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Optimizing Irrigation Schedule to Maximize Water Use Efficiency of *Hibiscus sabdariffa* under Shalatien Conditions

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Abstract: A substantial experiment was conducted throughout two consecutive growing seasons of 2005/2006 and 2006/2007 at the experimental station of Shalatien, South – east of Egypt to elucidate the optimizing irrigation schedule to maximize water use efficiency of Roselle, *Hibiscus sabdariffa*., under moisture stress. This work was accomplished by designing 75 experimental units with split plot design. The main plots for five irrigation water quantities, (i.e. Q_1, Q_2, Q_3, Q_4 and Q_5) and the sub-main plots for the three plant densities, i.e. 28000, 56000 and 84000 plants/fed. as D_1, D_2 and D_3 respectively. The variables studied were distributed in five replicates. Soil of the location is sandy calcareous; *Lithic torripsamnents* and *Typic torripsamnents*; where $CaCO_3$ content is more than 7%. Water use efficiency, water economy under drip irrigation system was calculated and irrigation schedules were estimated. The achieved result could be summarized as follows:

1- A positive correlation responses between branch number and decreasing plant densities.
2- The heaviest densities and irrigation water schedule (Q_2) produced the shortest plants.
3- The highest Fresh and dry Sepal yields, Kg/fed; (for the three plant densities, respectively i.e. 2234, 2920 kg/fed and 444, 510 kg/fed); were associated with Q_3D_1 treatment, in the two successive seasons.
4- A highly significant increase of Fresh and dry weight of different plant organs per plant and the whole plant which tended to increase with D_1 under Q_3 treatment. So, it could be observed that, the most effective treatment on increasing the fresh and dry weight of leaves, stems, roots and whole plant, gm/ plant was Q_3D_1, which they increased significantly in both seasons.
5- The number of fruits per plant significantly increased by decreasing plant densities, the highest number of fruits per plant recorded by the following order $Q_3D_1 > Q_2 D_1 > Q_4D_1 > Q_5 D_1 > Q_1 D_1$.
6- The greatest seed yield was obtained by managing water use and saving 20%. So, it is recommended to use 80% of applied irrigation water under trickle irrigation system.
7- The highest value of fruit number/plant was obtained by Q_3D_1 treatment, i.e. 2341.08 m^3/fed. While the lowest value was associated with Q_1D_3 treatment, i.e. 1386.04 m^3/fed. Such increase reached 68.90%.
8- The highest values were associated with Q_1D_1 treatment for the two consecutive growing seasons, i.e., 1.44, 1.57 kg/m^3 and 0.79, 0.86 kg/m^3 for WUE and Weco, respectively and 1.83 for crop coefficient. While the lowest values were associated with Q_5D_3 treatment, i.e., 0.31, 0.32 kg/m^3 and 0.22, 0.23 kg/m^3 for WUE and Weco, respectively and 1.41 for crop coefficient. Such increase reached 364.52%, 390.63% for WUE and Weco and 29.79% for KC.
9- The highest value of poly saccharides content was associated with Q_5D_3 treatment, i.e. 630 and 642 mg/gm, while the lowest value was associated with Q_1D_1, i.e. 292.50 and 295.50 mg/gm. Such differences reached 115.58 and 117.26%, for the two successive seasons, respectively.
10- Soluble sugar content gave the highest value when treated by Q_1D_3 treatment, i.e. 98.40 an 98.60 mg/gm, while the lowest value was associated with Q_5D_1 treatment, i.e. 41.70 and 42.80 mg/gm. for the two successive seasons, respectively. Such increase reached 135.97 and 130.37%.
11- Total soluble solids percentages in dried sepals were increased with decreasing plant density and decreased with increasing plant density.
12- The highest anthocyanins, mg/gm was formed in flowers' cups of Roselle plants with low density in both seasons. So, the lowest values recorded in this case were 99.12, 93.24 and 90.18 mg/gm, i.e. D_1, D_2 and D_3 when they irrigated with the lowest irrigation water quantity, Q_1.

Key words: Irrigation schedule % Water use efficiency % *Hibiscus Sabdariffa* % Irrigation water quantities % Plant densities % Water economy % Crop coefficient

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INTRODUCTION

In the course of land reclamation and improvement, Medicinal and Aromatic plants were recognized as being useful in desert regions with its climatic conditions favorable for the growth of these plants and the extension in this region is promising. All reviews showed clearly that benefits were associated with structural improvements, Roselle, *Hibiscus sabdariffa* L. (Karkadeih), is an annual or perennial bushy sub shrub, about 5-8 feet height, with branched, erect, smooth and often purplish stem, belonging to Family *Malvaceae*. This plant is indigenous to tropic Africa [1]. It can be planted fairly in wide range of countries in tropical and subtropical region. The main product of this crop is the dried fleshy epicalyx and calyx, which is used in preparing acidulous refreshing hot or cold bavarages and infusions which are a popular admired drink in many hot climatic countries. It is known that the plant vegetative characteristics have a direct relation with agricultural practices such as plant densities, which mostly affected the vegetative growth and then the yield. The competition for light, water and minerals is reflected on metabolic processes in plant. With planting Roselle plants on 50cm. (one side ridge), 25cm (one side ridge) and 25cm (two sides). Khater and Ahmed [2] reported that plant height was increased by decreasing planting distances. Also, they found that the highest yield was obtained from planting on one side ridge and 50 cm spacing between plants. In addition, they showed that the percentage of anthocyanins content and total organic acid in dried sepals decreased significantly as the highest of plant densities. Shalaby and Razin [3] found that the widest spacing produced the greatest number of fruits per plant. However, the narrower spacings gave greater fruit and fresh calyces weights and higher yields of dry calyces. The best results were obtained with the 50cm. spacing. The average calyces yield was 214.8-218.9 kg/fed for Masri and 187.1-190.4 kg/fed for Sudani. In addition, they mentioned that high densities gave higher anthocyanins per unit area. But didn't significantly affect the calyx content of anthocyanins. Abd El-Salam [4] on *Pimpinella anisum* showed that total carbohydrates content in herb increased by increasing the planting distances from 20 to 80 cm.

MATERIALS AND METHODS

A substantial experiment was conducted throughout the two consecutive growing seasons of 2005/2006 and 2006/2007 at the experimental station of El-Shalatien, south-east of Egypt, Red Sea governorate. The station is located at 22° to 24° No latitude, 35° 30′ to 36° 30′ E longitude aiming to optimize irrigation schedule and maximize water use efficiency of Roselle, *Hibiscus sabdariffa*. Roselle seeds were obtained from Department of the Medicinal and Aromatic Plants, Agricultural Research Center, Giza. They were sown on the 15th March in the two successive seasons. Nitrogen, potassium were applied through three equal doses using 300 kg N/fed as superphosphate and 100 kg/fed as potassium sulphate. The first applied dose was done after 15 days of planting, while the 2nd and 3rd ones were added after 45 an 90 days from cultivation. Inoculation of seed with mixture of Azospirillum sp. Plus Rhizobium sp. Inocula were added as soil application in the rhizosphere three times after 30, 75 and 120 days from sowing. The analysis of the used organic manures is shown in Table 1. The physical soil properties were analyzed according to Piper [5]. While, Tables 2 a & b and 3 show some chemical characteristics

Table 1: The properties of the applied organic manure

Organic manure	Organic carbon %	Total nitrogen %	Organic matter %	C/N ratio
Sheep dung	23.71	2.06	40.76	11.51

Table 2a: Soil physical properties of Shalatien location

	Particle size distribution %							
Depth, cm	Coarse sand	Medium sand	Fine sand	Silt	Clay	T.C	Pd (g/cm^3)	Moisture content %
0-20	3	31	61	3	2	Sandy	1.66	4.85
20-40	6	22	66	4	2	Sandy	1.69	4.53
40-60	5	25	61	6	3	Sandy	1.68	4.42
60-80	5	29	57	6	3	Sandy	1.67	4.66
80-100	5	30	56	6	3	Sandy	1.66	3.81
>100	5	31	55	6	3	Sandy	1.65	3.81

Table 2b: Soil chemical properties of Shalatien location

				Cations me/l				Anions me/l			
Depth, cm	EC dS/m	pH	$CaCO_3$ %	Na^+	K^+	Ca^{++}	Mg^{++}	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-20	0.77	7.7	2.3	0.62	0.49	3.66	2.91	-	0.42	3.92	3.33
20-40	0.66	7.6	1.10	0.63	0.40	2.82	2.75	-	0.42	3.09	3.09
40-60	0.49	7.5	0.85	0.55	0.39	1.99	1.96	-	0.36	2.8	1.90
60-80	0.50	7.5	0.60	0.51	0.42	2.81	1.26	-	0.38	2.65	1.95
80-100	0.36	7.3	0.58	0.48	0.38	1.92	0.80	-	0.26	1.75	1.61
>100	0.34	7.3	0.55	0.32	0.38	1.19	1.51	-	0.39	1.52	1.49

Table 3: Irrigation water chemical analysis

		Cations me/l				Anions me/l				
$EcdSm^{-1}$	PH	Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	SAR
1.2	7.6	0.49	0.30	0.30	0.11	-	0.12	0.68	0.38	0.78

Table 4: Average meteorological data of Shalatien Station of (2005-2007) as the cultivated period

Month	Min. Tmp.°C	Max. Tmp.°C	Av. Tmp.°C	Min WS Km/h	Max WS Km/h	Av. WS Km/h	RH %	Total Slr. W/m^2	ET_O mm.
March	23.32	34.44	28.88	12.73	37.57	25.15	48.43	0.32	7.14
April	24.64	35.80	30.22	12.41	34.65	23.53	47.08	0.32	7.63
May	26.89	39.70	33.30	11.51	35.10	23.31	43.77	0.31	8.10
June	28.78	39.79	34.29	11.17	35.34	23.26	48.88	0.27	7.27
July	20.01	30.56	25.29	12.99	35.84	24.42	53.15	0.29	6.00
August	16.17	26.44	21.31	12.83	37.42	25.13	55.01	0.23	4.61

Table 5: Computed daily potential evapotranspiration ETm (mm) in Shalatien region

Months	March	April	May	June	July	Aug.	Seasonal Etm		
Quantities	mm/ day						mm/day	Mm/season	m^3/fed*
$Q_1$60%))	1.80	5.00	5.90	6.00	7.00	1.00	4.45	654.51	850.87
Q_2(80%)	3.70	6.10	7.40	7.80	8.20	3.00	6.03	886.90	1152.97
Q_3(100%)	5.73	6.87	8.64	9.42	9.80	5.00	7.58	1113.77	1447.90
Q_4(120%)	6.07	8.26	9.68	10.54	10.94	5.10	8.43	1239.46	1611.29
Q_5(140%)	7.84	9.60	10.40	11.60	11.99	5.20	9.44	1387.33	1803.53
Mean	6.062	8.582	10.118	10.922	11.516	4.734	8.732	1299.1	1654.14

* One feddan = 4200 m^2

of the studied soil and some chemical characteristics of irrigation water which were determined according to Jackson [6] and Richards [7].

The experimental field was divided into 75 plots. They were cultivated by Roselle, *Hibiscus sabdariffa* plants. Land preparation and other agricultural practices were similar for all treatments. Five irrigation schedules (i.e., 60, 80, 100, 120 and 140%) were applied depending upon potential evapotranspiration that calculated as corresponding to Radiation approach according to the meteorological data prevailing in the studied region were shown in Table 4 according to Kaicun *et al*. [8].

Five treatments for irrigation application quantities were chosen based on daily calculated consumptive use. Table 5 showed the computed daily potential evapotranspiration ETo (mm) of El- Shalatien region.

The organic manure was thoroughly mixed with 0-20 cm soil surface layer two weeks before planting, (i.e. 10 Ton/fed.). Seedlings were thinned to be one plant, two plants and three plants as densities, (i.e. 28000, 56000 and 84000 plants/fed.), under each of emitters of trickle irrigation system, after three weeks from sowing. The harvesting data was on 15th of November. The plants from all treatments were taken in order to determine the following data: A) Growth characters: 1. Plant height (cm.). 2. Fresh and dry weights of leaves, stems and roots per plant (gm). B). Yield and yield attributes: 1. Number of fruits per plant. 2. Fresh and dry weights of fruits and sepals (gm /plant.) 3. Total yield of dry sepals (kg/ fed.) 4. Seed yield per plant and per feddan. C). Chemical analysis: 1. Determination of total carbohydrates percentage according to Michel-Dubois *et al*. [9]. 2. Determination of total anthocyanins, according to Du and Francis [10] for Roselle, *Hibiscus sabdariffa*.

Statistical analysis was performed according to Snedecor and Cochran [11]. L.S.D. test was used to compare the average means or treatments.

RESULTS AND DISCUSSION

Concerning the plant height as affected by different plant density and irrigation water quantities treatments, data presented in Table 6 showed that, the tallest plants reached 175.8 cm. in the first season, while in the second season was 175.7 cm. These results were obtained from Q_2D_1 treatment. In the meantime the heaviest densities (D_3) combined with irrigation water schedule (Q_2) produced the shortest plants, which were 130.2 and 135.6 cm. in the first and second seasons, respectively. This may be attributed to the competition between plants for obtaining more light. These results were agreed with those reported by Khater and Ahmed [2] on Roselle plants and Abd-El- Salam [4] on anise plants. The highest number of branches per plant in the first season was associated with the Q_2D_3 treatment, there were 9.5 and 12.7. While the lowest one was associated with the Q_1D_1 treatment. They were 5.0 and 5.9 per plant for the two seasons, respectively. These results were in harmony with those reported by Balyan *et al*. [12] on celery and Abd-El-Salam [4] on anise plants. The positive correlation responses which were recorded between branches number and decreasing plant densities might be due to the more suitable unit area for roots and plant growth and more suitable amount of light in case of lower densities compared to the highest ones.

Fresh and dry Sepal yields, kg/fed, as affected by irrigation water quantities and plant densities for the two consecutive growing seasons were recorded in Table 7. The highest values were associated with Q_3D_1 treatment, i.e. 2234, 2920 kg/fed and 444, 510 kg/fed for fresh and dry weights in the two successive seasons. While the lowest values were associated with Q_5D_3 treatment, i.e. 1555, 1826 kg/fed and 222, 250 kg/fed for fresh and dry weights in the two successive seasons as well. Such increase reached 43.67, 59.91% and 100, 104% for fresh and dry weights in the two consecutive growing seasons, respectively. These results were agreed with those reported by Khater and Ahmed [2], Sobhan and Husain [13], El-Barkoki *et al*. [14] on Roselle plants and Abd-El-Salam [4] on anise plants. The increase in plant height as a result of decreasing the plant densities, might be due to the competition between plants for obtaining more light Fresh and dry weight of different plant organs per plant and the whole plant of *Hibiscus sabdariffa,* L. during the two consecutive growing seasons of 200/2006 and 2006/2007 as affected by irrigation water quantities and plant densities were recorded in Table 8. Data showed a highly significant increase of Fresh and dry weight of different plant organs per plant and the whole plant which tended to increase with D_1 under Q_3 treatment. The highest values were recorded as2234, 2920 and 444, 510 kg/fed for fresh and dry weight in the two successive seasons, respectively. Such increase reached 148.40, 190% and 137.77, 186.61% for the fresh and dry weights of the whole plant in the two successive seasons, comparing with the lowest values which associated with D_3Q_1

Table 6: Effect of irrigation water quantities and plant densities on plant height and number of branches per plant of Roselle, *Hibiscus sabdariffa* L. during the two consecutive growing seasons 2005/2006 and 2006/2007

		Plant height (cm)		Number of branches/plant	
Irrigation water quantities	D	1st season	2nd Season	1st season	2nd season
Q_1,60%	D_1	140.2	145.6	5.0	5.9
	D_2	135.0	140.8	6.5	7.0
	D_3	130.2	135.6	7.3	10.5
Q_2,80%	D_1	175.1	175.7	6.3	7.0
	D_2	152.3	160.0	8.0	9.0
	D_3	150.0	144.1	9.5	12.7
Q_3,100%	D_1	163.8	178.3	6.7	7.3
	D_2	152.3	154.7	8.3	9.3
	D_3	146.8	149.0	9.2	12.5
Q_4,120%	D_1	166.2	170.2	7.0	7.3
	D_2	155.4	161.3	8.5	9.0
	D_3	150.8	159.2	9.3	11.2
Q_5,140%	D_1	150.2	162.5	6.1	6.5
	D_2	140.3	151.6	7.2	8.2
	D_3	138.1	143.2	9.5	10.7
LSD	0.05	10.02	7.29	0.80	1.51
	0.01	16.62	11.99	1.25	2.51

Table 7: Effect of irrigation water quantities and plant densities on sepals yield per plant and per feddan of *Hibiscus sabdariffa* L. during the two seasons of 2005/2006 and 2006/2007

		Sepals yield, gm./ plant				Sepals yield, kg/fed.			
		Fresh Weight		Dry Weight		Fresh weight		Dry Weight	
Irrigation water quantities	D	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Q_1, 60%	D_1	108.2	132.6	18.4	19.0	2164.0	2652.0	368.0	380.0
	D_2	85.2	85.1	10.1	11.1	2043.5	2042.5	242.5	266.5
	D_3	58.4	60.0	7.4	7.8	1751.0	1801.0	223.0	235.0
Q_2, 80%	D_1	111.0	145.0	22.0	25.1	2220.0	2900.0	440.0	502.0
	D_2	88.7	91.7	16.0	17.1	2127.5	2201.0	384.0	410.5
	D_3	60.1	70.2	11.1	13.4	1804.0	2105.0	334.0	401.0
Q_3, 100%	D_1	111.7	146.0	22.2	25.5	2234.0	2920.0	444.0	510.0
	D_2	88.8	92.2	16.1	17.4	2131.0	2211.5	385.0	416.5
	D_3	60.0	70.0	11.0	12.9	1801.0	2100.0	330.0	386.0
Q_4, 120%	D_1	110.2	140.0	20.0	24.0	2204.0	2800.0	400.0	480.0
	D_2	87.7	88.6	15.0	15.3	2105.0	2126.5	360.0	366.0
	D_3	59.2	66.7	10.1	10.1	1776.0	2001.0	303.0	302.0
Q_5, 140%	D_1	100.4	138.1	17.3	18.5	2008.0	2762.0	346.0	370.0
	D_2	75.3	85.2	9.6	9.8	1807.0	2045.0	229.0	234.0
	D_3	51.8	60.9	7.4	8.3	1555.0	1826.0	222.0	250.0
LSD	0.05	4.22	8.19	3.12	2.26	22.33	24.70	15.91	16.32
	0.01	6.99	13.58	5.17	3.74	39.50	42.11	27.40	28.55

Table 8: Effect of irrigation water quantities and plant densities on fresh and dry weight of different plant organs per plant and the whole plant of *Hibiscus sabdariffa* L. during the two seasons of 2005/2006 and 2006/2007.

		Fresh weight of leaves, gm/plant		Fresh weight of stems, gm/plant		Fresh weight of roots, gm/plant		Fresh weight of the whole plant, gm/plant	
Irrigation water quantities	D	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd Season
Q_1, 60%	D_1	321.8	344.9	840.1	920.8	63.2	70.2	1225.1	1335.9
	D_2	175.4	178.4	555.1	557.9	37.2	41.7	767.6	778.0
	D_3	125.5	128.4	368.4	370.6	29.6	32.0	527.5	531.1
Q_2, 80%	D_1	350.2	355.4	875.8	1080.2	75.6	82.0	1301.6	1517.6
	D_2	182.8	185.4	575.3	595.2	45.3	50.1	803.3	830.6
	D_3	130.2	139.2	417.7	447.6	39.1	41.5	587.0	628.2
Q_3, 100%	D_1	353.2	360.6	880.1	1093.0	77.0	86.6	1310.3	1540.2
	D_2	184.4	187.2	594.8	598.2	46.8	50.8	825.9	836.1
	D_3	130.2	133.3	403.6	443.5	36.7	40.1	570.5	616.9
Q_4, 120%	D_1	351.0	358.4	877.0	1071.2	75.0	85.0	1303.0	1514.6
	D_2	182.8	185.1	586.8	592.2	45.5	50.0	815.0	827.2
	D_3	129.9	132.2	413.9	420.4	36.7	40.1	580.5	592.7
Q_5, 140%	D_1	342.2	347.5	852.3	1053.4	74.0	84.0	1268.5	1484.9
	D_2	175.8	177.9	575.9	581.1	42.5	44.6	794.2	803.5
	D_3	125.8	128.4	407.3	414.7	34.1	36.8	567.2	579.9
LSD	0.05	2.07	8.30	3.90	7.05	4.87	3.41	26.34	31.14
	0.01	3.42	13.16	6.47	11.69	8.08	5.65	39.01	44.53

Table 8: Continue

Irrigation Water quantities	D	Dry weight of leaves, gm/plant 1st season	2nd season	Dry weight of stems, gm/plant 1st season	2nd season	Dry weight of roots, gm/plant 1st season	2nd season	Dry weight of the whole plant, gm/plant 1st season	2nd Season
Q_1, 60%	D_1	30.7	35.6	231.6	280.6	35.4	44.3	297.7	360.5
	D_2	20.5	22.3	161.4	151.3	21.6	24.4	203.5	197.9
	D_3	16.7	18.8	116.8	110.2	16.9	19.6	150.4	148.6
Q_2, 80%	D_1	51.6	55.8	250.6	300.4	42.2	50.2	344.4	406.4
	D_2	31.1	32.3	170.2	171.3	27.1	27.6	228.4	231.1
	D_3	24.4	27.8	126.3	132.8	22.3	23.8	172.9	184.5
Q_3, 100%	D_1	55.9	58.2	257.5	313.6	44.2	54.1	357.6	425.9
	D_2	33.8	34.0	171.1	175.1	28.1	29.3	233.0	238.3
	D_3	23.5	26.9	123.6	130.2	21.7	23.5	168.8	180.6
Q_4, 120%	D_1	50.2	55.3	250.1	310.6	40.8	50.6	341.1	416.5
	D_2	30.1	32.6	170.1	195.1	25.3	25.8	225.4	253.5
	D_3	23.5	25.1	123.5	129.5	20.2	23.4	167.1	178.1
Q_5, 140%	D_1	42.3	48.1	240.6	290.8	40.1	49.2	323.0	388.1
	D_2	25.4	28.2	165.4	175.4	24.2	25.3	214.9	228.8
	D_3	20.2	22.6	116.8	120.5	18.5	22.2	155.5	165.4
LSD	0.05	1.75	1.95	5.21	5.20	0.67	1.45	12.37	14.22
	0.01	2.90	3.23	8.64	8.62	1.12	2.40	20.50	21.75

treatment. Similar results were obtained by Abd El Salam [4] on anise plants who reported that decreasing densities resulted in the continuous increase in fresh and dry weights of plant. This might be attributed to the increase of the fresh and dry weights of plant organs (leaves, stem and roots per plant) which resulted from planted with D_1 density.

Generally, it could be observed that, the most effective treatment on increasing the fresh and dry weight of leaves per plant was Q_3D_1, i.e., 353.2, 360.6 and 55.9, 58.2 gm/plant which increased significantly in both seasons. Such increase reached 180.76, 180.84 % and 234.73, 209.57 % comparing the least effective treatment, Q_1D_3, i.e., 125.5, 128.4 and 16.7, 18.8 gm/plant. The previous results are agreed with those obtained by Mansour *et al*. [15] on Senna plants who found that the lowest density gave the best results for fresh and dry weight of leaves per plant.

Results concerning the effect of irrigation water quantities and plant densities on number, fresh and dry weight of fruits per plant of *Hibiscus sabdariffa* L. during the two consecutive growing seasons were presented in Table 9. These results indicated that, the number of fruits per plant significantly increased by decreasing plant densities, the highest number of fruits per plant recorded by the following order $D_1Q_3 > D_1Q_2 > D_1Q_4 > D_1Q_5 > D_1Q_1$. The highest values were 96.6 and 144.2 for the 1st and 2nd seasons, respectively. On the other hand, the lowest values were associated with D_3Q_1. Such increase reached 80.9% and 186.11%. These results were in agreement with those by Shalaby and Razin [3] and Abo-Dahab, *et al*. [16] on Roselle plants. This effect may be due to the effect of D_1 treatment on producing more branches carrying more number of fruits per plant.

Results presented in the same table showed that in both seasons, Q_3D_1treatment showed a significant increase for the fresh and dry weights of fruits per plant in comparison with Q_1D_3treatment. The heaviest fresh and dry weights were obtained from plant densities Q_3D_1treatment, while the lightest fresh and dry weights were produced from plant densities Q_1D_3 treatment. The differences between treatments were highly significant in the two seasons. Such differences reached 105.41, 130.15 % and 162.19, 131.10% for fresh and dry weights in both seasons. These results are in harmony with those obtained by Abd El Salam [4] on anise plants, found that, the lowest fruit yield per plant was obtained when plants more dense.

Seed yield of Roselle during the two successive seasons as affected by irrigation water quantities and plant densities was demonstrated in Table 10, data concerning the individual plant seed productivity,

Table 9: Effect of irrigation water quantities and plant densities on number, fresh and dry weight of fruits per plant of *Hibiscus sabdariffa* L. during the two seasons of 2005/2006 and 2006/2007

Irrigation Water Quantities	D	Number of fruits per plant		Fresh weight of fruits, gm/plant		Dry weight of fruits, gm/plant	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Q_1,60%	D_1	77.3	126.5	377.6	385.2	90.6	110.4
	D_2	75.3	66.4	290.2	295.8	65.2	75.1
	D_3	53.4	50.4	203.5	216.9	52.1	67.2
Q_2, 80%	D_1	90.6	140.6	409.8	480.5	130.9	150.6
	D_2	90.1	91.3	322.4	330.3	90.2	130.7
	D_3	65.7	71.1	233.7	265.0	73.0	104.0
Q_3, 100%	D_1	96.6	144.2	418	499.2	136.6	155.3
	D_2	92.1	93.3	329.5	339.0	93.2	131.9
	D_3	63.4	66.8	232.8	250.2	71.9	99.6
Q_4, 120%	D_1	90.6	120.8	402.5	410.6	99.7	110.6
	D_2	90.1	95.5	305.2	315.1	70.8	80.1
	D_3	61.8	71.9	230.2	240.3	60.1	65.1
Q_5, 140%	D_1	80.7	100.7	380.2	395.6	81.6	93.7
	D_2	80.3	92.8	270.3	300.9	60.2	70.9
	D_3	55.2	66.9	193.6	221.2	48.2	52.2
LSD	0.05	7.77	7.64	21.5	28.2	11.79	27.62
	0.01	12.92	12.70	36.55	46.53	21.22	45.81

Table 10: Effect of irrigation water quantities and plant densities on seed yield of *Hibiscus sabdariffa, L.* during the two seasons of 200/2006 and 2006/2007

Irrigation water quantities	D	Seed yield, gm./ plant		Seed yield, kg/fed*.	
		1st season	2nd season	1st season	2nd Season
Q_1, 60%	D_1	18.5	20.2	370.0	404.0
	D_2	20.3	21.6	406.0	432.0
	D_3	13.5	14.3	272.7	286.7
Q_2, 80%	D_1	23.1	38.1	462.0	762.0
	D_2	22.2	24.1	443.0	482.0
	D_3	15.5	22.9	310.0	457.3
Q_3, 100%	D_1	23.4	39.0	468.0	780.0
	D_2	22.6	24.5	451.0	490.0
	D_3	15.3	21.8	305.3	435.3
Q_4, 120%	D_1	23.2	40.2	464.0	804.0
	D_2	22.5	25.0	450.0	500.0
	D_3	15.5	23.3	310.0	466.7
Q_5, 140%	D_1	20.0	23.0	400.0	460.0
	D_2	20.0	21.3	400.0	426.0
	D_3	13.7	14.4	273.3	288.0
LSD	0.05	2.68	3.20	9.44	13.51
	0.01	4.44	5.29	15.63	25.09

* One feddan = 4200 m^2

detected that the highest seed yield per plant was increased significantly by low plant density, (Q_3D_1treatment), as they were 23.4 an 39 gm/plant, (468 and 780 kg/fed) for the two successive seasons, while the lowest one was associated with Q_1D_3, i.e., it was 13.5 and 14.3 gm/plant, (i.e., 272.7 and 286.7kg/fed.) Such increase reached 71.62 and 172.06 %. It is worth to mention that the greatest seed yield was obtained by managing water use and saving 20%. So, it is recommended to use 80% of applied irrigation water under trickle irrigation system. These results are in accordance with those obtained by Abd El Salam [4] on anise plants, who stated that the low density gave the highest seed yield per plant, Khater and Ahmed [2] on Roselle plants and El- Deeb and Zayed [17] on *Hyssopus officinals* This may be attributed to the optimum response of seed formation to irrigation water quantities and plant densities with great efficiency without water losses.

Table 11: Seasonal actual evapotranspiration (ETa), mm/day of *Hibiscus sabdariffa* L. grown in Shalatien region

Water quantity	Intervals	March	April	May	June	July	Seasonally		
		Mm/month					mm/day	mm/Season	m^3/fed
Q_1 60%	D_1	73.33	94.03	139.11	32.25	32.12	2.42	370.84	1557.53
	D_2	70.02	90.12	132.94	27.44	29.56	2.29	350.08	1470.34
	D_3	66.20	86.45	128.11	21.36	27.89	2.16	330.01	1386.04
Q_2 80%	D_1	101.06	120.00	157.48	56.20	34.41	3.07	469.15	1970.43
	D_2	99.51	115.80	151.59	51.51	31.93	2.94	450.34	1891.43
	D_3	95.17	110.40	147.56	45.22	30.07	2.80	428.42	1799.36
Q_3 100%	D_1	129.27	146.40	175.15	70.31	36.27	3.64	557.40	2341.08
	D_2	127.10	140.10	170.19	64.45	35.03	3.51	536.87	2254.85
	D_3	121.52	136.20	164.61	60.33	33.79	3.38	516.45	2169.09
Q_4 120%	D_1	154.07	161.10	187.55	75.31	38.13	4.03	616.16	2587.87
	D_2	149.73	155.10	179.49	68.75	35.96	3.85	589.03	2473.93
	D_3	144.46	150.30	174.22	66.11	35.03	3.73	570.12	2394.51
Q_5 140%	D_1	169.18	176.23	199.14	80.22	40.36	4.35	665.13	2793.55
	D_2	164.22	168.54	181.65	72.63	36.11	4.07	623.15	2617.24
	D_3	159.31	162.34	176.35	70.64	36.94	3.96	605.58	2543.44
LSD 5%	D	2.44	2.58	2.61	2.11	1.21	0.22	4.55	15.13
	Q	2.66	2.75	2.81	2.33	1.42	0.41	5.11	20.12
	D X Q	2.55	2.63	2.75	2.22	1.33	0.36	4.89	17.02

Table 12: Water use efficiency, Water economy and Crop coefficient as affected by Irrigation water quantities and Plant densities of Roselle during the two seasons of 200/2006 and 2006/2007

Irrigation water quantities	D	WUE, kg/m^3		Weco, kg/m^3		KC
		1st Season	2nd season	1st season	2nd season	
$Q_{1,}$ 60%	D_1	1.44	1.57	0.79	0.86	1.83
	D_2	0.90	0.91	0.52	0.53	1.73
	D_3	0.62	0.62	0.38	0.38	1.63
Q_2, 80%	D_1	1.13	1.32	0.66	0.77	1.71
	D_2	0.70	0.72	0.42	0.44	1.64
	D_3	0.51	0.54	0.33	0.35	1.56
Q_3, 100%	D_1	0.90	1.06	0.56	0.66	1.62
	D_2	0.57	0.58	0.37	0.37	1.56
	D_3	0.39	0.43	0.26	0.28	1.50
$Q_{4,}$ 120%	D_1	0.81	0.94	0.50	0.59	1.61
	D_2	0.51	0.51	0.33	0.33	1.54
	D_3	0.36	0.37	0.24	0.25	1.49
Q_5, 140%	D_1	0.70	0.82	0.45	0.53	1.55
	D_2	0.44	0.45	0.30	0.31	1.45
	D_3	0.31	0.32	0.22	0.23	1.41

Concerning the interaction effect between soil moisture deficits through irrigation water amounts and plant densities on actual evapotranspiration of Roselle, data presented in Table 11 show highly significant interaction effect between the studied treatments where the highest value of fruit number/plant was obtained by Q_3D_1 treatment, i.e. 2341.08 m^3/fed. While the lowest value was associated with the treatment of Q_1D_3 treatment, i.e. 1386.04 m^3/fed. Such increase reached 68.90%.

Data presented in Table 12 showed that water use efficiency, water economy and crop coefficient values as affected by irrigation water schedules and plant densities, were emphasized by aforementioned values of reference and actual evapotranspiration relative to the fresh weights of the whole plants. So, the highest values were associated with Q_1D_1 treatment for the two consecutive growing seasons, i.e., 1.44, 1.57 kg/m^3 and 0.79, 0.86 kg/m^3 for WUE and Weco, respectively and 1.83 for crop

Table 13: Average of carbohydrates content (mg/gm) as affected by plant densities and irrigation water quantities for the two successive seasons of 2005/2006 and 2006/2007

Irrigation water quantities	Poly saccharides content - Plant densities D1	D2	D3	Mean	Soluble sugar content - Plant densities D1	D2	D3	Mean	G. Mean
1 st Season									
Q_1	292.50	332.0	490.0	371.50	62.50	80.20	98.40	80.37	225.93
Q_2	332.50	371.0	545.0	416.17	60.40	75.35	94.20	76.65	246.41
Q_3	372.50	410.0	600.0	460.83	58.30	70.50	90.00	72.93	266.88
Q_4	375.00	445.0	615.0	478.33	50.00	60.65	81.15	63.93	271.13
Q_5	377.50	480.0	630.0	495.83	41.70	50.80	72.30	54.93	275.38
Mean	350.00	407.60	576.00	444.53	54.58	67.50	87.21	69.76	257.15
2 nd Season									
Q_1	295.50	340.50	496.00	377.33	63.20	81.50	98.60	81.10	229.22
Q_2	340.50	379.50	552.00	424.00	61.60	76.50	94.40	77.50	250.75
Q_3	380.50	430.50	615.50	475.50	60.20	71.60	90.60	74.13	274.82
Q_4	385.50	455.50	638.00	493.00	53.20	61.80	82.00	65.67	279.33
Q_5	387.50	492.50	642.00	507.33	42.80	52.10	72.80	55.90	281.62
Mean	357.90	419.70	588.70	455.43	56.20	68.70	87.68	70.86	263.15
G. Mean	353.95	413.65	582.35	449.98	55.39	68.1	87.445	70.31	260.15

Table 14: Effect of irrigation water quantities on chemical properties, mg/gm dry matter for the flowers' cups of Hibiscus Sabdariffa plants for two successive seasons of 2005/2006 and 2006/2007

Irrigation water quantities	Plant densities	Total Soluble Solids % 1st season	2nd season	Total Acidity % 1st season	2nd season	Anthocyanins, mg/plant 1st season	2nd season	Phlafonines Mg/plant 1st Season	2nd season
Q_1	D_1	22.61	22.67	11.10	11.12	95.18	106.00	6.57	6.62
	D_2	21.04	21.34	12.10	12.12	86.04	106.00	6.57	6.62
	D_3	19.55	19.81	13.10	13.12	85.18	96.12	6.57	6.62
Mean		21.07	21.27	12.10	12.12	85.43	96.07	6.57	6.62
Q_2	D_1	22.71	22.79	11.19	11.20	96.27	108.10	7.24	7.25
	D_2	21.14	21.45	12.19	12.20	90.04	98.22	7.24	7.25
	D_3	20.65	20.91	13.19	13.20	86.08	94.11	7.24	7.25
Mean		21.50	21.72	12.19	12.20	90.80	100.14	7.24	7.25
Q_3	D_1	33.81	34.62	11.05	11.10	97.58	109.05	5.60	5.66
	D_2	32.25	32.65	12.05	12.10	91.12	99.01	5.60	5.66
	D_3	31.74	31.78	13.05	13.10	88.19	95.40	5.60	5.66
Mean		32.60	33.02	12.05	12.10	92.30	101.15	5.60	5.66
Q_4	D_1	34.21	34.52	11.07	11.12	98.52	109.85	5.69	5.74
	D_2	33.45	33.85	12.07	12.12	92.15	99.55	5.69	5.74
	D_3	32.24	32.97	13.07	13.12	89.20	96.18	5.69	5.74
Mean		33.30	33.78	12.07	12.12	93.29	101.86	5.69	5.74
Q_5	D_1	34.20	34.51	11.07	11.12	99.12	109.90	5.74	5.78
	D_2	33.48	33.85	12.07	12.12	93.24	100.00	5.74	5.78
	D_3	32.81	33.07	13.07	13.12	90.18	97.18	5.74	5.78
Mean		33.54	33.80	12.07	12.12	94.18	102.36	5.74	5.78
G. Mean		28.40	28.71	12.10	12.13	91.20	100.32	6.17	6.21

coefficient. While the lowest values were associated with Q_5D_3 treatment, i.e., 0.31, 0.32 kg/m^3 and 0.22, 0.23 kg/m^3 for WUE and Weco, respectively and 1.41 for crop coefficient. Such increase reached 364.52%, 390.63% for WUE and Weco and 29.79% for KC. The present results are in harmony with that obtained by Gaber and El-Dosouky[18], Seidhom [19] on peas, beans and fodder beet, Abdel-Rahman [20], Abd El – Rahman [21].on sugar beet and El-Boraie [22].

Average of carbohydrates content (mg/gm) as affected by plant densities and irrigation water quantities for the two consecutive growing seasons was recorded in Table 13. Data stated that mean values of poly saccharides content, mg/gm tended to increase with increasing irrigation water quantities and plant densities as well. On contrary, the opposite trend was observed by soluble sugar content which increased by decreasing irrigation water quantities, while increased by increasing plant densities for the two successive seasons.

The highest value of poly saccharides content was associated with Q_5D_3 treatment, i.e. 630 and 642 mg/gm, while the lowest value was associated with Q_1D_1, i.e. 292.50 and 295.50 mg/gm. Such differences reached 115.58 and 117.26%, for the two successive seasons, respectively. On the other hand, soluble sugar content which obtained the opposite trend, gave the highest value when treated by Q_1D_3 treatment, i.e. 98.40 an 98.60 mg/gm, while the lowest value was associated with Q_5D_1 treatment, i.e. 41.70 and 42.80 mg/gm. for the two successive seasons, respectively. Such increase reached 135.97 and 130.37%. Similar results coincided with those obtained by Kandeel [23] on chamomile, Khater and Ahmed [2], Shalaby and Razin [3] and Abo – Dahab *et al*. [16] on Roselle plants.

The previous results may be due to the fact that low density allowed more absorption of elements from the soil to plants also minimized the competition of plants for light and water, thus increased the photosynthesis process which in turn stimulated the biosynthesis of anthocyanins.

Results presented in Table 14 showed the Effect of irrigation water quantities and plant densities on chemical properties, mg/gm dry matter of the flowers' cups of Roselle plants for two consecutive growing seasons. Data detected those total soluble solids percentages in dried sepals were increased with decreasing plant density and decreased with increasing plant density. The highest percentages of total soluble solids were 34.21 and 24.52 % for the two successive seasons, respectively when plants irrigated with Q_4, while the lowest percentages were associated with Q_1D_3, i.e. with the highest plant density, they were 19.55 and 19.81%. Such differences were nearly 75 and 24%.

First season results showed that the plant density (D_3) produced the lowest anthocyanins compared to the other densities, in the two seasons. While the highest anthocyanins, mg/gm was formed in flowers' cups of Roselle plants with low density in both seasons. So, the lowest values recorded in this case were 99.12, 93.24 and 90.18 mg/gm, i.e. D_1, D_2 and D_3 when they irrigated with the lowest irrigation water quantity, Q_1. While they were 95.18, 86.04 and 85.18 mg/gm in dried sepals for D_1, D_2 and D_3, when they irrigated with the highest irrigation water quantity, Q_5, in the first season, respectively.

Second season results showed the same trend, i.e. values were 106.0, 106 and 96.12 mg/gm, i.e. D_1, D_2 and D_3 when they irrigated with the lowest irrigation water quantity, Q_1. While they were 109.90, 100.00 and 97.18 mg/gm in dried sepals for D_1, D_2 and D_3, when they irrigated with the highest irrigation water quantity, Q_5, respectively.

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