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Effect of Deficit Irrigation during Growth Stages on Water Use Efficiency of Tomato under New El-Salhia Conditions

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ABSTRACT

There is no doubt the application of deficit irrigation during different growth stages is one of the most important modern methods for the optimal management to saving irrigation water while, application deficit irrigation on all growth stages for plant may have a negative impact on the quality and productivity of fruits, so this study aimed to determine the best of tomato growth stages that can be apply deficit irrigation on it without affecting the plant. Field experiments were carried out at a private farm in New Salhia area, El- Sharqia governorate, Egypt, during successful summer seasons of 2021 – 2022 to deliberated the effect of deficit irrigation water (DI) during different growth stages compared to full irrigation water (FI) under surface drip irrigation system types (T-Tape and GR) on quality parameters, marketable yield (MY), Actual evapotranspiration (ETa), water use efficacy (WUE), irrigation water use efficiency (IWUE) and yield response factor (Ky) for tomato fruit (*Solanum lycopersicum, L.*) by used the split plot design with three replicates for the experiment. The results concluded that; 1) The studied quality parameters of tomato fruits gave the highest values except pH at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR for both seasons. 2) The marketable yield of tomato fruits gave the highest values at apply treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR for both seasons. 3)The seasonal ETa gave the lowest values: 328.76 and 320.57 mm for both seasons, respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR. 4) The highest values of WUE and IWUE for tomato fruits were 16.82 and 11.69 kg/m^3; 17.78 and 11.94 kg/m^3 for both seasons, respectively, at apply treatment DI (I=100, D=75, M=75, L=50%) and dripper type GR. 5) The lowest values of Ky for tomato fruits were 0.19 and 0.21 for both seasons respectively, at apply treatment DI (I=100, D=75, M=100, L=100%) and dripper type GR. 6) The dripper type GR caused a noticeable increase in the values of MY for tomato fruit by about 17% and decrease in the values of ETa about 6% compared that to apply dripper type T-Tape at apply treatment FI (I=100, D=100, M=100, L=100%). Finally, this study concluded that the cultivation tomato under DI (I=100, D=75, M=75, L=50%) and dripper type GR treatment can probably save about 40% of amount irrigation water additive versus lost approximately 13 % of MY for tomato fruits compared to apply treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR, hence excluded dripper type T-Tape due it gave the lowest values for all treatments compared with dripper type GR.

Keywords: Deficit irrigation; surface drip irrigation T-Tape; Actual evapotranspiration; Water use efficiency; Irrigation water use efficiency; Yield response factor.

1. Introduction

Competition for fresh water suitable for agriculture is increasing all over the world in light of the steady increase in population and industrial rehabilitation. More than 40% of food production in the world depends on supplementary irrigation due to the widening gap between water availability and demand (Ahmad, 2016). In case of not having a lot possibility of supplementary fresh water resources to be advanced or finding alternative water resources the only option is to Controlling available fresh water sources suitable for irrigation and optimal management to preserve them (Haliński, Stepnowski, 2016). The agricultural sector is the main consumer of fresh irrigation water so any effort to improve WUEf in this sector gets a lot of attention so, raising WUEf through improved of modern irrigation

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techniques and Increasing the capacity of soil output complementary to making the better employ of irrigation water and saving water for other uses (Aldulaimy *et al.,* 2019). Egypt is one of the major tomato producers in the world, that the crop is occupying about 4% of the total annual cultivated space, and producing about 7.8 million ton per year, so tomato is one of the most widely cultivated vegetables in the world due to the special nutritional value of their fruits (MALR, 2017).Tomato fruit is a substantial origin of the antioxidants lycopene, vitamin (β-carotene), vitamin C and minerals important for human health which has a defensive role versus cancer and cardiovascular diseases (Raiola *et al.,* 2014). Many studies have shown must before defining a more careful deficit irrigation water strategy, large information of the relationship between marketable yield, quality parameters for tomato fruit and deficit irrigation water at various growth stages is wished for. Equations regarding deficit irrigation water to marketable yield and quality parameters for tomato fruit will assist to orientation tomato irrigation for the production of high quality tomatoes. Many researches have shown a relationship between tomato yield and ETa (Chen *et al.,* 2013; Kuscu *et al.,* 2014). The deficit irrigation affected throughout various growth intervals on saving irrigation water additive for tomato fruit under drip and gated pipe irrigation systems, the fruiting and vegetative growth stages were the maximum tolerant to deficit irrigation; while, the reproductive stage was the most sensitive for DI (Al-Harbi, *et al.,* 2015). Applying deficit irrigation of 80% ETc for all tomato growth intervals could decrease the amount of the irrigation water 20% versus loss of yield about 17%, and a slight raise in water output of about 2%. While, the same deficit level saved about 16% of the applied water when it applied only at initial and ripening growth stages crop yield reduction by 5%. Deficit irrigation strategies can improve water productivity, and fruits quality of tomato crop (Hendy *et al.,* 2019). The flowering, fruit development, and fruit ripening stages for tomato yield were sensitive to water deficit. However, the effects of deficit irrigation on both marketable yield and water consumption for tomato fruit are not understandable due to the intricacy of the rapport, despite a lot of former studies (Chen *et al.,* 2014). The deficit irrigation water during different growth stages effect on fruit goodness as it turns out that the formation of quality parameters has varied according to levels of deficit irrigation water through various the growth intervals (Silveira *et al.,* 2020). The employ of deficit irrigation through various growth stages in tomato agriculture is useful because it raises water use efficiency and ameliorates tomato goodness (Wang *et al.,* 2015). The fruit quality was more critical to deficit water at the flowering and fruit development intervals than at fruit maturation, which expresses that equilibrium between progress fruit goodness and passable yield can be carried out under a suitable deficit water levels at the flowering and fruit development intervals. The deficit irrigation water significantly reduction ET and progress tomato fruit quality. Fruit quality parameters such as titratable acidity, vitamin C contents and total soluble solids for tomato fruit increase with increasing deficit irrigation water while the marketable yield for tomato fruit decreases with increasing DI compared with full irrigation (Jiang *et al.,* 2019). The fruit yield gave the maximum value at apply full irrigation treatment (without water deficit) while, deficit water purposed significant decrease in fruit yield. The fruit yield is greatly reduced due to severe water deficit also; severe water deficit can lead to a gradual decrease in CO_2 deficiency rates due to the closure of stomata and a reduction in the surface area of the leaves, and thus reduce the content and activity of the photosynthetic pigment (Ghazouani *et al.,* 2019). Deficit irrigation technique irrigated effective roots zone with lower water than wanted for evapotranspiration (Owusu-Sekyere *et al.,* 2012). The main target of deficit irrigation water raise crop water use efficiency (WUE) by decrease amount of irrigation water added. It is potential to conserve water use efficiency in treatment tomato to realize enough fruit yield. Total crop water needs for tomato ranges from 400 to 800 mm from development/implant to gathering, consisting on irrigation water, soil, climate, crop type and crop management (Battilani *et al.,* 2012). There is a linear relationship between prorated decline tomato yield (Y) and the deficit of seasonal evapotranspiration (ET) as many researches shown there is a positive linear and nonlinear relationships between marketable tomato yield and seasonal ET but there is very little research formulating the relationship between fruit quality and water deficit. (Kuscu *et al.,* 2014). Some scientists have developed a linear model relative decrease of fruit tomato yield (1−Ya/Ym) versus relative decrease in seasonal ETa (1−ETa/ETm) which was as well utilized to correlate tomato yield production with seasonal ETa (Stewart *et al.,* 1977); (Chen *et al.,* 2014) and (Kuscu *et al.,* 2014). The amount irrigation water of T-Tape drip irrigation system was very considerably so that the cultivation line and working line were ordinarily waterish thus become nature soil very bad Which reduces the ability of the roots to absorb water and nutrients and exploitation it. Because of T-Tape drip irrigation system irrigates only cultivation line thus; deficit irrigation water in

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the non-irrigated line on the long-dated may affect the regularity of the distribution of plant roots in the soil evenly to some extent disadvantageous to movement nutrients in soil and absorption in the non-irrigation zone (Saddique and Shahbaz, 2019). T-Tape drip type gave the lowest value for all treatments while the GR drip type at depth 15cm in the clay soil gave the highest value for all treatments except depth 45 cm with subsurface drip irrigation system gave very poor results for all treatments, so, it is advised to apply deficit irrigation at 70 and 85% to save about 30 and 15% amount of irrigation water added respectively, under sub-surface drip irrigation system without any remarkable impact on distribution efficiency, water productivity, moisture content and drip performance. Also, T-Tape drip line at 45 cm depth gave the lowest percentage of water application efficiency (EA) was 72 % at apply deficit irrigation 100% of applied irrigation water. While GR drip line at 15 cm depth gave the highest percentages of EA were 88 and 91 % at applying deficit irrigation 70 and 85% respectively, (Abdrabou *et al.,* 2022). T-Tape irrigation system treatment gave the minimum relative membrane permeability (RMP) and water uptake capacity (WUC) while, GR irrigation system treatment created the maximum total yield (TY), relative water content (RWC), WUEf this is consequent to the water application efficiency of the GR drip irrigation system, which supplies water equipping for growth of plant and to perform all the physiological and pivotal operations. Also, gave the minimum value for water saturation deficit (Bader *et al.,* 2020).

This study aimed to investigate the effect of deficit irrigation water during different growth stages under surface drip irrigation system types (T-Tape and GR) on quality growth parameters, marketable yield, actual evapotranspiration, water use efficiency, irrigation water use efficiency and yield response factor for tomato fruits.

2. Materials and Methods

2.1. Experimental

Field experiments were performed in El- Salhia El-Gedida area, El- Sharqia Governorate, Egypt, at (30° 23` 07`` N: 31° 15` 29`` E.; 26 m a.s.l.) during two successful summer seasons 2021 and 2022 by used the split plot design with three replicates for the experiment, the experimental was split into equal plots with an area 25 m^2 per plot with space left 2 m separation area between each plot and the other to eschew horizontal infiltration and variables overlapping. The obtained data has been subjected to statistical analysis using Co-state software program conforming to Snedecor and Cochran (1989). Fig (1) explained the tomato (*Solanum lycopersicum,* L.) was irrigated with three deficit irrigation water (DI) during different growth stages (Initial$_{100\%}$ - development$_{100,75,50\%}$ - mid-season$_{100,75,50\%}$ - Late$_{100,75,50\%}$) by using probability tree compared to full irrigation water (FI) for all growth stages (Initial$_{100\%}$ - development$_{100\%}$ - mid-season$_{100\%}$ - Late$_{100\%}$) under surface drip irrigation system types (T-Tape and GR). Chemical and organic fertilizers doses have been added as recommended The Ministry of Agriculture and land reclamation to perfect soil management practices.

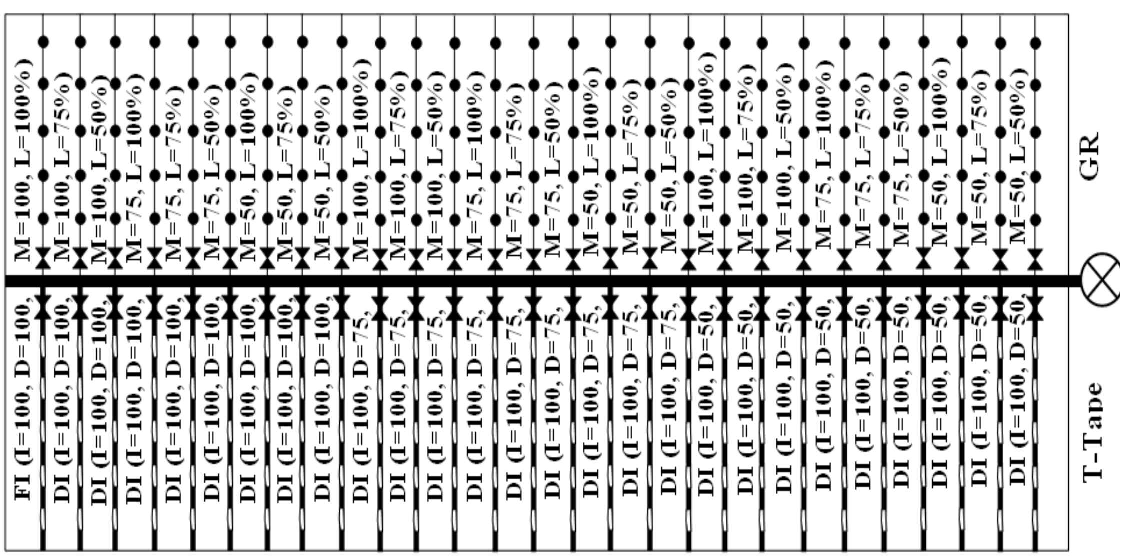

Fig. 1: Field experiment layout.

2.2. Soil characteristics

Soil samples were collected to determine the physical and chemical soil characteristics. The methodological procedures followed the methods described by Page *et al.,* (1982) and Klute (1986) as shown in Tables 1 & 2.

Table 1: Physical characteristics of the experimental soil.

Soil depth (cm)	Particle size distribution %			Textural class	OM %	ρ_b g/cm^3	Ks cm/h	FC %	PWP %	AW %
	Sand	Silt	Clay							
0-20	91.89	5.17	2.94	S	0.38	1.56	16.14	11.91	4.79	7.12
20-40	92.36	5.03	2.61	S	0.34	1.58	16.62	11.35	4.67	6.68
40-60	92.73	4.91	2.36	S	0.19	1.61	17.07	10.83	4.42	6.41

Table 2: Chemical characteristics of the experimental soil.

Soil depth (cm)	EC (dS/m)	pH	$CaCO_3$ %	CEC Cmole/kg	Soluble ions (%) in saturated soil paste extract							
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}
0-20	2.14	7.41	3.97	3.72	9.49	1.31	6.24	4.36	8.29	2.68	-	10.43
20-40	2.26	7.28	3.52	3.34	9.97	1.43	6.49	4.71	8.96	2.89	-	10.75
40-60	2.31	7.23	3.39	3.17	10.31	1.59	6.36	4.84	9.13	3.06	-	10.91

2.3. Irrigation water characteristics

Chemical analyses of the irrigation water were performed according to the methods described by Ayers and Westcot (1994) and are presented in Table 3.

Table 3: Chemical analysis for irrigation water**.**

Sample	pH	EC dS m^{-1}	SAR	Soluble cations, meq/l				Soluble anions, meq/l			
				Na^+	K^+	Ca^{++}	Mg^{++}	CL^-	HCO_3^-	$CO_3^=$	$SO_4^=$
Mean	7.58	1.35	1.08	2.39	1.27	9.53	0.31	5.45	1.87	-	6.18

2.4. Reference evapotranspiration ETo

The reference evapotranspiration (ETo) shown in Table 4 was calculated by using the Cropwate 8 software based on Penman-Monteith equation FAO 56 method Allen *et al.,* (1998).

Table 4: Calculated reference evapotranspiration, mm through tomato growth period.

Month	April	May	June	July
ETo mm/day	4.97	5.89	6.65	6.32

2.5. Crop evapotranspiration ETc

The crop evapotranspiration ETc shown in Table 5 was calculated by using the equation:

$$ET_C = KC_{FAO} \cdot ETO \quad \text{(mm/period)}$$ Allen *et al.,* (1998)

Where:
Kc_{FAO}: Crop coefficient from FAO No.(56).
ETo: Reference crop evapotranspiration, mm/period.

Table 5: Calculated crop evapotranspiration (ETc), mm through tomato growth period.

Stages	**Initial**	**Develop.**	**Mid**	**Late**	**Seasonal**
Planting date	**1/4 to 30/4**	**1/5to 4/6**	**5/6 to 9/7**	**10/7 to 29/7**	**1/4 to 29/7**
Period length (day)	30	35	35	20	120
Kc_{FAO} (-)	0.60	0.87	1.15	0.80	--------
ETo (mm)	149.10	209.19	229.78	126.40	714.47
$ETc_{100\%}$ (mm)	89.46	182.00	264.25	101.12	636.82
Eff. Rainfall (mm)	0	0	0	0	0

2.6. Defect irrigation water DI during growth stages

The defect irrigation water during different growth stages based on amounts of applied irrigation water (IR) for tomato fruits shown in tables (6&7) was calculated by using the equation:

$$IR_{100,\,75,\,50\%} = (ETc - pe)Kr / Ea) + LR \text{ (mm/period)}$$ Keller and Karmeli (1974)

Where:

Kr: Correction factor for limited wetting at tomato percent round coverage by canopy 80%, Kr = 0.90. **Smith (1992).**

Ea: Irrigation efficiency for surface drip irrigation types

T-Tape and GR= 85%, **Allen *et al.*, (1998).**

Pe: Effective rainfall, 0 mm/season.

LR: Leaching requirements, under salinity levels of irrigation water (0.14 x ETc), mm.

Table 6: Calculated applied irrigation water (IR), mm through tomato growth period.

Deficit irrigation, (DI)				**Applied irrigation water, (mm)**				
				Growth Stages				
I	**D**	**M**	**L**	**Initial**	**Development**	**Mid**	**Late**	**Seasonal**
100	**100**	**100**	**100**	106.98	217.64	306.86	120.93	752.41
100	**100**	**100**	**75**	106.98	217.64	306.86	90.70	722.18
100	**100**	**100**	**50**	106.98	217.64	306.86	60.47	691.95
100	**100**	**75**	**100**	106.98	217.64	230.15	120.93	675.70
100	**100**	**75**	**75**	106.98	217.64	230.15	90.70	645.46
100	**100**	**75**	**50**	106.98	217.64	230.15	60.47	615.23
100	**100**	**50**	**100**	106.98	217.64	153.43	120.93	598.98
100	**100**	**50**	**75**	106.98	217.64	153.43	90.70	568.75
100	**100**	**50**	**50**	106.98	217.64	153.43	60.47	538.52
100	**75**	**100**	**100**	106.98	163.23	306.86	120.93	698.00
100	**75**	**100**	**75**	106.98	163.23	306.86	90.70	667.77
100	**75**	**100**	**50**	106.98	163.23	306.86	60.47	637.54
100	**75**	**75**	**100**	106.98	163.23	230.15	120.93	621.29
100	**75**	**75**	**75**	106.98	163.23	230.15	90.70	591.05
100	**75**	**75**	**50**	106.98	163.23	230.15	60.47	560.82
100	**75**	**50**	**100**	106.98	163.23	153.43	120.93	544.57
100	**75**	**50**	**75**	106.98	163.23	153.43	90.70	514.34
100	**75**	**50**	**50**	106.98	163.23	153.43	60.47	484.11
100	**50**	**100**	**100**	106.98	108.82	306.86	120.93	643.59
100	**50**	**100**	**75**	106.98	108.82	306.86	90.70	613.36
100	**50**	**100**	**50**	106.98	108.82	306.86	60.47	583.13
100	**50**	**75**	**100**	106.98	108.82	230.15	120.93	566.88
100	**50**	**75**	**75**	106.98	108.82	230.15	90.70	536.64
100	**50**	**75**	**50**	106.98	108.82	230.15	60.47	506.41
100	**50**	**50**	**100**	106.98	108.82	153.43	120.93	490.16
100	**50**	**50**	**75**	106.98	108.82	153.43	90.70	459.93
100	**50**	**50**	**50**	106.98	108.82	153.43	60.47	429.70

2.7. Actual evapotranspiration Eta

$$\mathbf{ETa = (M_2\,\% - M_1\,\%)\,/100.\,db\,.\,D\ \ (mm)}$$ Doorenbos and Pruitt (1984)

Where:
M_2 : moisture content after irrigation %.
M_1 : moisture content before irrigation %.
d_b : specific density of soil .
D : mean depth, mm

2.8. Water use efficiency

$$\mathbf{WUE} = \mathbf{MY / ETa}\ \ \mathbf{(kg/m^3)}$$ Howell (2001)

Where:
Y: Marketable yield of tomato fruit, (kg/h).

2.9. Irrigation water use efficiency

$$\mathbf{IWUE} = \mathbf{MY / IR}\ \ \mathbf{(kg/m^3)}$$ Michael (1978)

Where:
IR : Seasonal applied irrigation water, m^3, Table 6.

2.10. Yield response factor (Ky)

$$\left(1-\frac{MY}{Y_m}\right)=K_y\left(1-\frac{ETa}{ETm}\right)\quad (-)$$ **(Allen et al., 1998)**

Where:
ETa: Actual evapotranspiration, mm/season.
ETm: Crop evapotranspiration (without stress), mm/season**.**
Ym: Maximum yield at $IR_{100\,\%}$, t/ha.

3. Results and Discussion

3.1. Effect of DI on quality parameters for tomato fruit under T-Tape and GR

Data in Tables (7, 8, 9 and 10) Illustrated that the values of quality parameters for tomato fruit titratable acidity (TA) %, total sugar (TS) %, total soluble solid (TSS) %, vitamin C content (VC) mg/100 g FW and β-Carotene (βC) mg/100 g, increased with increasing deficit irrigation water (DI) during different growth stages for all treatments except, pH, decreased with increasing DI under surface drip irrigation system types (T-tape and GR). Moreover that, dripper type GR has a clear effect on all treatments compared to T-Tape dripper type. The results showed the same trend for both seasons 2021 and 2022. The highest values of tomato fruits TA, TS, TSS, VC and βC were (0.76 %, 4.56 %, 7.04 %, 37.78 mg/100 g FW and 12.91 mg/100 g) for the 1st season; (0.85 %, 4.75 %, 7.32 %, 39.52 mg/100 g FW and 13.39 mg/100 g) for the 2nd season respectively, except pH were (4.12 and 4.21) for both seasons respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR.

While, the lowest values of tomato fruits TA, TS, TSS, VC and βC were (0.40 %, 2.95 %, 4.56 %, 19.61 mg/100 g FW and 7.52 mg/100 g) for the 1st season; (0.42 %, 3.06 %, 4.73 %, 20.49 mg/100 g FW and 7.85 mg/100 g) for the 2nd season respectively, except pH were (3.95 and 4.12) for both seasons respectively, at apply treatment full irrigation FI (I=100, D=100, M=100, L=100%) and dripper type T-Tape. The values of all growth parameters for tomato fruit TA, TS, TSS, pH, VC and βC at treatment full irrigation (FI) and dripper type GR were listed increased significantly by about (22.50, 13.90, 15.13, 14.68, 26.93 and 16.09 %) for the 1st season; (21.43, 13.73, 15.22, 14.32, 27.23 and 15.41 %) for the 2nd season respectively, compared to that at treatment FI and dripper type T-Tape. These is due to the fruit quality was more sensitive to deficit water at the flowering and fruit development stages than at fruit maturation, which expresses that equilibrium between progress fruit quality and passable yield can be carried out under a suitable deficit water levels at the flowering and fruit development intervals. Also, the deficit irrigation water led to significantly reduction ET and progress tomato fruit quality. on the other hand, dripper type GR gave the amount of water is low and thus stresses the root zone, which leads to produced, ABA and transport it to leaves and adjust stomata aperture, reduce transpiration rate, when drought and wetness appeared by turns in different regions of root as that irrigation levels inducing water deficit had a conspicuous effect on plant water status. Moreover that, the water application efficiency for dripper type GR higher than dripper type T-Tape, which provides perfect water distribution uniformity for the growth of the plant and to carry out all the physiological and vital processes. These results are in agreement with that found by Chen *et al.,* (2013); Kuscu *et al.,* (2014); Wang *et al.,* (2015); Jiang *et al.,* (2019); Saddique and Shahbaz, (2019); Silveira *et al.,* (2020); Bader *et al.,* (2020) and Abdrabou *et al.,* (2022).

Table 7: Effect of deficit irrigation water through different growth stages on TA, TS and TSS for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2021.

DI				TA (%)		TS (%)		TSS (%)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	100	100	100	0.40	0.49	2.95	3.36	4.56	5.25
100	100	100	75	0.43	0.52	3.09	3.52	4.83	5.56
100	100	100	50	0.51	0.60	3.24	3.69	5.09	5.87
100	100	75	100	0.43	0.52	3.10	3.54	4.94	5.67
100	100	75	75	0.45	0.56	3.25	3.71	5.16	5.93
100	100	75	50	0.56	0.64	3.42	3.92	5.47	6.29
100	100	50	100	0.45	0.56	3.28	3.75	5.15	5.95
100	100	50	75	0.49	0.61	3.43	3.93	5.41	6.24
100	100	50	50	0.56	0.69	3.64	4.16	5.68	6.57
100	75	100	100	0.44	0.52	3.09	3.51	4.81	5.52
100	75	100	75	0.47	0.55	3.24	3.68	5.06	5.81
100	75	100	50	0.56	0.63	3.40	3.86	5.35	6.15
100	75	75	100	0.46	0.56	3.25	3.72	5.07	5.84
100	75	75	75	0.49	0.59	3.41	3.91	5.31	6.12
100	75	75	50	0.61	0.67	3.58	4.11	5.61	6.47
100	75	50	100	0.49	0.58	3.43	3.92	5.36	6.18
100	75	50	75	0.52	0.63	3.61	4.12	5.58	6.45
100	75	50	50	0.61	0.72	3.79	4.34	5.87	6.79
100	50	100	100	0.47	0.56	3.24	3.69	4.98	5.76
100	50	100	75	0.50	0.59	3.41	3.87	5.21	6.03
100	50	100	50	0.61	0.67	3.58	4.08	5.53	6.38
100	50	75	100	0.50	0.59	3.41	3.91	5.27	6.09
100	50	75	75	0.54	0.62	3.58	4.11	5.51	6.37
100	50	75	50	0.65	0.69	3.76	4.32	5.79	6.70
100	50	50	100	0.53	0.62	3.59	4.12	5.57	6.42
100	50	50	75	0.56	0.65	3.77	4.33	5.82	6.71
100	50	50	50	0.65	0.76	3.97	4.56	6.11	7.04
LSD 0.05		IS		0.02		0.05		0.03	
		DI		0.01		0.03		0.02	
		IS X DI		0.03		0.07		0.05	

Table 8: Effect of deficit irrigation water through different growth stages on pH, VC and βC for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2021.

DI				pH (-)		VC (mg/100 g FW)		βC (mg/100 g)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	100	100	100	3.95	4.53	19.61	24.89	7.52	8.73
100	100	100	75	3.89	4.47	20.59	25.91	7.89	9.16
100	100	100	50	3.82	4.39	24.37	29.65	8.97	10.41
100	100	75	100	3.87	4.42	21.53	26.90	8.12	9.27
100	100	75	75	3.78	4.34	22.75	28.16	8.54	9.75
100	100	75	50	3.71	4.28	26.49	31.84	9.68	11.04
100	100	50	100	3.78	4.34	23.06	28.49	8.51	9.86
100	100	50	75	3.73	4.28	24.50	29.91	8.96	10.41
100	100	50	50	3.66	4.23	28.32	33.76	10.11	11.73
100	75	100	100	3.87	4.45	21.47	26.61	8.03	9.16
100	75	100	75	3.79	4.36	22.63	27.79	8.47	9.64
100	75	100	50	3.74	4.30	26.45	31.63	9.59	10.92
100	75	75	100	3.78	4.34	23.21	28.38	8.45	9.79
100	75	75	75	3.71	4.26	24.43	29.65	8.87	10.27
100	75	75	50	3.65	4.22	28.37	33.56	10.03	11.65
100	75	50	100	3.70	4.25	24.69	29.93	8.98	10.35
100	75	50	75	3.66	4.21	26.25	31.47	9.47	10.89
100	75	50	50	3.61	4.17	30.43	35.61	10.65	12.31
100	50	100	100	3.78	4.34	23.11	28.05	8.40	9.61
100	50	100	75	3.71	4.26	24.84	29.63	8.84	10.12
100	50	100	50	3.67	4.22	28.27	33.59	10.02	11.46
100	50	75	100	3.69	4.23	25.11	30.03	8.83	10.20
100	50	75	75	3.64	4.18	26.75	31.58	9.30	10.73
100	50	75	50	3.60	4.15	30.43	35.65	10.51	12.15
100	50	50	100	3.63	4.17	27.53	32.10	9.41	10.83
100	50	50	75	3.59	4.14	28.98	33.62	9.89	11.39
100	50	50	50	3.57	4.12	32.35	37.78	11.17	12.91
LSD 0.05		IS		0.04		0.06		0.05	
		DI		0.02		0.04		0.03	
		IS X DI		0.05		0.08		0.07	

Table 9: Effect of deficit irrigation water through different growth stages on TA, TS and TSS for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2022.

DI				TA (%)		TS (%)		TSS (%)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	100	100	100	0.42	0.51	3.06	3.48	4.73	5.45
100	100	100	75	0.45	0.54	3.21	3.65	4.99	5.74
100	100	100	50	0.54	0.62	3.37	3.83	5.31	6.11
100	100	75	100	0.45	0.54	3.21	3.67	5.14	5.89
100	100	75	75	0.47	0.58	3.37	3.85	5.38	6.17
100	100	75	50	0.59	0.67	3.55	4.06	5.72	6.56
100	100	50	100	0.48	0.58	3.41	3.89	5.33	6.14
100	100	50	75	0.51	0.63	3.57	4.08	5.64	6.49
100	100	50	50	0.64	0.72	3.78	4.31	5.95	6.84
100	75	100	100	0.46	0.54	3.21	3.65	4.98	5.73
100	75	100	75	0.49	0.57	3.37	3.83	5.22	6.01
100	75	100	50	0.58	0.65	3.54	4.02	5.54	6.36
100	75	75	100	0.48	0.58	3.37	3.86	5.27	6.07
100	75	75	75	0.51	0.61	3.54	4.06	5.52	6.36
100	75	75	50	0.64	0.70	3.72	4.27	5.86	6.74
100	75	50	100	0.51	0.63	3.57	4.08	5.54	6.39
100	75	50	75	0.56	0.67	3.76	4.29	5.82	6.72
100	75	50	50	0.69	0.78	3.95	4.52	6.13	7.08
100	50	100	100	0.49	0.58	3.37	3.84	5.17	5.96
100	50	100	75	0.52	0.61	3.55	4.04	5.43	6.25
100	50	100	50	0.63	0.69	3.73	4.25	5.76	6.63
100	50	75	100	0.54	0.61	3.54	4.06	5.49	6.30
100	50	75	75	0.57	0.64	3.72	4.27	5.77	6.61
100	50	75	50	0.68	0.75	3.91	4.49	6.10	6.98
100	50	50	100	0.56	0.68	3.74	4.29	5.79	6.65
100	50	50	75	0.59	0.73	3.93	4.51	6.07	6.97
100	50	50	50	0.73	0.85	4.14	4.75	6.38	7.32
LSD 0.05		IS		0.04		0.07		0.05	
		DI		0.02		0.05		0.03	
		IS X DI		0.03		0.04		0.04	

Table 10: Effect of deficit irrigation water through different growth stages on pH, VC and βC for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2022.

DI				pH (-)		VC (mg/100 g FW)		βC (mg/100 g)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	100	100	100	4.12	4.71	20.49	26.07	7.85	9.06
100	100	100	75	4.04	4.63	21.57	27.23	8.23	9.51
100	100	100	50	3.96	4.54	25.43	31.19	9.36	10.80
100	100	75	100	3.99	4.56	22.54	28.27	8.43	9.69
100	100	75	75	3.91	4.47	23.79	29.51	8.86	10.18
100	100	75	50	3.84	4.41	27.67	33.43	10.04	11.53
100	100	50	100	3.89	4.45	24.16	29.75	8.89	10.24
100	100	50	75	3.81	4.37	25.64	31.19	9.37	10.79
100	100	50	50	3.74	4.32	29.79	35.28	10.56	12.17
100	75	100	100	4.00	4.59	22.62	27.81	8.34	9.58
100	75	100	75	3.93	4.51	23.81	29.03	8.79	10.07
100	75	100	50	3.88	4.45	27.85	33.29	9.96	11.43
100	75	75	100	3.91	4.47	24.27	29.54	8.81	10.15
100	75	75	75	3.84	4.39	25.54	30.86	9.25	10.67
100	75	75	50	3.76	4.34	29.69	35.01	10.47	12.09
100	75	50	100	3.81	4.37	25.96	31.12	9.37	10.73
100	75	50	75	3.75	4.31	27.61	32.85	9.89	11.31
100	75	50	50	3.69	4.26	32.02	37.18	11.14	12.76
100	50	100	100	3.92	4.47	24.25	29.43	8.72	10.04
100	50	100	75	3.84	4.39	26.07	31.15	9.17	10.56
100	50	100	50	3.78	4.34	29.63	35.51	10.40	11.98
100	50	75	100	3.79	4.35	26.44	31.26	9.25	10.63
100	50	75	75	3.74	4.29	28.16	32.91	9.74	11.19
100	50	75	50	3.71	4.26	32.05	37.38	11.02	12.67
100	50	50	100	3.72	4.29	28.81	33.64	9.75	11.25
100	50	50	75	3.68	4.24	30.34	35.19	10.25	11.83
100	50	50	50	3.65	4.21	33.86	39.52	11.59	13.39
LSD 0.05		IS		0.02		0.05		0.04	
		DI		0.03		0.04		0.03	
		IS X DI		0.05		0.07		0.06	

3.2. Effect of DI on marketable yield for tomato fruit under T-Tape and GR

Data in Tables (11 and 12) presented that the values of marketable yield (MY) t/ha for tomato fruits decreased with increasing DI during different growth stages under surface drip irrigation system types (T-tape and GR). In addition, dripper type GR has a clear effect on all treatments compared to T-Tape dripper type. The results confirmed the same trend for both seasons 2021 and 2022. The highest values of MY for tomato fruits were (65.78 and 67.53 t/ha) for both seasons respectively, at apply treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR. While, the lowest values were (23.81 and 24.42 t/ha) for both seasons respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type T-Tape. Meanwhile, the values of MY for tomato fruits at treatment FI and dripper type GR were increased significantly by about 17% for both seasons compared to that under treatment FI and dripper type T-Tape. These results may be attributed to the severe water deficit can lead to a gradual decrease in CO_2 deficiency rates due to the closure of stomata and a reduction in the surface area of the leaves, and thus reduce the content and activity of the photosynthetic pigment

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moreover that, most biochemical, morphological and physiological processes related to plant development are come to terms pending water deficit and can result in poor photosynthesis, respiration, and nutrient metabolism compared with full irrigation which supplies the effective roots zone with its full water needs, thus reducing soil dry conditions that negatively affect all the vital processes of the plant. besides that the development and mid-season growth stages of tomato fruit were sensitive to water stress compared to late season It's also, the water application efficiency for dripper type GR higher than dripper type T-Tape, which provides perfect water distribution uniformity for the growth of the plant and to carry out all the physiological and vital processes these results are in accordance with Chen *et al.,* (2013); Kuscu *et al.,* (2014); Chen *et al.,* (2014); Al-Harbi, *et al.,* (2015); Ghazouani *et al.,* (2019); Hendy *et al.,* (2019); Jiang *et al.,* (2019); Saddique and Shahbaz, (2019); Bader *et al.,* (2020) and Abdrabou *et al.,* (2022).

Table 11: Effect of deficit irrigation water through different growth stages on MY, ETa, WUE and IWUE for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2021.

DI				**MY (t/ha)**		**Eta (mm/season)**		**WUE (Kg/m^3)**		**IWUE (Kg/m^3)**	
Growth stages				**Surface drip irrigation system types**							
I	**D**	**M**	**L**	**T-Tape**	**GR**	**T-Tape**	**GR**	**T-Tape**	**GR**	**T-Tape**	**GR**
100	**100**	**100**	**100**	56.05	65.78	574.95	543.64	10.93	13.56	8.35	9.80
100	**100**	**100**	**75**	55.43	64.85	560.67	519.31	11.08	14.00	8.60	10.07
100	**100**	**100**	**50**	50.15	57.17	521.43	474.19	10.78	13.52	8.13	9.26
100	**100**	**75**	**100**	55.42	64.53	557.83	504.42	11.14	14.34	9.19	10.71
100	**100**	**75**	**75**	53.82	62.91	532.58	486.25	11.33	14.50	9.35	10.93
100	**100**	**75**	**50**	49.84	56.15	522.45	471.17	10.69	13.36	9.08	10.23
100	**100**	**50**	**100**	48.13	56.06	476.31	423.86	11.33	14.83	9.01	10.49
100	**100**	**50**	**75**	46.57	53.68	459.87	404.64	11.35	14.87	9.18	10.58
100	**100**	**50**	**50**	39.61	44.34	446.93	394.32	9.94	12.61	8.25	9.23
100	**75**	**100**	**100**	54.76	64.97	527.89	507.51	11.63	14.35	8.80	10.44
100	**75**	**100**	**75**	52.68	63.45	506.96	493.04	11.65	14.43	8.84	10.65
100	**75**	**100**	**50**	46.13	55.91	489.61	469.16	10.56	13.36	8.11	9.83
100	**75**	**75**	**100**	50.85	60.23	502.69	453.80	11.34	14.88	9.18	10.87
100	**75**	**75**	**75**	49.57	58.68	487.83	432.35	11.39	15.22	9.40	11.13
100	**75**	**75**	**50**	49.32	58.46	449.07	389.71	12.31	16.82	9.86	11.69
100	**75**	**50**	**100**	43.13	50.26	429.35	381.23	11.26	14.78	8.88	10.35
100	**75**	**50**	**75**	40.29	46.93	405.59	360.65	11.14	14.59	8.78	10.23
100	**75**	**50**	**50**	29.61	37.51	379.61	360.27	8.74	11.67	6.86	8.69
100	**50**	**100**	**100**	53.83	63.75	521.86	479.45	11.56	14.91	9.38	11.10
100	**50**	**100**	**75**	51.94	61.01	499.78	452.11	11.65	15.13	9.49	11.15
100	**50**	**100**	**50**	40.56	49.35	446.94	426.03	10.17	12.99	7.80	9.49
100	**50**	**75**	**100**	46.24	57.49	458.13	434.57	11.32	14.83	9.14	11.37
100	**50**	**75**	**75**	44.58	55.27	440.37	410.34	11.35	15.10	9.31	11.55
100	**50**	**75**	**50**	37.23	43.11	437.69	395.29	9.54	12.23	8.24	9.54
100	**50**	**50**	**100**	37.12	44.76	389.51	354.02	10.68	14.17	8.49	10.24
100	**50**	**50**	**75**	33.08	41.08	373.76	347.94	9.92	13.24	8.06	10.01
100	**50**	**50**	**50**	23.81	29.63	356.54	328.76	7.49	10.10	6.21	7.73
LSD 0.05		**IS**		**0.07**		**0.87**		**-**		**-**	
		DI		**0.05**		**4.59**		**-**		**-**	
		IS X DI		**0.09**		**4.75**		**-**		**-**	

Table 12: Effect of deficit irrigation water through different growth stages on MY, ETa, WUE and IWUE for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2022.

DI				MY (t/ha)		ETa (mm/season)		WUE (Kg/m^3)		IWUE (Kg/m^3)	
Growth stages				Surface drip irrigation system types							
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	100	100	100	57.51	67.53	559.48	526.81	11.52	14.37	8.57	10.06
100	100	100	75	56.87	66.61	546.15	505.39	11.67	14.78	8.83	10.34
100	100	100	50	51.29	58.75	507.31	461.76	11.33	14.26	8.31	9.52
100	100	75	100	56.84	66.18	543.16	490.92	11.73	15.11	9.43	10.98
100	100	75	75	55.17	64.56	518.79	473.45	11.92	15.29	9.58	11.21
100	100	75	50	51.12	57.81	509.31	459.04	11.25	14.12	9.32	10.53
100	100	50	100	49.28	57.42	465.31	412.86	11.87	15.59	9.22	10.75
100	100	50	75	47.57	54.85	446.87	390.64	11.93	15.74	9.38	10.81
100	100	50	50	40.43	45.29	435.93	383.29	10.40	13.25	8.42	9.43
100	75	100	100	56.89	66.73	539.48	496.81	11.82	15.06	9.14	10.72
100	75	100	75	55.76	65.19	527.15	481.39	11.86	15.18	9.36	10.94
100	75	100	50	49.71	57.45	497.31	457.16	11.21	14.09	8.74	10.10
100	75	75	100	51.76	61.19	485.54	433.78	11.95	15.81	9.34	11.04
100	75	75	75	50.43	59.68	471.39	416.23	11.99	16.07	9.57	11.32
100	75	75	50	50.31	59.75	435.13	376.67	12.96	17.78	10.06	11.94
100	75	50	100	44.24	51.58	420.27	373.15	11.80	15.50	9.11	10.62
100	75	50	75	41.62	48.36	401.19	354.32	11.63	15.30	9.07	10.54
100	75	50	50	30.34	38.45	370.34	351.47	9.18	12.26	7.03	8.90
100	50	100	100	55.24	65.42	510.19	468.76	12.14	15.65	9.62	11.40
100	50	100	75	53.18	62.65	487.34	441.51	12.23	15.91	9.72	11.45
100	50	100	50	41.59	50.62	436.59	414.04	10.68	13.71	8.00	9.73
100	50	75	100	47.45	57.98	448.41	412.23	11.86	15.77	9.38	11.47
100	50	75	75	45.81	55.76	431.35	389.57	11.91	16.05	9.57	11.65
100	50	75	50	38.09	43.63	427.27	382.39	9.99	12.79	8.43	9.66
100	50	50	100	38.07	45.91	382.65	346.89	11.15	14.84	8.71	10.50
100	50	50	75	33.95	42.13	366.47	339.12	10.39	13.93	8.28	10.27
100	50	50	50	24.42	30.37	349.83	320.57	7.83	10.62	6.37	7.92
LSD 0.05	IS			0.09		0.91		-		-	
	DI			0.06		4.63		-		-	
	IS X DI			0.11		4.78		-		-	

3.3. Effect of DI on seasonal actual evapotranspiration under T-Tape and GR

Data in Tables (11 and 12) indicated that the values of seasonal actual evapotranspiration (ETa) mm for tomato fruits decreased with increasing DI during different growth stages under surface drip irrigation system types (T-tape and GR). Also, dripper type GR has a clear effect on all treatments compared to T-Tape dripper type. The results reported the same trend for both seasons 2021 and 2022. The lowest values of seasonal ETa were (328.76 and 320.57 mm) for both seasons respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR**.** While, the highest values were (574.95 and 559.48 mm) for both seasons respectively, at apply treatment FI (I=100, D=100, M=100, L=100%) and dripper type T-Tape. Meanwhile, the values of seasonal ETa at treatment FI and dripper type GR were decreased significantly by about 6% for both seasons compared to that under treatment FI and dripper type T-Tape. This was probably due the water deficit is responsible for changing the condition on account of limited transpiration. The decrease of transpiration handicap water uptake from the soils on account of damage in the roots systems, order, regulation, framework, arrangement, method, which finally led at latest reasons the water case variance in plants. Lower water uptake is thought to be responsible for decreasing RMP rate. Also, deficit irrigation technique irrigated effective roots zone with lower water than wanted for evapotranspiration. These results were similar to those reported by Battilani *et al.,* (2012); Owusu-Sekyere *et al.,* (2012) and Saddique and Shahbaz, (2019).

3.4. Effect of DI on WUE and IWUE for tomato fruit under T-Tape and GR

Data in Tables (11 and 12) showed that the highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for tomato fruits were (16.82 and 11.69 kg/m^3); (17.78 and 11.94 kg/m^3) for both seasons respectively, at apply treatment DI (I=100, D=75, M=75, L=50%) and dripper type GR. While, the lowest values were (7.49 and 6.21 kg/m^3); (7.83 and 6.37 kg/m^3) for both seasons respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type T-Tape. Meanwhile, the values of WUE and IWUE were increased significantly by about (24 and 19 %) at apply treatment DI (I=100, D=75, M=75, L=50%) and dripper type GR for both seasons compared to that under treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR. Inanition that, the values of WUE and IWUE were increased significantly by about (37 and 19%) at apply treatment, DI (I=100, D=75, M=75, L=50%) and dripper type GR for both seasons compared to that under treatment DI (I=100, D=75, M=75, L=50%) and dripper type T-Tape. These results may be traced back to the effect of deficit irrigation during different growth stages on the marketable yield of tomato fruits, as well as its effect on seasonal ETa for plant, in addition to that the percentage of irrigation water distribution efficiency added to the type of dripper type GR exceeded the dripper type T-Tape, which is reflects on the regularity of the distribution irrigation water in the spread effective roots zone, which is reflected in productivity as well as the actual evaporation transpiration which increases crop yield and reduces water consumption. In the end, the purpose of calculating of WUE and IWUE consumption is to obtain the highest productivity with the lowest possible water unit and then to provide more quantities of added irrigation water. These results are consistent with the findings of Battilani *et al.,* (2012); Wang *et al.,* (2015) and Bader *et al.,* (2020).

3.5. Effect of DI on crop yield response factor for tomato fruit under T-Tape and GR

The crop yield response factor (Ky) was determined for DI during different growth stages under surface drip irrigation system types (T-tape and GR). Also, dripper type GR has a clear effect on all treatments compared to T-Tape dripper type. The results confirmed the same trend for both seasons 2021 and 2022. Data in Tables (13 and 14) reported that the values of Ky for tomato fruits increased with increasing DI during different growth stages for all surface drip irrigation system types (T-tape and GR) treatments. The lowest values of Ky for tomato fruit were (0.19 and 0.21) for both seasons respectively, at apply treatment DI (I=100, D=75, M=100, L=100%) and dripper type GR. While, the highest values of Ky for tomato fruit were (1.51 and 1.54) for both seasons respectively, at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type T-Tape. These results may be attributed that The Ky usually indicates a linear relationship between prorated decline tomato marketable yield (Y) and the deficit of seasonal evapotranspiration (ETa). When crops have Ky values that are greater than one, they are considered to be not be tolerant to deficit irrigation. On the contrary, crops with Ky values lower than one are considered to be tolerant to deficit irrigation. These results were similar to those reported by Stewart *et al.,* (1977); (Chen *et al.,* 2014) and (Kuscu *et al.,* 2014).

Table 13: Effect of deficit irrigation water through different growth stages on Ky for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2021.

DI				1-(MY/Ym)		1-(ETa/ETm)		Ky (-)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	**100**	**100**	**100**	0.00	0.00	0.00	0.00	0.00	0.00
100	**100**	**100**	**75**	0.01	0.01	0.02	0.04	0.45	0.32
100	**100**	**100**	**50**	0.11	0.13	0.09	0.13	1.13	1.02
100	**100**	**75**	**100**	0.01	0.02	0.03	0.07	0.38	0.26
100	**100**	**75**	**75**	0.04	0.04	0.07	0.11	0.54	0.41
100	**100**	**75**	**50**	0.11	0.15	0.09	0.13	1.21	1.10
100	**100**	**50**	**100**	0.14	0.15	0.17	0.22	0.82	0.67
100	**100**	**50**	**75**	0.17	0.18	0.20	0.26	0.85	0.72
100	**100**	**50**	**50**	0.29	0.33	0.22	0.27	1.32	1.19
100	**75**	**100**	**100**	0.02	0.01	0.08	0.07	0.28	0.19
100	**75**	**100**	**75**	0.06	0.04	0.12	0.09	0.51	0.38
100	**75**	**100**	**50**	0.18	0.15	0.15	0.14	1.19	1.10
100	**75**	**75**	**100**	0.09	0.08	0.13	0.17	0.74	0.51
100	**75**	**75**	**75**	0.12	0.11	0.15	0.20	0.76	0.53
100	**75**	**75**	**50**	0.12	0.11	0.22	0.28	0.55	0.39
100	**75**	**50**	**100**	0.23	0.24	0.25	0.30	0.91	0.79
100	**75**	**50**	**75**	0.28	0.29	0.29	0.34	0.95	0.85
100	**75**	**50**	**50**	0.47	0.43	0.34	0.34	1.39	1.27
100	**50**	**100**	**100**	0.04	0.03	0.09	0.12	0.43	0.26
100	**50**	**100**	**75**	0.07	0.07	0.13	0.17	0.56	0.43
100	**50**	**100**	**50**	0.28	0.25	0.22	0.22	1.24	1.15
100	**50**	**75**	**100**	0.18	0.13	0.20	0.20	0.86	0.63
100	**50**	**75**	**75**	0.20	0.16	0.23	0.25	0.87	0.65
100	**50**	**75**	**50**	0.34	0.34	0.24	0.27	1.41	1.26
100	**50**	**50**	**100**	0.34	0.32	0.32	0.35	1.05	0.92
100	**50**	**50**	**75**	0.41	0.38	0.35	0.36	1.17	1.04
100	**50**	**50**	**50**	0.58	0.55	0.38	0.40	1.51	1.39
LSD 0.05		**IS**		-		-		-	
		DI		-		-		-	
		IS X DI		-		-		-	

Table 14: Effect of deficit irrigation water through different growth stages on Ky for tomato fruits under surface drip irrigation system types T-Tape and GR for season 2022.

DI				1-(MY/Ym)		1-(ETa/ETm)		Ky (-)	
Growth stages				Surface drip irrigation system types					
I	D	M	L	T-Tape	GR	T-Tape	GR	T-Tape	GR
100	**100**	**100**	**100**	0.00	0.00	0.00	0.00	0.00	0.00
100	**100**	**100**	**75**	0.01	0.01	0.02	0.04	0.47	0.34
100	**100**	**100**	**50**	0.11	0.13	0.09	0.12	1.16	1.05
100	**100**	**75**	**100**	0.01	0.02	0.03	0.07	0.40	0.29
100	**100**	**75**	**75**	0.04	0.04	0.07	0.10	0.56	0.43
100	**100**	**75**	**50**	0.11	0.14	0.09	0.13	1.24	1.12
100	**100**	**50**	**100**	0.14	0.15	0.17	0.22	0.85	0.69
100	**100**	**50**	**75**	0.17	0.19	0.20	0.26	0.86	0.73
100	**100**	**50**	**50**	0.30	0.33	0.22	0.27	1.34	1.21
100	**75**	**100**	**100**	0.01	0.01	0.04	0.06	0.30	0.21
100	**75**	**100**	**75**	0.03	0.03	0.06	0.09	0.53	0.40
100	**75**	**100**	**50**	0.14	0.15	0.11	0.13	1.22	1.13
100	**75**	**75**	**100**	0.10	0.09	0.13	0.18	0.76	0.53
100	**75**	**75**	**75**	0.12	0.12	0.16	0.21	0.78	0.55
100	**75**	**75**	**50**	0.13	0.12	0.22	0.28	0.56	0.40
100	**75**	**50**	**100**	0.23	0.24	0.25	0.29	0.93	0.81
100	**75**	**50**	**75**	0.28	0.28	0.28	0.33	0.98	0.87
100	**75**	**50**	**50**	0.47	0.43	0.34	0.33	1.40	1.29
100	**50**	**100**	**100**	0.04	0.03	0.09	0.11	0.45	0.28
100	**50**	**100**	**75**	0.08	0.07	0.13	0.16	0.58	0.45
100	**50**	**100**	**50**	0.28	0.25	0.22	0.21	1.26	1.17
100	**50**	**75**	**100**	0.17	0.14	0.20	0.22	0.88	0.65
100	**50**	**75**	**75**	0.20	0.17	0.23	0.26	0.89	0.67
100	**50**	**75**	**50**	0.34	0.35	0.24	0.27	1.43	1.29
100	**50**	**50**	**100**	0.34	0.32	0.32	0.34	1.07	0.94
100	**50**	**50**	**75**	0.41	0.38	0.34	0.36	1.19	1.06
100	**50**	**50**	**50**	0.58	0.55	0.37	0.39	1.54	1.41
LSD 0.05		**IS**		-		-		-	
		DI		-		-		-	
		IS X DI		-		-		-	

5. Conclusion

These study evaluated the effectiveness of deficit irrigation water (DI) during different growth stages compared to full irrigation water (FI) under surface drip irrigation system types (T-Tape and GR) on quality parameters, MY, seasonal ETa, WUE, IWUE and Ky for tomato fruits. Results of the current study concluded that the values of quality parameters for tomato fruits increased with increasing DI during different growth stages except pH decreased with increasing DI for both surface drip irrigation system types T-Tape and GR moreover that, the quality parameters for tomato fruits gave the highest values at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR except pH gave the highest values at apply treatment FI (I=100, D=100, M=100, L=100%) dripper type GR, for both seasons 2021 – 2022. While, the values of MY and seasonal ETa for tomato fruits decreased with increasing DI during different growth stages for both surface drip irrigation system types T-Tape and GR. In addition that, the MY for tomato fruits gave the highest values at apply treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR. On the other hand, the seasonal ETa for tomato fruits gave the lowest values at apply treatment DI (I=100, D=50, M=50, L=50%) and dripper type GR. Meanwhile, the values of WUE and IWUE were increased significantly by about (24 and 19 %) at apply treatment DI (I=100, D=75, M=75, L=50%) and dripper type GR for both seasons compared to that under treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR. Inanition that, the values of WUE and IWUE were increased significantly by about (37 and 19%) at apply treatment, DI (I=100, D=75, M=75, L=50%) and dripper type GR for both seasons compared to that under treatment DI (I=100, D=75, M=75, L=50%) and dripper type T-Tape. The Ky for tomato fruits gave the lowest values at apply treatment DI (I=100, D=75, M=100, L=100%) and dripper type GR. Finally, the development and mid-season growth stages for tomato fruit were very sensitive to applicant DI for all treatment compared to late stage.

So, it is recommended to apply treatment DI (I=100, D=75, M=75, L=50%) and dripper type GR to cultivate tomato fruits under New El-Salhia conditions where this treatment can probably save about 40% of amount irrigation water additive versus lost approximately 13 % of MY for tomato fruits compared to that at treatment FI (I=100, D=100, M=100, L=100%) and dripper type GR. This indicates that the deficit irrigation water technique during various growth stages can be recommended to apply on the other crops to find out critical and tolerant stages for apply it and therefore, providing large quantities of added irrigation water versus less lost in the yield with excluded, dripper type T-Tape due it gave the lowest values for all treatments compared with dripper type GR.

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