regimes on water productivity and related components of tomato plants in both seasons.

Treatment	Yield (ton/hectare)	Yield Reduction (%)	Total Water (m^3/hectare)	Water Productivity (kg/m^3)	Water Saving, %
			First Season (2022)		
T100	77.09±4.40a	0.00	2615.25	29.48±1.68a	0.00
T75	59.02±6.47b	23.44	2026.53	29.12±3.19a	22.51
T50	33.69±4.55c	56.30	1437.81	23.43±3.17b	45.02
			Second Season (2023)		
T100	76.56±2.88a	0.00	3030.39	25.26±0.95a	0.00
T75	53.85±2.48b	29.66	2361.98	22.80±1.05b	22.06
T50	33.40±3.46c	56.38	1693.56	19.72±2.04c	44.11

Means having the same alphabetical letter (s) are not significantly differ at 0.05 level according to Duncan's multiple range test.

6. Correlation Analysis for Tomato Yield, Fresh Biomass (FB), Dry Biomass (DB), Canopy Water Content (CWC), and SPAD Values.

The correlation analysis (R2) conducted on tomato stress indicators, including FB, DB, CWC, and SPAD, revealed a consistent trend across the first and second seasons. Additionally, the combined data from both seasons also displayed the same trend. In the first season, all parameters exhibited a significantly strong correlation with tomato yield (R2 = 0.90, 0.90, 0.78, and 0.63, respectively), as shown in Figure 6. Similarly, during the second season, the correlations remain high and significantly associated with tomato yield (R2 = 0.96, 0.94, 0.88, and 0.76), as shown in Figure 7. Combining data from both seasons, the correlations remain high and significant (R2 = 0.93, 0.92, 0.82, and 0.66), as shown in Figure 8. These relationships might be helpful in predicting and estimating tomato yield.

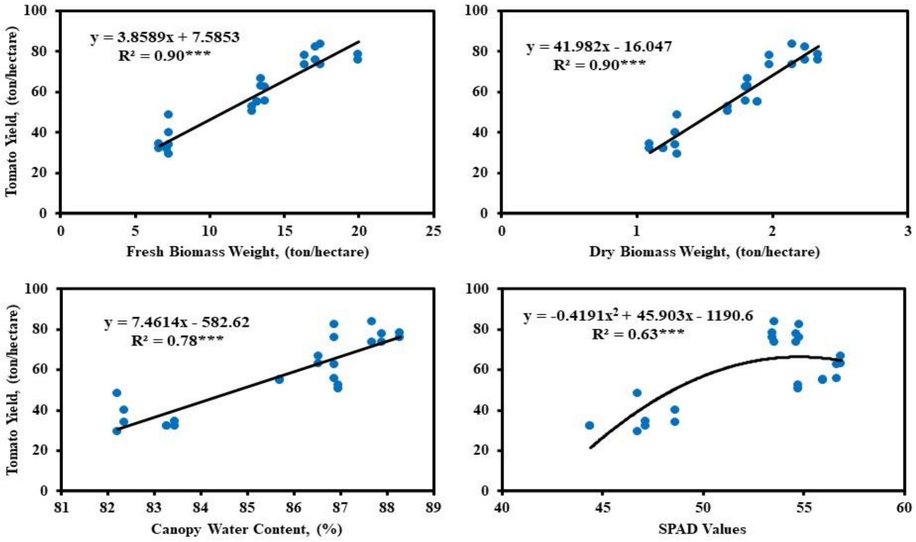

Fig. 6. Relationship between Tomato Yield (ton/ha) and FB (ton/ha), DB (ton/ha), CWC (%), and SPAD values during First Season.

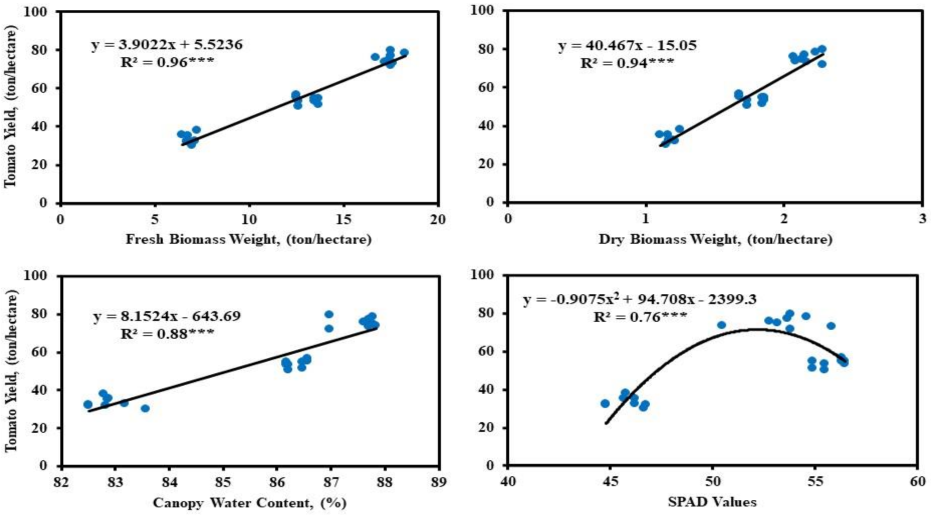

Fig. 7. Relationship between Tomato Yield (ton/ha) and FB (ton/ha), DB (ton/ha), CWC (%), and SPAD values during Second Season.

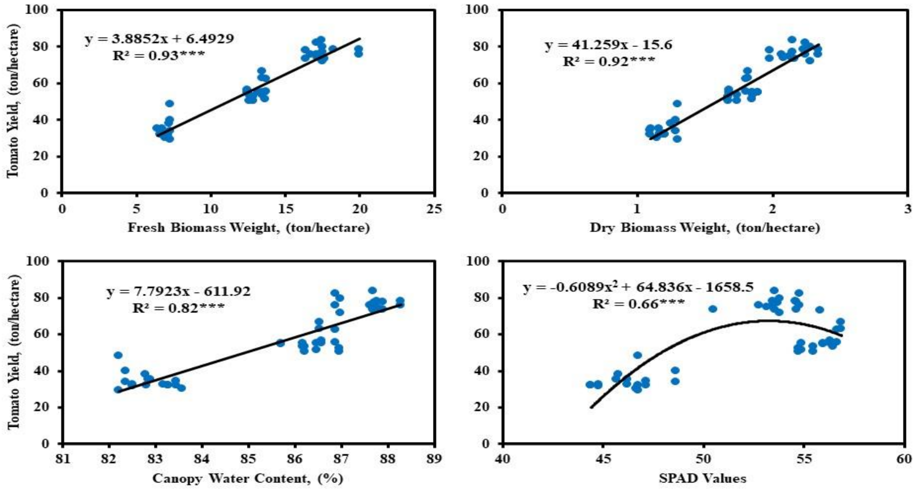

Fig. 8. Relationship between Tomato Yield (ton/ha) and FB (ton/ha), DB (ton/ha), CWC (%), and SPAD values during combined data from Both Seasons

CONCLUSION

The current research emphasizes the impact of different irrigation regimes on the yield of tomatoes, water productivity, and indicators of crop stress. The findings demonstrated that the highest values of fresh biomass weight, dry biomass weight, canopy water content, soil moisture content, tomato yield, and water productivity (WP) were achieved when irrigation was set at T100, followed by T75, while the lowest values were observed at T50. Regarding relative chlorophyll content, the highest values were recorded under T75, followed by T100 and T50 for both seasons. The highest WP values recorded with T100 (27.37 kg/m3), followed by T75 (25.96 kg/m3), and the lowest WP value at T50 (21.58 kg/m3) on average. In both seasons, implementing T75 and T50 resulted in a 22.29% and 44.57 reduction in the irrigation water applied (IWA) while decreasing the total yield by 26.55% and 56.34%, respectively, compared to T100. In conclusion, this study highlights that employing a moderate deficit irrigation strategy at T75 is a viable technique for tomato production, as it achieves a balance between water savings and acceptable yields.

REFERENCES

Abd-Elhakim, A., M. Elmeadawy, I. El-Sybaee, and M. Egela. (2021). Effect use of pulsed deficit drip irrigation for tomato crop in greenhouse powered by solar energy. Misr Journal of Agricultural Engineering, 38(1), 1-14.

Abdulhadi, J. S. and H. H. Alwan. (2021). Evaluation of the scheduling of an existing drip irrigation network: Fadak Farm, Karbala, Iraq. In IOP Conference Series: Materials Science and Engineering (Vol. 1067, No. 1, p. 012024). IOP Publishing.

Afzal, A., S. W. Duiker, J. E. Watson, and D. Luthe. (2017). Leaf thickness and electrical capacitance as measures of plant water status. Transactions of the ASABE, 60(4), 1063-1074.

Al-Ghobari, H. M. and A. Z. Dewidar. (2018). Integrating deficit irrigation into surface and subsurface drip irrigation as a strategy to save water in arid regions. Agricultural Water Management, 209, 55-61.

Ali, M. H. and M. S. U. Talukder. (2008). Increasing water productivity in crop production—A synthesis. Agricultural water management, 95(11), 1201-1213.

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9), D05109.

Attia, M. M., A. Swelam, A. A. Sallam, and A. M. Osman. (2019). Effect of Irrigation Regimes, Nitrogen, and Mulching Treatments on Water Productivity of Tomato under Drip Irrigation System. Misr Journal of Agricultural Engineering, 36(3), 861-878.

Bai, H. and L. C. Purcell. (2018). Aerial canopy temperature differences between fast-and slow-wilting soya bean genotypes. Journal of Agronomy and Crop Science, 204(3), 243-251.

Çetin, Ö. and D. Uygan. (2008). The effect of drip line spacing, irrigation regimes and planting geometries of tomato on yield, irrigation water use efficiency and net return. Agricultural Water Management, 95(8), 949-958.

Ding, Y. and J. Zhang. (2020). Estimation of SPAD value in tomato leaves by multispectral images. In Journal of Physics: Conference Series (Vol. 1634, No. 1, p. 012128). IOP Publishing.

Djurović, N., M. Ćosić, R. Stričević, S. Savić, and M. Domazet. (2016). Effect of irrigation regime and application of kaolin on yield, quality and water use efficiency of tomato. Scientia Horticulturae, 201, 271-278.

Doorenbos, J. and W. O. Pruitt. (1977). Crop water requirements. FAO irrigation and drainage paper 24. Land and Water Development Division, FAO, Rome, 144(1).

El-Labad, S. A., M. I. Mahmoud, S. A. AboEl-Kasem, and A. I. ElKasas. (2019). Effect of irrigation levels on growth and yield of tomato under El-Arish region conditions. Sinai Journal of Applied Sciences, 8(1), 9-18.

El Marazky, M. S. (2018). EFFECTS OF SCHEDULING TECHNIQUES OF WATER APPLICATION FOR DRIP IRRIGATION SYSTEM ON TOMATO YIELD IN ARID REGIO. Egyptian Journal of Agricultural Research, 96(1), 237-251.

Ella, V. B., J. Keller, M. R. Reyes, and R. Yoder. (2013). A low-cost pressure regulator for improving the water distribution uniformity of a microtube-type drip irrigation system. Applied Engineering in Agriculture, 29(3), 343-349.

Etissa, E., N. Dechassa, and Y. Alemayehu. (2016). Estimation of yield response (ky) and validation of cropWat for tomato under different irrigation regimes. Irrigation & Drainage Systems Engineering, 5(2), 1-6.

Evett, S. R., B. B. Ruthardt, S. T. Kottkamp, T. A. Howell, A. D. Schneider, and J. A. Tolk (2002). Accuracy and precision of soil water measurements by neutron, capacitance, and TDR methods. In Proceedings of the 17th Water Conservation Soil Society Symposium, Thailand.

FAOSTAT, C. (2022). Livestock Products Available online: https://www.fao.org/faostat/en/#data.QCL/visualize (accessed on 29 July 2022).

Filek, M., M. Łabanowska, J. Kościelniak, J. Biesaga-Kościelniak, M. Kurdziel, I. Szarejko, and H. Hartikainen. (2015). Characterization of barley leaf tolerance to drought stress by chlorophyll fluorescence and electron paramagnetic resonance studies. Journal of Agronomy and Crop Science, 201(3), 228-240.

Gabr, M. E. S. (2022). Management of irrigation requirements using FAO-CROPWAT 8.0 model: A case study of Egypt. Modeling Earth Systems and Environment, 8(3), 3127-3142.

Halimi, A. H. and A. H. Tefera (2019). Application of CROPWAT model for estimation of irrigation scheduling of Tomato in changing climate of Eastern Europe: the case study of Godollo, Hungary. Int J Agric Environ Sci, 6, 1-11.

Ismail, S. M. (2010). Influence of deficit irrigation on water use efficiency and bird pepper production (Capsicum annuum L.). Meteor. Environ. Arid Land Agric. Sci, 21(2943), 21-2.

Khan, M. J., A. Malik, M. Rahman, M. Afzaal, and S. Mulk. (2019). Assessment of crop water requirement for various crops in Peshawar, Pakistan using CROPWAT model. Irrig. Drain. Syst, 10(9).

Kizza, T., B. Fungo, R. Kabanyoro, and R. Nagayi. (2016). Effect of drip irrigation regimes on the growth and yield of tomatoes in Central Uganda. J. Sci. Res. Adv, 3(2016), 306-312.

Koech, R. and P. Langat. (2018). Improving irrigation water use efficiency: A review of advances, challenges and opportunities in the Australian context. Water, 10(12), 1771.

Machado, R. M. and M. D. R. G. Oliveira, (2005). Tomato root distribution, yield and fruit quality under different subsurface drip irrigation regimes and depths. Irrigation Science, 24(1), 15-24.

Mehdizadeh, M., E. I. Darbandi, H. Naseri-Rad, and A. Tobeh. (2013). Growth and yield of tomato (Lycopersicon esculentum Mill.) as influenced by different organic fertilizers.

Morillo, J. G., M. Martín, E. Camacho, J. R. Díaz, and P. Montesinos. (2015). Toward precision irrigation for intensive strawberry cultivation. Agricultural Water Management, 151, 43-51.

Nangare, D. D., Y. Singh, P. S. Kumar, and P. S. Minhas. (2016). Growth, fruit yield and quality of tomato (Lycopersicon esculentum Mill.) as affected by deficit irrigation regulated on phenological basis. Agricultural Water Management, 171, 73-79.

Noreldin, T., S. Ouda, S. M. M. Abdou, and Y. KMR. (2014). USING BISM MODEL TO CALCULATE WATER REQUIREMENTS FOR SOME VEGETABLE CROPS IN EGYPT. Fayoum Journal of Agricultural Research and Development, 28(2), 111-120.

Paltineanu, I. C. and J. L. Starr. (1997). Real-time soil water dynamics using multisensor capacitance probes: Laboratory calibration. Soil Science Society of America Journal, 61(6), 1576-1585.

Philipova, N., O. Nicheva, V. Kazandjiev, and M. Chilikova-Lubomirova. (2012). A computer program for drip irrigation system design for small plots. Journal of Theoretical and Applied Mechanics, 42(4), 3-18.

Power, N. A. S. A. (2022). Data Access Viewer Available online: https://power. larc. nasa. gov/data-access-viewer. Last accessed, 11(10).

Ragab, M. E., O. M. Sawan, F. H. ZF, A. M. El-Bassiony, and S. M. El-Sawy. (2018). Increasing the productivity of tomato plants grown in sandy soil under deficit irrigation water conditions. Research & Reviews: Journal of Agriculture and Allied Sciences, 7(2), 76-87.

Salman, M., M. García-Vila, E. Fereres, D. Raes, and P. Steduto. (2021). The AquaCrop model–Enhancing crop water productivity: Ten years of development, dissemination and implementation 2009–2019 (Vol. 47). Food & Agriculture Org..

Sarker, M., S. Choudhury, N. Islam, T. Zeb, B. Zeb, and Q. Mahmood. (2020). The effects of climatic change mediated water stress on growth and yield of tomato. Cent. Asian J. Environ. Sci. Technol. Innov, 1(2), 85-92.

Savva, A. P. and K. Frenken. (2002). Crop water requirements and irrigation scheduling (p. 132). Harare: FAO Sub-Regional Office for East and Southern Africa.

Semananda, N. P., J. D. Ward, and B. R. Myers. (2016). Evaluating the efficiency of wicking bed irrigation systems for small-scale urban agriculture. Horticulturae, 2(4), 13.

Shalaby, T. A. and A. El-Banna. (2013). Molecular and horticultural characteristics of in vitro induced tomato mutants. Journal of Agricultural Science, 5(10), 155.

Sivakumar, R. and S. Srividhya. (2016). Impact of drought on flowering, yield and quality parameters in diverse genotypes of tomato (Solanum lycopersicum L.). Adv. Hortic. Sci, 30, 3-11.

Soussa, H. K. (2010). Effects of drip irrigation water amount on crop yield, productivity and efficiency of water use in desert regions in Egypt. Nile Basin Water Science& Engineering Journal, 3(2), 96-109.

Tembe, K. O., G. N. Chemining'wa, J. Ambuko, and W. Owino. (2017). Effect of water stress on yield and physiological traits among selected African tomato (Solanum lycopersicum) land races.

Yıldırım, M. and E. Bahar. (2017). Water and radiation use-efficiencies of tomato (Lycopersicum esculentum L.) at three different planting densities in open field. Mediterranean Agricultural Sciences, 30(1), 39-45.

Zhang, H., Y. Xiong, G. Huang, X. Xu, and Q. Huang. (2017). Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. Agricultural Water Management, 179, 205-214.

Zinkernagel, J., J. F. Maestre-Valero, S. Y. Seresti, and D. S. Intrigliolo. (2020). New technologies and practical approaches to improve irrigation management of open field vegetable crops. Agricultural Water Management, 242, 106404.

Zotarelli, L., J. M. Scholberg, M. D. Dukes, R. Munoz-Carpena, and J. Icerman. (2009). Tomato yield, biomass accumulation, root distribution and irrigation water use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. Agricultural water management, 96(1), 23-34.

تأثير مستويات الري على الإنتاج الكلي لمحصول الطماطم وإنتاجية المياه تحت نظام الري بالتنقيط

محمد صلاح أحمد عبدالباقى[1] ، محمد ماهر إبراهيم [1]، صلاح السيد محمد السيد[2] و نادية جمال عبدالفتاح[1]

[1] قسم الهندسة الزراعية ، كلية الزراعة ، جامعة المنصورة
[2] معهد الدراسات و البحوث البيئية ، جامعة مدينة السادات

الملخص

لا تزال ندرة المياه تشكل تحديا كبيرا للزراعة العالمية. وقد ظهر العجز في الري كإستراتيجية فعالة لتحسين إنتاجية المياه دون المساس بإنتاجية المحاصيل. هدفت هذه الدراسة إلى تقييم تأثيرالإجهاد المائى على محصول الطماطم وإنتاجية المياه. حيث أجريت تجربتان حقليتان على مدار موسمين متتاليين (2022م و2023م) بإستخدام نظام الرى بالتنقيط. ثلاث مستويات من الإجهاد المائى: 100 ٪ (T100) ، و 75 ٪ (T75) و 50٪ (T50) من الإحتياجات المائية للمحصول. تم تقييم مؤشرات إجهاد النباتات و التى تتضمن: قياس الوزن الطازج و الجاف للنباتات و قياس محتوها المائى ، وقياس محتوى الكلوروفيل النسبى ،و رطوبة التربة. و أظهرت النتائج أن أعلى قيم للوزن الطازج و الجاف للنباتات و محتوها المائى و رطوبة التربة و إنتاجية المحصول تم تحقيقها بالمعاملة T100 يليها المعاملة T75 ، و لوحظ أدنى قيم تم تحقيقها عند المعاملة T50 و فيما يتعلق بمحتوى الكلوروفيل النسبى ، أوضحت النتائج أن أعلى قيم عند المعاملة T75، تليها المعاملة T100 و المعاملة T50 لكلا الموسمين. أوضحت النتائج أيضاً أن أعلى قيم إنتاجية المياه عند المعاملة T100 بمتوسط 27.37 كجم/م^{3} تليها المعاملة T75 بمتوسط 25.96 كجم/م^{3} و أدنى قيم لإنتاجية المياه عند المعاملة T50 بمتوسط 21.58 كجم/م^{3}. أدت المعاملة T75 و المعاملة T50 إلى توفير22.29٪ و 44.57% من إجمالى مياه الرى المستخدمة بالمقارنة مع المعاملة T100 على التوالى خلال الموسمين. في الختام ، تسلط هذه الدراسة الضوء على أن تطبيق الري المعتدل عند المعاملة T75 يعتبر تقنية مجدية لإنتاج الطماطم.

الكلمات المفتاحية: الرى الناقص؛ إنتاجية محصول الطماطم؛ إنتاجية المياه؛ مؤشرات إجهاد المحاصيل؛ الرى بالتنقيط.