Egypt. J. Soil Sci. **Vol. 57,** No. 4, pp. 393 - 406 (2017)

Effect of Deficit Irrigation During Growth Stages on Water Use Efficiency of Carrot Under El-Ismailia Conditions

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THIS experiment was performed during the summer seasons 2015 - 2016, at a private farm in the El Kasasin area, Ismailia Governorate, Egypt, to study the effect of deficit irrigation (DI) during growth stages compared to full irrigation (FI) under surface drip (SDI) and sub-surface drip (SSDI) on marketable yield (Ym), plant quality parameters, water use efficacy (WUE) and irrigation water use efficiency (IWUE) of carrot *(Daucus carota* L.*)* crop. The experimental design was a split plot design with three replicates. The obtained results indicated that, the values of quality parameters, Ym, ETa for carrot roots decreased with increasing DI during the growth stages especially (initial and development stages) except L-ascorbic acid content and total sugar content which increased with increasing DI under SDI and SSDI for both seasons. In addition; the maximum values of Ym for carrot roots were 8.38 and 8.56 Mg fed^{-1} , respectively, under the FI (I=100, D=100, M=100, L=100%) and SSDI treatment. While, the minimum values of ETa were 154.00 and 157.79 mm , respectively, under the DI (I=60, D=60, M=60, L=100%) and SSDI treatment. Moreover, the values of WUE and IWUE under the DI (I=80, D=80, M=60, L=100%) and SSDI treatment for both seasons increased significantly to reach; 50 and 28 % compared with the control treatment (FI and SDI). Finally, the DI (I=80, D=80, M=60, L=100%) and SSDI treatments save approxymately 34% of the applied irrigation water although the reduction of Ym was approxymately 4% compared with the control treatment (FI and SDI). Deficit irrigation (DI) strategy has been chosen for use in the study as it maximizes irrigation water productivity and optimizes crop yields.

Kyewords: Deficit irrigation, Actual evapotranspiration; Water use efficiency, Irrigation water use efficiency.

Introduction

Rationalization of irrigation water became a unique and necessary way to save the water used in sandy soil of Egypt. Scheduling the required irrigation water for each crop will help in minimizing the water lost during the growing season. Regulated deficit irrigation (RDI) is a strategy that applies less than the full replacement volume of water consumed by a plant, usually during a specific developmental stage. The key to the regulated deficit irrigation strategy is the timing of the deficit and the degree of the deficit applied to achieve a desired effect on the plant. Regulated deficit irrigation is water saving technology that is relatively inexpensive and easy to implement (Webber et al., 2007). When water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage. Therefore, timing the water deficit appropriately is a tool for scheduling irrigation where a limited supply of water is available. Growth of all crops is generally divided into four stages with regard to irrigation practice ; initial stage, development stage, mid-season and late season stage (Allen et al., 1998). Deficit irrigation (DI) could be used to raise the crop yield to crop water consumption ratio where crops have growth stages in their development where they are tolerant to water stress (Geerts and Raes, 2009). A certain level of water stress is applied to the crops in DI strategy either during specific growth stages or throughout the growing season, without necessarily causing significant yield reduction compared with the benefits achieved by diverting saved water to irrigate other crops (Leskovar, 2010). Withholding water during the vegetative (initial) period, as opposed to the flowering (development) or fruit forming stages, has less impact on final yield. The water savings associated with regulated deficit

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DOI :10.21608/ejss.2017.612.1076

irrigation are attributed to reductions in stomata conductance which occurs as a result of the plant roots encountering drying soil, and precedes any change in leaf water potential via signals (Kazemeini et al., 2009). The expectation is that any yield reduction will be insignificant compared with benefits gained through diverting the saved water to irrigated other crops (Sadgipour, 2008). A mean crop evapotranspiration of 56% of the total water requirements would be utilized during mid-season and 20% at late season stages, while the development and initial stages, respectively use 17% and 7% of the total water required by mung bean (Agugo et al., 2009). Water use efficiency may be calculated as units of dry yield per unit land area (Y, kg m^{-2}) divided by units of water consumed by the crop per unit land area (ET, m^3 m^{-2}, usually reported as mm) to produce that yield. Another key parameter for evaluating water efficiency is the irrigation water use efficiency (IWUE, kg m^{-3}) which is expressed as the amount of crop yield per total irrigation water applied (Ibragimov et al., 2007). Regulated deficit irrigation is one way of maximizing water use efficiency for higher yield per unit irrigation water applied by exposing the crop to a certain level of water stress through a particular period or throughout the whole growing season (Bekele and Tilahun, 2007). Plant growth parameters measured were: fruit weight, mean fruit dimensions, number of fruit per plant. It was observed for all the crops with the exception of carrot that reducing the ETc by 20 % did not significantly affect the yield components. This implies that irrigation water could be reduced when cropping these crops and the extra stretched to bring more land under production (Owusu-Sekyere and Andoh, 2011). During the experimental periods the differences in yield and its components under FI-100 and FI-DI60 treatments were not significant. Reduction of water supply after mid-season stage by 40% (FI-DI60) seems to have low impact on soil salinity and yield of carrot crop as compared to full irrigation regime (Nagaz et al., 2012). We found that the highest yield of carrot crop in sandy soil was obtained with the 100 % Epan treatment. The maximum WUE corresponded to 75 % Epan treatment, with an applied water volume of 3864 m^3 ha^{-1}, which corresponds to the water application level recommended for drip irrigation scheduling in carrot. The decrease applied in the water volume did not affect crop yield nor quality parameters significantly. On the other hand, the excess of soil water caused a decrease in plant density and root size. The relationship between crop yield and applied water volume obtained for the carrot crop with drip irrigation will help to improve the management of the water resources for this crop under water scarcity conditions (Quezada et al., 2011).

This study aimed to investigate the effect of deficit irrigation water during growth stages under surface and sub-surface drip irrigation on carrot root production, growth parameters quality, actual evapotranspiration (ETa), WUE and IWUE.

Materials and Methods

Experiments

Field experiments were performed in the El Kasasin area, Ismailia Governorate, Egypt (30° 29` N: 32° 13` E. 17 m a.s.l) during the summer seasons 2015-2016. In a split plot design with three replicates, the experimental was divided into 20 m^2 plots; each bounded by 1.5 m wide barren to avoid horizontal infiltration. The obtained data were subjected to statistical analysis according to Snedecor and Cochran (1989) using Co-state software program. Figure 1 showed that carrot *(Daucus carota* L.*)* was irrigated by three levels of DI during growth stages ($Initial_{100,80,60\%}$- $development_{100,80,60\%}$ - mid-$season_{100,80,60\%}$ - $Late_{100\%}$) by using probability tree compared with full irrigation (FI) for all growth stages ($Initial_{100\%}$ - $development_{100\%}$ - mid-$season_{100\%}$ - $Late_{100\%}$) under surface (SDI) and sub-surface drip irrigation (SSDI). Soil management practices were applied using doses of fertilizer as recommended by the Ministry of Agriculture and Land Reclamation.

The length (L) cm, diameter (D) cm, total soluble solid (TSS) %, total carotenoid content (TCC) mg100 g^{-1} FW, L-ascorbic acid content (LAC) mg100 g^{-1} FW and total sugar content (TSC) mg100 g^{-1} FW were determined for carrot roots. WUE kg m^{-3}, IWUE kg m^{-3} and ETa mm, were calculated at different (DI) during growth stages under SDI and SSDI for carrot roots plots.

Soil characteristics

Soil samples were collected for some physical and chemical soil characteristics. The methodological procedures were done according to the methods described by Klute (1986) and Page et al. (1982) **,** respectively (Tables 1&2).

Irrigation water characteristics

Chemical analyses of the irrigation water were measured according to the methods described by Ayers and westcot (1994) (Table 3).

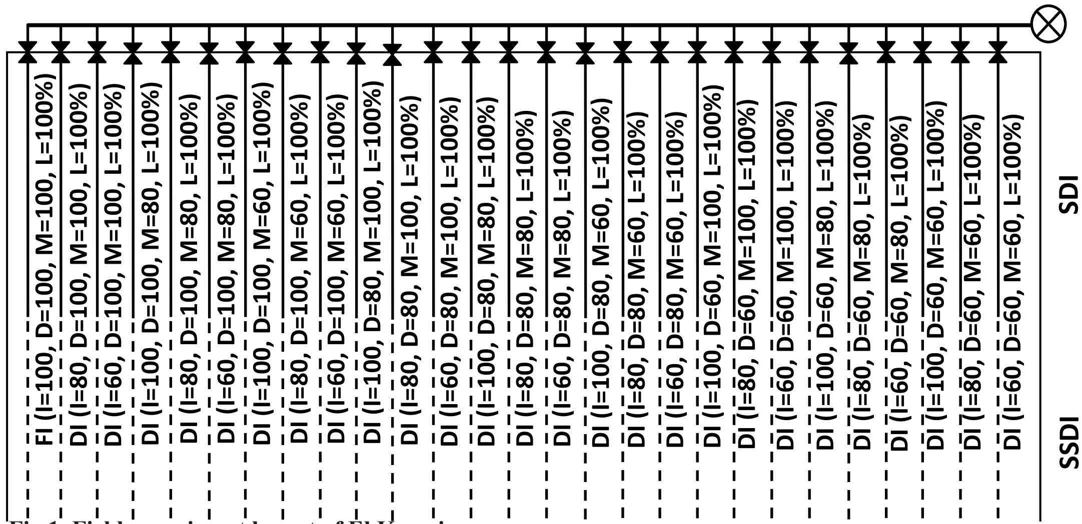

Fig.1. Field experiment layout of El Kasasin area

TABLE 1. Some physical characteristics of experimental soil

Soil depth (cm)	Particle size distribution %					Textural class	OM %	ρ_b g/cm^3	Ks cm/h	FC %	WP %	AW %
	C. sand	M. sand	F. sand	Silt	Clay							
0-15	8.59	69.15	10.57	6.76	4.93	S	0.49	1.56	11.67	11.95	3.61	8.34
15-30	9.84	67.62	12.38	6.45	3.71	S	0.47	1.58	12.14	11.49	3.53	7.96
30-45	10.17	65.73	14.45	6.39	3.26	S	0.43	1.59	12.81	10.73	3.28	7.45

TABLE 2. Some chemical characteristics of experimental soil

Soil depth (cm)	EC (dS m^{-1})	pH	$CaCO_3$ %	CEC cmole kg^{-1}	Soluble ions (meq/l) in the saturated soil paste extract							
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}
0-15	1.97	7.54	2.21	5.14	9.43	1.19	4.81	4.27	9.65	2.84	-	7.21
15-30	2.14	7.42	2.37	4.34	9.07	2.31	5.43	4.59	10.27	2.79	-	8.34
30-45	2.49	7.37	2.45	3.95	8.79	3.94	6.36	5.81	12.19	2.63	-	10.08

Reference evapotranspiration (ETo)

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

Crop evapotranspiration (ETc)

The crop evapotranspiration (ETc) shown in Table 5 was calculated using the following equation:

- $ETc = Kc_{FAO} \cdot ETo$ (mm day^{-1}) (Allen et al., 1998)

where: Kc_{FAO} is the crop coefficient from FAO No. (56). ETo is the reference crop evapotranspiration, mm day^{-1}

Leaching requirement (LR)

The leaching requirement LR was calculated using the following equation:

- $LR = EC_w / (5 (EC_e) - EC_w) \times 100$ (%) (Allen et al., 1998)

Where: ECw is the electrical conductivity of the irrigation water, dS m^{-1}.
ECe is the average electrical conductivity of the soil solution extract, dS m^{-1}.

Deficit irrigation water (DI) during growth stages

The deficit irrigation water at each growth stages based on the amounts of applied irrigation water (IR) for carrot root shown in Tables 6&7 was calculated using the following equation:

- $IR_{100, 80, 60\%} = (ETc - pe) Kr / Ea) + LR$ (mm period^{-1}) (Keller and Karmeli, 1974)

Where: Kr is correction factor for limited wetting at a carrot percentage round coverage by canopy 80%, Kr = 0.90. (Smith, 1992).

Ea is the irrigation efficiency for surface drip (85%) (Allen et al., 1998).

Pe is the effective rainfall, 0 mm.

LR is the leaching requirements, under salinity levels of irrigation water (0.07 x ETc), mm.

Convert mm to m^3 = water per mm depth * Area (3.57 not 4.2 for drip irrigation)

- Actual evapotranspiration ETa = (M_2 % – M_1 %) / 100 . d_b . D (mm) (Doorenbos and Pruitt, 1984)

Where: M_2 is the moisture content after irrigation %.

M_1 is the moisture content before irrigation %.

d_b is the specific density of soil .

D is the mean depth, mm.

- Water use efficiency WUE = Ya / ETa(kgm^{-3}) (kg m^{-3}) (Howell et al., 2001)

Where:Ya is the actual yield of the crop,(kg fed^{-1}).

- Irrigation water use efficiency IWUE = Ya / IR (kg m^{-3}) (Michael, 1978)

Where: IR is the seasonal amounts of applied irrigation water, (m^3), Tables (6&7).

TABLE 3. Some 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	7.09	0.74	1.68	2.54	0.31	2.46	2.09	3.26	3.11	-	1.03

TABLE 4. Calculation reference evapotranspiration (mm day^{-1}) through carrot growth period

Seasons	Month	August	September	October	November
2015	**ETo, mm day^{-1}**	7.03	5.86	4.51	2.89
2016		7.12	5.95	4.58	2.93

TABLE 5. Calculation crop evapotranspiration (mm day^{-1}) through carrot growth period

Seasons	Stages	Initial	Develop.	Mid	Late	Seasonal
	Period length (day)	20	30	30	20	100
	Kc_{FAO} (-)	0.70	0.85	1.05	0.30	--------
2015	**ETo (mm) 2015**	135.92	170.40	130.44	57.80	494.56
	$ETc_{100\%}$ (mm) 2015	95.14	178.92	123.92	17.34	415.32
2016	**ETo (mm) 2016**	137.72	173.02	132.45	58.60	501.79
	$ETc_{100\%}$ (mm) 2016	96.40	181.67	125.83	17.58	421.48

TABLE 6. Calculation applied irrigation water (IR), mm for carrot season 2015

Deficit irrigation, (DI)				Applied irrigation water, (mm) Growth Stages				
I	D	M	L	Initial	Development	Mid	Late	Seasonal
100	100	100	100	107.60	202.35	140.14	19.61	469.70
80	100	100	100	86.08	202.35	140.14	19.61	448.18
60	100	100	100	64.56	202.35	140.14	19.61	426.66
100	100	80	100	107.60	202.35	112.11	19.61	441.67
80	100	80	100	86.08	202.35	112.11	19.61	420.15
60	100	80	100	64.56	202.35	112.11	19.61	398.63
100	100	60	100	107.60	202.35	84.08	19.61	413.64
80	100	60	100	86.08	202.35	84.08	19.61	392.12
60	100	60	100	64.56	202.35	84.08	19.61	370.60
100	80	100	100	107.60	161.88	140.14	19.61	429.23
80	80	100	100	86.08	161.88	140.14	19.61	407.71
60	80	100	100	64.56	161.88	140.14	19.61	386.19
100	80	80	100	107.60	161.88	112.11	19.61	401.20
80	80	80	100	86.08	161.88	112.11	19.61	379.68
60	80	80	100	64.56	161.88	112.11	19.61	358.16
100	80	60	100	107.60	161.88	84.08	19.61	373.17
80	80	60	100	86.08	161.88	84.08	19.61	351.65
60	80	60	100	64.56	161.88	84.08	19.61	330.13
100	60	100	100	107.60	121.41	140.14	19.61	388.76
80	60	100	100	86.08	121.41	140.14	19.61	367.24
60	60	100	100	64.56	121.41	140.14	19.61	345.72
100	60	80	100	107.60	121.41	112.11	19.61	360.73
80	60	80	100	86.08	121.41	112.11	19.61	339.21
60	60	80	100	64.56	121.41	112.11	19.61	317.69
100	60	60	100	107.60	121.41	84.08	19.61	332.70
80	60	60	100	86.08	121.41	84.08	19.61	311.18
60	60	60	100	64.56	121.41	84.08	19.61	289.66

TABLE 7. Calculation applied irrigation water (IR), mm for carrot season 2016

DI				Applied irrigation water, (mm) Growth stages				
I	D	M	L	Initial	Development	Mid	Late	Seasonal
100	100	100	100	109.03	205.46	142.30	19.88	476.67
80	100	100	100	87.22	205.46	142.30	19.88	454.86
60	100	100	100	65.42	205.46	142.30	19.88	433.06
100	100	80	100	109.03	205.46	113.84	19.88	448.21
80	100	80	100	87.22	205.46	113.84	19.88	426.40
60	100	80	100	65.42	205.46	113.84	19.88	404.60
100	100	60	100	109.03	205.46	85.38	19.88	419.75
80	100	60	100	87.22	205.46	85.38	19.88	397.94
60	100	60	100	65.42	205.46	85.38	19.88	376.14
100	80	100	100	109.03	164.37	142.30	19.88	435.58
80	80	100	100	87.22	164.37	142.30	19.88	413.77
60	80	100	100	65.42	164.37	142.30	19.88	391.97
100	80	80	100	109.03	164.37	113.84	19.88	407.12
80	80	80	100	87.22	164.37	113.84	19.88	385.31
60	80	80	100	65.42	164.37	113.84	19.88	363.51
100	80	60	100	109.03	164.37	85.38	19.88	378.66
80	80	60	100	87.22	164.37	85.38	19.88	356.85
60	80	60	100	65.42	164.37	85.38	19.88	335.05
100	60	100	100	109.03	123.28	142.30	19.88	394.49
80	60	100	100	87.22	123.28	142.30	19.88	372.68
60	60	100	100	65.42	123.28	142.30	19.88	350.88
100	60	80	100	109.03	123.28	113.84	19.88	366.03
80	60	80	100	87.22	123.28	113.84	19.88	344.22
60	60	80	100	65.42	123.28	113.84	19.88	322.42
100	60	60	100	109.03	123.28	85.38	19.88	337.57
80	60	60	100	87.22	123.28	85.38	19.88	315.76
60	60	60	100	65.42	123.28	85.38	19.88	293.96

Results and Discussion

Effect of DI under SDI and SSDI on quality parameters for carrot roots

Data in Tables 8, 9, 10 and 11 showed that the values of quality parameters for carrot roots (length (L) cm, diameter (D) cm, total soluble solid (TSS) %, total carotenoid content (TCC) mg100 g^{-1} FW decreased with increasing deficit irrigation DI during growth stages.

The maximum values of carrot roots L, D, TSS and TCC for seasons 2015 - 2016 recorded (17.02 cm, 3.92 cm, 12.27 % and 18.51 mg 100 g^{-1}fw) and (17.23 cm, 3.97 cm, 12.43 % and 18.73 mg 100 g^{-1}fw) , respectively. Whereas LAC and TSC recorded (6.79 and 4.81 mg 100 g^{-1}fw) and (6.87 and 4.87 mg 100 g^{-1}fw) for both seasons respectively, under full irrigation (FI) (I=100, D=100, M=100, L=100%) and SSDI treatment.

While, the minimum values for both seasons recorded (7.39 cm, 0.38 cm, 4.21 % and 14.60 mg 100 g^{-1}fw) and (7.47 cm, 0.39 cm, 4.26 % and 14.76 mg 100 g^{-1}fw) , respectively.Whereas LAC and TSC recorded (7.43 and 5.45 mg 100 g^{-1}fw) and (7.54 and 5.51 mg 100 g^{-1}fw) for both seasons, respectively, under the DI (I=60, D=60, M=60, L=100%) and SDI treatment.

The values of L, D, TSS, TCC, LAC and TSC under full irrigation and SSDI treatment for both seasons were recorded increased significantly by about (14, 13, 12, 9, 8 and 11%) respectively, compared to that under control treatment. These results are similar to these reported by (Nagaz et al., 2012).

Effect of DI under SDI and SSDI on marketable yield for carrot roots

Data in Tables 12&13 show that the values of marketable yield (Ym) for carrot roots decreased with increasing DI during growth stages under SDI and SSDI for both seasons 2015 - 2016. The maximum values of Ym were 8.38 and 8.56 Mg fed^{-1} for both seasons, respectively, under FI (I=100, D=100, M=100, L=100%) and SSDI treatment. While, the minimum values of Ym were 2.39 and 2.46 Mg fed^{-1} for both seasons, respectively, under DI (I=60, D=60, M=60, L=100%) and SDI treatment. Meanwhile, the values of carrot roots Ym under FI and SSDI treatment for both seasons, respectively, increased significantly by approximately 14% compared the control treatment. These results may be attributed to that the initial and development growth stages of carrot roots were very sensitive for DI.These results are cosistent with the finding of Quezada et al. (2011).

TABLE 8. Effect of deficit irrigation for carrot root growth stages on L, D and TSS under SDI and SSDI for season 2015

DI	L (cm)	D (cm)	TSS (%)						
Growth stageS				Irrigation systems (IS)					
I	**D**	**M**	**L**	**SDI**	**SSDI**	**SDI**	**SSDI**	**SDI**	**SSDI**
100	100	100	100	14.98	17.02	3.48	3.92	10.94	12.27
80	100	100	100	14.76	16.67	3.35	3.77	10.61	11.93
60	100	100	100	13.54	15.25	2.84	3.20	9.12	10.19
100	100	80	100	14.87	16.79	3.41	3.83	10.76	12.07
80	100	80	100	14.35	16.07	3.27	3.68	10.38	11.58
60	100	80	100	14.02	15.65	3.14	3.50	9.94	11.05
100	100	60	100	14.14	15.93	3.09	3.46	10.09	11.23
80	100	60	100	13.97	15.52	3.04	3.39	9.87	10.97
60	100	60	100	12.85	14.19	2.36	2.61	10.52	11.65
100	80	100	100	14.63	16.27	3.30	3.67	10.39	11.51
80	80	100	100	14.49	16.04	3.22	3.55	10.25	11.25
60	80	100	100	13.82	15.15	2.80	3.08	9.08	9.92
100	80	80	100	14.76	16.06	3.26	3.54	10.53	11.54
80	80	80	100	14.54	15.64	3.14	3.41	10.11	11.06
60	80	80	100	13.37	14.32	2.76	2.99	8.56	9.31
100	80	60	100	13.71	14.81	2.90	3.13	8.84	9.63
80	80	60	100	13.48	14.39	2.82	3.04	8.69	9.44
60	80	60	100	13.00	13.84	2.58	2.80	8.02	8.71
100	60	100	100	11.23	12.07	1.33	1.44	6.61	7.18
80	60	100	100	9.98	10.69	1.11	1.20	5.45	5.91
60	60	100	100	9.16	9.72	0.78	0.85	5.21	5.59
100	60	80	100	10.94	11.68	1.26	1.37	6.38	6.85
80	60	80	100	9.79	10.40	0.92	1.02	5.32	5.73
60	60	80	100	8.67	9.13	0.64	0.71	4.92	5.28
100	60	60	100	9.90	10.49	0.97	1.05	5.34	5.76
80	60	60	100	8.84	9.30	0.71	0.78	5.07	5.45
60	60	60	100	7.39	7.73	0.38	0.42	4.21	4.52
		IS		0.02		0.01		0.02	
LSD 0.05		DI		0.05		0.01		0.04	
		IS X DI		0.07		0.03		0.05	

TABLE 9. Effect of deficit irrigation for carrot root growth stages on LAC, TSC and TCC under SDI and SSDI for season 2015

DI	TCC (mg 100 g^{-1} FW)	LAC (mg 100 g^{-1} FW)	TSC (mg 100 g^{-1} FW)						
Growth stageS				Irrigation systems (IS)					
I	D	M	L	SDI	SSDI	SDI	SSDI	SDI	SSDI
100	100	100	100	16.94	18.51	6.27	6.79	4.34	4.81
80	100	100	100	16.72	18.27	6.35	6.87	4.42	4.89
60	100	100	100	16.47	18.03	6.43	6.95	4.56	5.04
100	100	80	100	16.69	18.29	6.34	6.90	4.40	4.87
80	100	80	100	16.51	18.05	6.41	7.02	4.48	5.06
60	100	80	100	16.25	17.81	6.49	7.11	4.62	5.12
100	100	60	100	16.43	18.07	6.43	7.02	4.49	4.95
80	100	60	100	16.28	17.83	6.51	7.14	4.56	5.02
60	100	60	100	16.06	17.65	6.65	7.26	4.68	5.17
100	80	100	100	16.20	17.89	6.54	7.09	4.57	5.09
80	80	100	100	16.02	17.67	6.63	7.16	4.63	5.15
60	80	100	100	15.89	17.41	6.71	7.24	4.75	5.23
100	80	80	100	16.04	17.65	6.67	7.21	4.65	5.17
80	80	80	100	15.86	17.43	6.74	7.32	4.71	5.24
60	80	80	100	15.62	17.19	6.86	7.45	4.83	5.31
100	80	60	100	15.84	17.32	6.79	7.30	4.73	5.26
80	80	60	100	15.68	17.10	6.85	7.37	4.79	5.38
60	80	60	100	15.46	16.94	6.97	7.49	4.87	5.53
100	60	100	100	15.60	17.08	6.91	7.43	4.85	5.40
80	60	100	100	15.43	16.86	6.98	7.51	4.97	5.56
60	60	100	100	15.25	16.62	7.11	7.65	5.14	5.71
100	60	80	100	15.39	16.84	7.05	7.57	5.00	5.58
80	60	80	100	15.17	16.60	7.13	7.69	5.15	5.73
60	60	80	100	14.91	16.38	7.27	7.83	5.29	5.87
100	60	60	100	15.13	16.65	7.19	7.71	5.17	5.75
80	60	60	100	14.85	16.43	7.31	7.83	5.32	5.89
60	60	60	100	14.60	16.21	7.43	7.97	5.45	6.11
		IS		0.03		0.02		0.01	
LSD 0.05		DI		0.06		0.03		0.02	
		IS X DI		0.09		0.05		0.03	

TABLE 10. Effect of deficit irrigation for carrot root growth stages on L, SD and TSS under SDI and SSDI for season 2016

DI	L (cm)	SD (cm)	TSS (%)						
Growth stageS				**Irrigation systems (IS)**					
I	D	M	L	**SDI**	**SSDI**	**SDI**	**SSDI**	**SDI**	**SSDI**
100	100	100	100	15.19	17.23	3.52	3.97	11.07	12.43
80	100	100	100	14.95	16.86	3.39	3.81	10.75	12.07
60	100	100	100	13.71	15.42	2.87	3.23	9.23	10.30
100	100	80	100	15.03	16.99	3.45	3.87	10.90	12.21
80	100	80	100	14.50	16.28	3.31	3.72	10.49	11.73
60	100	80	100	14.17	15.86	3.18	3.54	10.06	11.18
100	100	60	100	14.34	16.12	3.13	3.50	10.21	11.36
80	100	60	100	14.12	15.70	3.07	3.42	9.98	11.09
60	100	60	100	12.96	14.35	2.39	2.64	10.65	11.80
100	80	100	100	14.81	16.48	3.34	3.71	10.53	11.65
80	80	100	100	14.64	16.25	3.26	3.59	10.37	11.38
60	80	100	100	14.00	15.32	2.83	3.11	9.20	10.03
100	80	80	100	14.93	16.23	3.30	3.58	10.65	11.67
80	80	80	100	14.68	15.85	3.18	3.45	10.23	11.19
60	80	80	100	13.51	14.51	2.79	3.02	8.67	9.42
100	80	60	100	13.89	14.99	2.93	3.16	8.95	9.76
80	80	60	100	13.63	14.58	2.85	3.07	8.78	9.54
60	80	60	100	13.17	14.01	2.61	2.83	8.12	8.81
100	60	100	100	11.35	12.20	1.34	1.45	6.69	7.27
80	60	100	100	10.13	10.82	1.12	1.21	5.51	5.98
60	60	100	100	9.27	9.85	0.79	0.86	5.27	5.65
100	60	80	100	11.09	11.83	1.27	1.38	6.45	6.93
80	60	80	100	9.91	10.51	0.93	1.03	5.38	5.80
60	60	80	100	8.78	9.25	0.65	0.72	4.97	5.35
100	60	60	100	10.02	10.61	0.98	1.06	5.40	5.83
80	60	60	100	8.95	9.41	0.72	0.79	5.12	5.51
60	60	60	100	7.47	7.82	0.39	0.43	4.26	4.58
			IS	0.03		0.01		0.03	
LSD 0.05			DI	0.05		0.02		0.05	
			IS X DI	0.08		0.04		0.07	

TABLE 11. Effect of defect irrigation for carrot root growth stages on LA, TS and TC under SDI and SSDI for season 2016

DI				TC (mg 100 g^{-1} FW)		LA (mg 100 g^{-1} FW)		TS (mg 100 g^{-1} FW)	
Growth stageS				Irrigation systems (IS)					
I	**D**	**M**	**L**	**SDI**	**SSDI**	**SDI**	**SSDI**	**SDI**	**SSDI**
100	100	100	100	17.16	18.73	6.35	6.87	4.39	4.87
80	100	100	100	16.94	18.48	6.43	6.95	4.47	4.95
60	100	100	100	16.68	18.25	6.51	7.03	4.61	5.10
100	100	80	100	16.89	18.51	6.42	6.98	4.45	4.93
80	100	80	100	16.67	18.29	6.49	7.10	4.53	5.12
60	100	80	100	16.42	18.07	6.57	7.19	4.67	5.18
100	100	60	100	16.65	18.30	6.51	7.12	4.54	5.02
80	100	60	100	16.48	18.04	6.6	7.24	4.61	5.09
60	100	60	100	16.20	17.85	6.74	7.36	4.73	5.24
100	80	100	100	16.42	18.13	6.62	7.18	4.62	5.16
80	80	100	100	16.17	17.91	6.71	7.25	4.68	5.21
60	80	100	100	16.09	17.57	6.79	7.33	4.80	5.29
100	80	80	100	16.23	17.85	6.76	7.31	4.71	5.24
80	80	80	100	16.01	17.68	6.83	7.42	4.77	5.31
60	80	80	100	15.75	17.43	6.95	7.56	4.89	5.37
100	80	60	100	16.04	17.51	6.87	7.39	4.78	5.33
80	80	60	100	15.86	17.35	6.95	7.46	4.84	5.45
60	80	60	100	15.68	17.17	7.07	7.58	4.92	5.58
100	60	100	100	15.72	17.29	7.01	7.53	4.91	5.47
80	60	100	100	15.64	17.11	7.08	7.61	5.03	5.64
60	60	100	100	15.46	16.85	7.21	7.75	5.20	5.79
100	60	80	100	15.58	17.07	7.15	7.67	5.06	5.64
80	60	80	100	15.36	16.79	7.23	7.79	5.21	5.79
60	60	80	100	15.13	16.61	7.37	7.93	5.35	5.93
100	60	60	100	15.31	16.83	7.29	7.82	5.23	5.81
80	60	60	100	15.04	16.57	7.41	7.94	5.38	5.95
60	60	60	100	14.76	16.39	7.54	8.08	5.51	6.18
		IS		0.03		0.02		0.02	
	LSD 0.05	DI		0.07		0.04		0.02	
		IS X DI		0.09		0.06		0.04	

Effect of DI under SDI and SSDI on seasonal actual evapotranspiration

Data in Tables 12&13 concluded that the values of seasonal ETa for carrot roots decreased with increasing DI during growth stages under SDI and SSDI for both seasons 2015-2016. The minimum values of ETa were 154.00 and 157.79 mm for both seasons , respectively, under DI (I=60, D=60, M=60, L=100%) and SSDI treatment. While, the maximum values of ETa were 311.95 and 317.25 mm for both seasons , respectively, under FI (I=100, D=100, M=100, L=100%) and SDI treatment. These results are consisten with Webber et al. (2007) and Geerts and Raes (2009).

TABLE 12. Effect of deficit irrigation for carrot root growth stages on Ym, ETa, WUE and IWUE under SDI and SSDI for season 2015

DI				Ym ($Mg\ fed^{-1}$)		ETa ($mm\ Season^{-1}$)		WUE ($Kg\ m^{-3}$)		IWUE ($Kg\ m^{-3}$)	
Growth stages				Irrigation systems (IS)							
I	D	M	L	SDI	SSDI	SDI	SSDI	SDI	SSDI	SDI	SSDI
100	100	100	100	7.34	8.38	311.95	284.38	6.59	8.25	4.38	5.00
80	100	100	100	7.12	8.05	278.31	255.19	7.17	8.84	4.45	5.03
60	100	100	100	6.29	7.12	254.56	234.56	6.92	8.50	4.13	4.67
100	100	80	100	7.25	8.19	275.42	250.61	7.37	9.15	4.60	5.19
80	100	80	100	6.97	7.82	253.24	229.63	7.71	9.54	4.65	5.21
60	100	80	100	6.72	7.48	237.73	216.49	7.92	9.68	4.72	5.26
100	100	60	100	6.80	7.53	243.08	224.52	7.84	9.39	4.60	5.10
80	100	60	100	6.69	7.49	236.63	220.71	7.92	9.51	4.78	5.35
60	100	60	100	5.44	6.04	200.53	187.28	7.60	9.03	4.11	4.57
100	80	100	100	7.02	7.87	293.45	269.53	6.70	8.18	4.58	5.14
80	80	100	100	6.90	7.68	252.13	230.99	7.67	9.31	4.74	5.28
60	80	100	100	6.30	7.06	239.08	218.80	7.38	9.04	4.57	5.12
100	80	80	100	7.05	7.61	256.86	238.58	7.69	8.93	4.92	5.31
80	80	80	100	6.82	7.29	225.01	209.34	8.49	9.75	5.03	5.38
60	80	80	100	6.01	6.47	213.53	197.51	7.88	9.18	4.70	5.06
100	80	60	100	6.18	7.00	228.15	211.75	7.59	9.26	4.64	5.25
80	80	60	100	6.05	7.04	214.09	199.99	7.92	9.86	4.82	5.61
60	80	60	100	5.76	6.12	202.26	187.28	7.98	9.15	4.89	5.19
100	60	100	100	4.31	4.79	250.62	230.56	4.82	5.82	3.11	3.45
80	60	100	100	3.82	4.28	233.75	216.68	4.58	5.53	2.91	3.26
60	60	100	100	3.32	3.61	212.07	193.35	4.39	5.23	2.69	2.92
100	60	80	100	4.14	4.53	226.84	210.42	5.11	6.03	3.21	3.52
80	60	80	100	3.66	3.91	207.46	189.36	4.94	5.78	3.02	3.23
60	60	80	100	3.04	3.28	184.12	168.23	4.62	5.46	2.68	2.89
100	60	60	100	3.69	3.97	200.38	184.58	5.16	6.02	3.11	3.34
80	60	60	100	3.17	3.34	181.26	167.71	4.90	5.58	2.85	3.01
60	60	60	100	2.39	2.53	168.89	154.00	3.96	4.60	2.31	2.45
		IS		0.01		0.96		0.04		0.01	
LSD 0.05		DI		0.06		5.69		0.20		0.05	
		IS X DI		0.07		5.01		0.20		0.04	

TABLE 13. Effect of defect irrigation for carrot root growth stages on Ym, ETa, WUE and IWUE under SDI and SSDI for season 2016

DI	Ym (Mg fed^{-1})	ETa (mm $Season^{-1}$)	WUE (Kg m^{-3})	IWUE (Kg m^{-3})							
Growth stages				Irrigation systems (IS)							
I	D	M	L	SDI	SSDI	SDI	SSDI	SDI	SSDI	SDI	SSDI
100	100	100	100	7.51	8.56	317.25	289.65	6.63	8.28	4.41	5.03
80	100	100	100	7.27	8.23	283.57	260.03	7.18	8.87	4.48	5.07
60	100	100	100	6.45	7.29	260.06	239.26	6.95	8.53	4.17	4.72
100	100	80	100	7.39	8.35	279.34	254.48	7.41	9.19	4.62	5.22
80	100	80	100	7.12	7.97	257.71	233.74	7.74	9.55	4.68	5.24
60	100	80	100	6.86	7.61	241.49	219.51	7.96	9.71	4.75	5.27
100	100	60	100	6.94	7.70	246.93	229.40	7.87	9.40	4.63	5.14
80	100	60	100	6.82	7.64	240.57	224.21	7.94	9.54	4.80	5.38
60	100	60	100	5.56	6.17	204.25	190.57	7.63	9.07	4.14	4.59
100	80	100	100	7.18	8.04	298.41	274.24	6.74	8.21	4.62	5.17
80	80	100	100	7.05	7.83	256.86	235.28	7.69	9.32	4.77	5.30
60	80	100	100	6.42	7.19	242.63	221.76	7.41	9.08	4.59	5.14
100	80	80	100	7.20	7.76	261.39	242.83	7.72	8.95	4.95	5.34
80	80	80	100	6.97	7.44	229.75	212.75	8.50	9.80	5.07	5.41
60	80	80	100	6.13	6.60	216.51	201.14	7.93	9.19	4.72	5.09
100	80	60	100	6.31	7.13	232.13	215.42	7.61	9.27	4.67	5.27
80	80	60	100	6.19	7.18	218.46	203.60	7.94	9.88	4.86	5.64
60	80	60	100	5.87	6.26	205.28	190.91	8.01	9.18	4.91	5.23
100	60	100	100	4.42	4.91	256.52	235.74	4.83	5.83	3.14	3.49
80	60	100	100	3.94	4.37	239.30	220.87	4.61	5.54	2.96	3.28
60	60	100	100	3.39	3.70	214.95	196.89	4.42	5.26	2.71	2.95
100	60	80	100	4.25	4.63	232.17	214.06	5.13	6.06	3.25	3.54
80	60	80	100	3.73	3.99	209.73	192.74	4.98	5.80	3.04	3.25
60	60	80	100	3.11	3.36	187.21	171.67	4.65	5.48	2.70	2.92
100	60	60	100	3.78	4.04	203.85	187.13	5.19	6.05	3.14	3.35
80	60	60	100	3.26	3.42	185.48	170.46	4.92	5.62	2.89	3.03
60	60	60	100	2.46	2.61	171.32	157.79	4.02	4.63	2.34	2.49
LSD 0.05		DI		0.01		0.99		0.04		0.01	
		IS		0.12		4.59		0.19		0.08	
		DI X IS		0.07		5.13		0.20		0.05	

Effect of DI under SDI and SSDI on WUE and IWUE

Data in Tables 12&13 show that the maximum values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for carrot roots were 9.86 and 5.61 kg m^{-3}, 9.88 and 5.64 kg m^{-3}) for seasons 2015-2016 , respectively, under DI (I=80, D=80, M=60, L=100%) and SSDI treatment. While, the minimum values were 3.96 and 2.31 kg m^{-3}, 4.02 and 2.34 kg m^{-3} for seasons 2015-2016 , respectively, under DI (I=60, D=60, M=60, L=100%) and SDI treatment. Meanwhile, the values of WUE and IWUE under the DI (I=80, D=80, M=60, L=100%) and SSDI treatment for both seasons 2015-2016 increased significantly by approximately 50 and 28 % compared with the control treatment (FI and SDI). These results may be because the deficit irrigation (DI) could be used to raise the crop yield to crop water consumption ratio where crops have growth stages in their development whereas they are tolerant to water stress. These results were similar to those reported by Ibragimov et al. (2007), Bekele & Tilahun (2007), Geerts & Raes (2009) and Quezada et al. (2011).

Conclusion

Results of the current study demonstrated beneficial effects, of DI during growth stages compared to FI under SDI and SSDI on the Ym, the studied quality parameters, seasonal ETa, WUE and IWUE for carrot roots. This study concluded that:

1- The quality parameters values , Ym and ETa for carrot roots decreased with increasing DI during growth stages except LAC TSC increased with increasing DI under SDI and SSDI for both seasons 2015 - 2016.
2- The maximum values of Ym were 8.38 and 8.56 Mg fed^{-1} for both seasons , respectively, under the FI (I=100, D=100, M=100, L=100%) and SSDI treatment**.**
3- The minimum values of ETa were 154.00 and 157.79 mm for both seasons , respectively, under DI (I=60, D=60, M=60, L=100%) and SSDI treatment.
4- The values of WUE and IWUE under DI (I=80, D=80, M=60, L=100%) and SSDI treatment for both seasons 2015-2016 increased significantly by approximately 50 and 28 % compared with the control treatment (FI and SDI).
5- The initial and development growth stages for carrot roots were very sensitive to applicant DI for all treatments compared with mid-season stage.

So, it is recommended to use DI (I=80, D=80, M=60, L=100%) under SSDI treatment for Ym of carrot roots. This treatment save approximately 34% of the applied irrigation water although the reduction of Ym was approximately 4% compared with the control treatment (FI and SDI). This means that the deficit irrigation technology during different growth stages can be recommended to apply on the other plants to find out sensitive and tolerant stages to apply it and therefore, save more irrigation water with less yield reduction.

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(*Received: 27* /1/2017)
accepted: 6 / 4 /2017)

تأثير الري الناقص خلال مراحل النمو على كفاءة الأستهلاك المائى للجزرتحت ظروف الأسماعيلية

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مما لا شك فيه أن أستخدام تقنية الرى الناقص خلال مراحل النموالمختلفة تحت نظام الرى بالتنقيط تؤثربشكل كبيرعلى أنتاجية النباتات وتوفيركميات من مياه الرى المضافة وذلك لأن هناك مراحل حساسة للنقص فى كميات مياه الرى المضافة وأخرى غيرحساسة وذلك يختلف من نبات لأخرلذا أجريت هذه التجربة الحقلية لدراسة تأثيرالرى الناقص خلال مراحل النمو المختلفة تحت نظامى الرى بالتنقيط السطحى والتحت سطحى على جودة وأنتاجية نبات الجزروكذلك كفاءة الأستهلاك المائى والأروائى له وبناءا على ذلك أمكن تحديد مدى تحمل كل مرحلة من مراحل النمو للنقص فى كميات مياه الرى المضافة لكلا النظامين ومن ثم توفيرها. أجريت هذه التجربة فى منطقة القصاصين بمحافظة الأسماعيلية – جمهورية مصر العربية وكانت أحداثياتها كالتالى (٣٠° ٢٩´ شمالا : ٣٢° ١٣´شرقا) وأرتفاع ١٧ متر فوق مستوى سطح البحرخلال الموسمين الصيفيين ٢٠١٥ – ٢٠١٦ تم أستخدام التصميم الأحصائى القطع المنشقة مرة واحدة بثلاث مكررات لكل معاملة وتم زراعة نبات الجزربأستخدام ثلاثة مستويات من الرى الناقص خلال مراحل النموالمختلفة (المرحلة الأولية (أ) ١٠٠،٨٠،٦٠ ٪ - مرحلة التطور(ت) ١٠٠،٨٠،٦٠ ٪ - مرحلة منتصف الموسم (م) ١٠٠،٨٠،٦٠ ٪ - مرحلة نهاية الموسم (ن) ١٠٠ ٪) وذلك بأستخدام شجرة الأحتمالات ومقارنتها بالرى الكامل (أ = ١٠٠ ، ت = ١٠٠ ، م = ١٠٠ ، ن = ١٠٠٪) تحت نظامى الرى بالتنقيط السطحى والتحت سطحى. وقد أوضحت النتائج المتحصل عليها الأتى :

١- نقص قيم قياسات الجودة والأنتاجية والأستهلاك المائى الفعلى لجذورالجزربزيادة مستويات الرى الناقص خلال مراحل النموالمختلفة تحت نظامى الرى بالتنقيط السطحى والتحت سطحى ماعدا حمض الأسكوربيك والسكريات الكلية تزداد قيمها بزيادة مستويات الرى الناقص تحت نظامى الرى.
٢- سجلت المعاملة المروية (بالرى الكامل تحت نظام الرى بالتنقيط التحت سطحى) أعلى أنتاجية (٨,٣٨ و٨,٥٦ طن/ فدان) لكلا الموسمين ٢٠١٥ – ٢٠١٦ على الترتيب بزيادة تقدربحوالى ١٤٪ مقارنة بالمعاملة التقليدية (الرى الكامل تحت نظام الرى بالتنقيط السطحى).
٣- سجلت قيم المعاملة المروية بالرى الناقص (أ = ٨٠ ، ت = ٨٠ ، م = ٦٠ ، ن = ١٠٠٪) تحت نظام الرى بالتنقيط التحت سطحى أعلى قيم لكفاءة الأستهلاك المائى والأروائى لجذور الجزر(٩,٨٦ و ٥,٦١ كجم/م٣) و(٩,٨٨ و ٥,٦٤ كجم/م٣) لكلا الموسمين على الترتيب بزيادة تقدر بحوالى ٥٠ و٢٨ ٪ مقارنة بالمعاملة التقليدية (الرى الكامل تحت نظام الرى بالتنقيط السطحى).
٤- مرحلتى النموالأولية والتطور لجذور الجذرحساسة جدا للرى الناقص مقارنة بمرحلة منتصف الموسم.

لذا يمكن التوصية بأستخدام معاملة الرى الناقص (أ = ٨٠ ، ت = ٨٠ ، م = ٦٠ ، ن = ١٠٠٪) تحت نظام الرى بالتنقيط التحت سطحى لأنها أعطت أعلى كفاءة للأستهلاك المائى والأروائى لجذورالجذرحيث أن هذه المعاملة يمكنها أن توفر حوالى ٣٤ ٪ من كمية مياه الرى المضافة بالرغم من النقص فى المحصول حوالى ٤ ٪ اذا ماقورن بالمعاملة التقليدية (الرى الكامل تحت نظام الرى بالتنقيط السطحى).هذا يعنى أنه يمكن التوصية بتطبيق تقنية الرى الناقص خلال مراحل النموالمختلفة على نباتات أخرى لتحديد المراحل الحساسة والمتحملة لتطبيقه وبالتالى توفيرالمزيد من كميات مياه الرى المضافة بأقل نقص فى أنتاجية المحصول.