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Effective Scheduling Method for Irrigating Citrus under Rotational Irrigation System in Sandy Soils

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ABSTRACT

Four field experiments were conducted on four citrus species (Noval orange, Lemon, Sour orange and Grapefruit) during 2016 and 2017 in the research farm of National Research Centre at Al-Nubariya Region, Al-Buhayrah Governorate, Egypt. Each experiment included three deferent methods from irrigation scheduling for irrigating citrus corps under dual-rotational irrigation system. The treatments were (1) Irrigation scheduling based on irrigation one day per week (control) "IS1", (2) Irrigation scheduling based on two days per week "IS2" and (3) Irrigation scheduling based on three days per week "IS3". The obtained results indicate that, citrus yields under rotational irrigation system were somewhat extent and increased as a result of increasing the irrigation day numbers per week. In this respect, the application of weekly water requirements in three days induced variable values of citrus yields in average of the two seasons (2016 and 2017). The highest significant value was detected with irrigation in three days weekly concerning yield as number of fruits or Kg/tree also as ton.ha^{-1} comparing with one or two irrigation days per a week. This was true for the four citrus species under the study. Concerning, fruit properties all irrigation treatments did not show a significant effect on most of the physical or chemical properties. The increasing of citrus yields might be due to improving the application efficiency of irrigation water as resulted by increasing the number of irrigation days per week which means saving the total water amount that went out of effective root zone by deep percolation, thus, mitigating the water stress inside effective root zone in addition to enhancing the application of fertigation process.

***Keywords*:** Irrigation scheduling, citrus crops, rotational irrigation system, sandy soils

Introduction

In arid countries with highly growth population, and limitation of fresh water, there is a significant pressure on agricultural sector for reducing its water consumption and make the fresh water available for the industrial and urban sectors (Abdelraouf and Abuarab 2012). The agricultural sector is facing a serious challenge to produce more food from minimum water amount, which can be achieved by increasing water productivity of crops (Abdelraouf *et al.*, 2013c). Increasing yield production is considered one of the important national goals to face the significant demand of the highly increasing in human population (Bakry *et al*., 2012). In Egypt, water productivity takes a high attention where irrigation water resources are limited and the rainfall is a limiting factor (Hozayn *et al.*, 2013). Water scarcity is one of the dangerous and major problems for crop production in Egypt, this is needs to reduce consumption of water irrigation by develop a new technologies that can be help full to benefit and utilize this precious input in an effective way (Abdelraouf *et al*., 2013b). Appling of modern irrigation methods is an important concept should be followed in the arid regions like Egypt for saving part of the irrigation water due to the limitation of water resources (El-Habbasha *et al.*,

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2014). Many methods and ways of conserving agricultural water have been investigated (Okasha *et al*., 2013).

Irrigation water distribution systems sometimes have multi-objectives such as adequacy, equity and timeliness. The systems of canal distributing the irrigation water have different design capacities, command areas and lengths requiring different duration of operation. The irrigation scheduling with these conditions especially for rotational irrigation water distribution becomes a complex process. Rotational irrigation water distribution has been introduced in some of the systems to manage the deficit and shortage of irrigation water. The scheduling of rotational irrigation is more complex compared to continuous irrigation as it requires additional managerial inputs in terms of number of gate operations, monitoring points and travel distance of gate operator. The manager requires special skill and knowledge to lay down priorities for allocating the irrigation water with a defined set of objectives develop and implement an irrigation schedule under these complex situations (Santhia and Pundarikanthanb, 2000). During last two decades, because of harmful and negative environmental affect of minerals and chemical fertilizers and increasing of their costs, applying of soil microorganisms in many parts of the world has increased (Abdelraouf *et al*., 2013 a)

Citrus fruits are the highest value fruit crop in terms of international trade. Citrus fruits are produced all over the world, 70% of the world's total citrus production is grown in the Northern Hemisphere. Citrus is considered as the major fruit crops in Egypt, due to cultivated area reached about 204095 hectare representing about 29% of the total fruit area (700854 ha) according to Ministry of Agriculture (2016). The total seasonal amount of irrigation water needed by a fully grown orchard for optimum yield depends on the daily course of evapotranspiration, the rainfall distribution, and the citrus variety grown. In a Mediterranean type climate, rainfall is concentrated in the winter months with little or no summer precipitation (Yoseph, 1998).

The aim of this study was determination of the most suitable scheduling method for irrigating citrus with a dual- irrigation system under sandy soil conditions and its impact on yield, quality traits and water productivity of some citrus crops.

Materials and methods:

Location and climate of experimental site:

Four field experiments were conducted during 2016 and 2017 the research farm of National Research Centre (NRC) (latitude 30º 30' 1.4"N, longitude 30º19' 10.9" E, and 21 m + MSL (mean sea level) at Al-Nubariya Region, Al-Buhayrah Governorate, Egypt. The experimental area has an arid climate with cool winters and hot dry summer. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from the meteorological data of the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center, Dokki, Egypt.

Physical and chemical properties of soil and irrigation water :

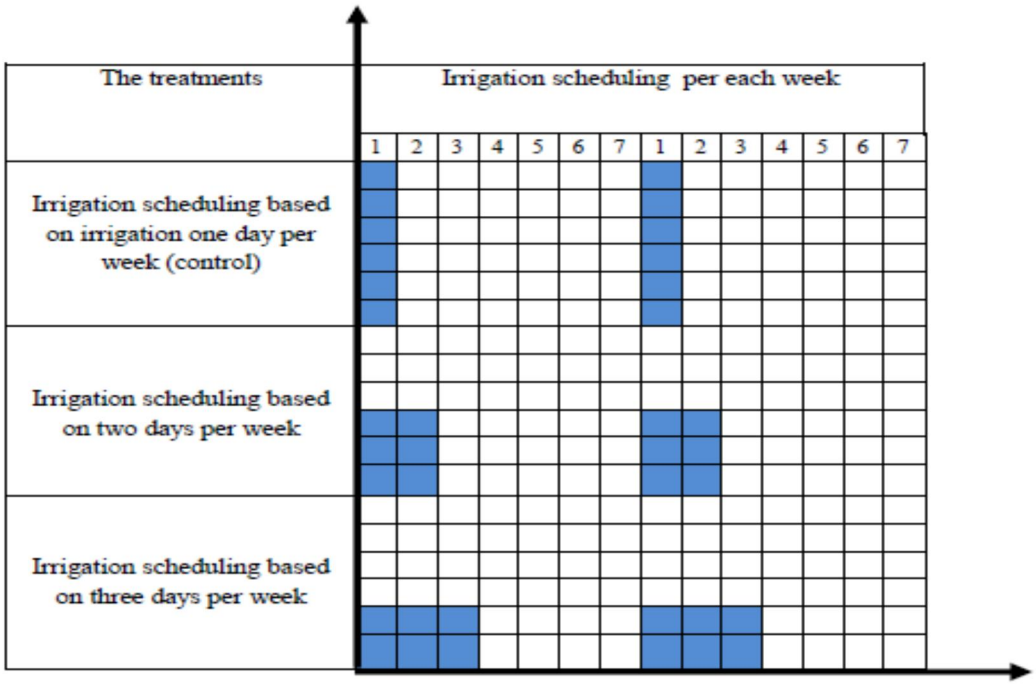
Irrigation water source was an irrigation channel passing through the experimental area, with an average pH of 7.35 and 0.41 dS m-1 as electrical conductivity (EC). The main physical and chemical properties of the soil are shown in table (1).

Table 1: Physical and chemical properties of the soil of the experimental area

Physical properties				
Soil layer depth (cm)	0–25	25-50	50-75	75-100
Texture	Sandy	Sandy	Sandy	Sandy
Course sand (%)	48.66	55.71	37.76	37.57
Fine sand (%)	48.83	40.58	58.43	57.32
Silt+ clay (%)	2.51	3.71	3.81	5.11
Bulk density (t m-3)	1.69	1.68	1.67	1.69
Chemical properties				
EC1:5 (dS m-1)	0.44	0.53	1.00	1.56
pH (1:2.5)	8.60	8.70	9.32	9.03
Total $CaCO_3$ (%)	7.00	2.34	4.66	5.02

Experimental design:

The experiment was three different methods from irrigation scheduling for irrigating citrus corps under dual-rotational irrigation system. The treatments were (1) Irrigation scheduling based on irrigation one day per week (control) "IS1", (2) Irrigation scheduling based on two days per week "IS2" and (3) Irrigation scheduling based on three days per week "IS3" as shown in figure (1).



Irrigation scheduling for irrigating citrus trees under rotational irrigation system during growing seasons

Fig. 1: The treatments of experiment deign

Irrigation requirements for citrus trees:

Daily irrigation water was calculated by following equation (1) and the average seasonal irrigation water was 7750 m^3/ha./season for average seasons 2016 and 2017 under drip irrigation system:

$$IRg = [(ET_O \times Kc \times Kr) / Ei] - R + LR \quad \ldots\ldots\ldots\ldots (1)$$

Where:

IRg = Gross irrigation requirements, mm/day,

ET_O= Reference evapotranspiration, mm/day , Kc = Crop factor (FAO-56)

Kr = Ground cover reduction factor and the values of Kr measured by Keller equation (2):

$$Kr = GC\% + 0.15 (1 - GC\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where GC%: ground cover = (shaded area per plant/area per plant)

Ei = Irrigation efficiency, %, R = Water received by plant from sources other than irrigation, mm (for example rainfall), LR = Amount of water required for the leaching of salts, mm

Evaluation Parameters

Application efficiency of irrigation water "AE_{IW}": Application efficiency relates to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field. According to El-Meseery, (2003) application efficiency "AE_{IW}" was calculated using the following relation (3):

$$AE_{IW} = Ds/ Da \quad \text{……..……..…….(3)}$$

Where: AE_{IW} = Application efficiency of irrigation water, (%), Ds = Depth of stored water in root zone (cm) calculated by equation (4) where:

$$Ds = (\theta 1 - \theta 2) * d * \rho \quad \text{……..…….(4)}$$

Da = Depth of applied water (cm), d = Soil layer depth (cm), θ1 = Soil moisture content after irrigation (%), θ2 = Soil moisture content before irrigation (%), ρ = Relative bulk density of soil (dimensionless).

Water stress: Measuring soil moisture content in effective root zone before and after irrigation and taking field capacity and wilting point as evaluation lines is considered as an evaluation parameter for exposure range of the plants to water stress "WS" (Abdelraouf, 2014). Soil moisture content was measured by profile probe device.

Yield of citrus crops: At harvest time of each four citrus species, yield as number of fruits and Kg per tree and ton per fed. were calculated.

Water productivity of citrus crops (Noval orange, Lemon, Sour orange and Grapefruit) "WP_{citrus}" was calculated according to James (1988) by equation (5) as follows:

$$WP_{citrus} = Ey/Ir \quad \text{……..…….. (5)}$$

Where: WP_{citrus} is water productivity of citrus (kg $_{citrus}$ / $m^3_{\text{irrigation water}}$), Ey is the economical yield (kg $_{citrus}$ /fed./season); Ir is the applied amount of irrigation water ($m^3_{\text{irrigation water}}$ /fed./season).

Fruit properties of citrus crops (Noval orange, Lemon, Sour orange and Grapefruit):

Fruit physical characteristics: The average values of fruit weight (gm),fruit diameter (cm), peel thickness, peel weight and pulp weight were determined. Fruit chemical characteristics: The following four fruit juice chemical properties of mature fruits were determined according to the A.O.A.C (1985) as follows: (1) Total soluble solids percentage (TSS %) fruit juice was determined using a Carl Zeiss hand refractometer. (2) Total titratable acidity percentage: Total acidity of fruit juice was estimated as g citric acid/100 ml juice according to the method described in A.O.A.C. (1990). (3) Vitamin C (mg/100 ml juice) was determined as the method described in A.O.A.C. (1990).

Statistical Analysis

All the obtained data in the two combined seasons of the study were statistically analyzed using the analysis of variance method according to Snedecor and Cochran (1980). while, the values of least significant differences (L.S.D. at 5 % level) were calculated to compare the means of different treatments.

Results and Discussion

The objective of the study in details was to determine the most suitable scheduling method for irrigating citrus trees (Noval orange, Lemon, Sour orange and Grapefruit) with a dual- irrigation system under sandy soil conditions and its impact on application efficiency of irrigation water, water stress on citrus trees inside root zone, yield, quality traits and water productivity of citrus crops (Noval orange, Lemon, Sour orange and Grapefruit) .

Application efficiency of irrigation water

The obtained results as shown in figure (2) indicate that, there was a significant effect of irrigation scheduling under rotational irrigation system on application efficiency of irrigation water "AE_{IW}" where AE_{IW} was increased as a result of increasing number of irrigation days per week. In both seasons, The AE_{IW} was improved where it was 74.5 % with IS1, but it recorded 95.2 % as a highest value with IS3. Increasing of application efficiency of irrigation water may be due to increasing of days number for irrigation per week where it led to increase the volume of water stored inside root zone and then saving from total amount of irrigation water which went out of effective root zone by deep percolation.

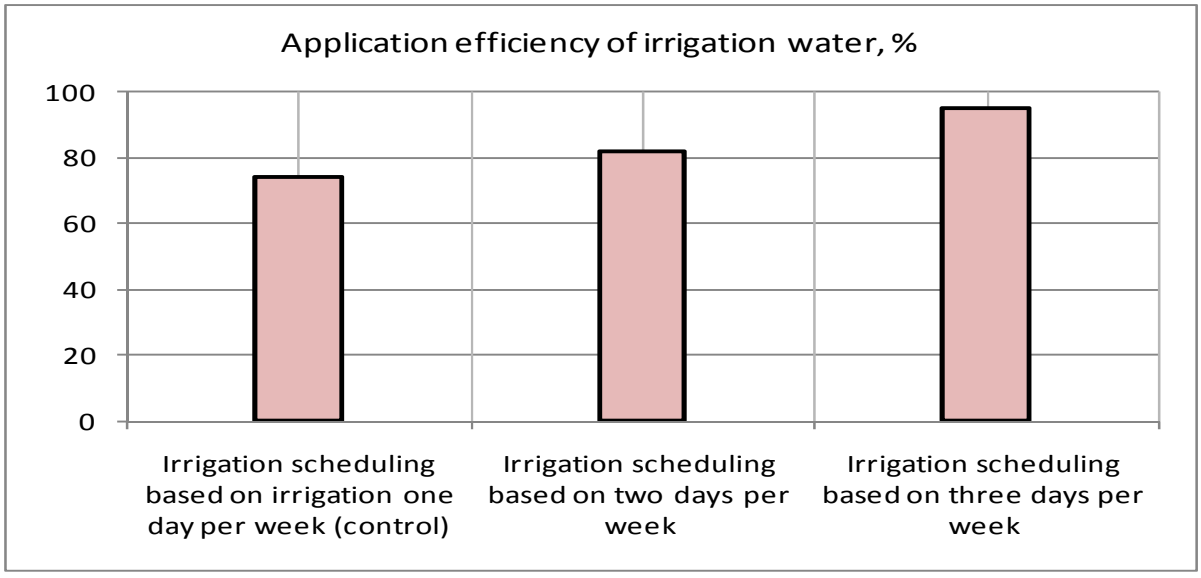


Fig. 2: Effect of irrigation scheduling under rotational irrigation system on application efficiency of irrigation water

Water stress on citrus trees

The obtained results of soil moisture content "SMC" before and after irrigation during two weeks only as illustrated in figure (3) indicate that, there was positive impact for irrigation scheduling on water stress "WS" with rotational irrigation system where, maximum WS has been observed under IS1compared with the other treatments as well as the minimum WS has been observed under IS3 in both seasons .The acceptable reduction of WS occurred within the irrigation scheduling in three days and that might be due to increasing the soil moisture content through three days inside effective root zone and this is due to increasing AE_{IW} and increasing water storage capacity inside effective root zone and kept the wetted soil volume in effective root zone and then the roots of citrus trees would not suffer from water stress under IS3 compared with IS1.

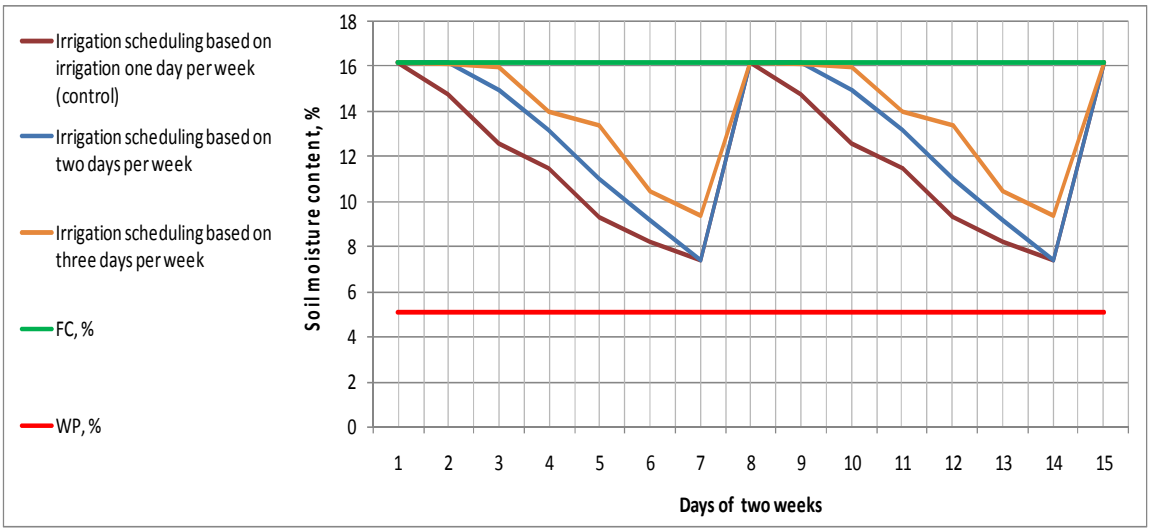


Fig. 3: Effect of irrigation scheduling under rotational irrigation system on water stress on citrus trees (Noval orange, Lemon, Sour orange and Grapefruit)

Yield of citrus trees

In general, the obtained results in tables (2, 3, 4 and 5) show that number of irrigation days significantly affected the yield of navel orange, lemon, sour orange and grapefruit trees. However, trees irrigated for three days per week recorded the highest yield as number of fruits or Kg per tree also the yield per hectare followed in decreasing order by two then one day irrigation per week. In this concern, the highest fruit numbers for navel orange, lemon, sour orange and grapefruit, respectively were 248.00, 365.70, 290.30 and 126.00 fruits per tree had been observed when the trees irrigated for three days per week, while the lowest numbers (125 .70, 176.70, 201.70 and 81.67 fruits per tree, respectively) were observed for the same species when the trees irrigated for one day a week. As for yield as Kg per tree and ton per hectare, the highest value for the four species, respectively were 52.01 Kg and 26.00 ton for navel orange, 45.25 Kg and 22.62 ton for lemon, 49.13 Kg and 24.56 ton for sour orange and 44.93 Kg and 22.46 ton for grapefruit trees were obtained when the trees irrigated three days per week. The lowest values for yield as Kg per tree and ton per hectare (36.69 Kg and 18.34 ton) for navel orange, (32.33 Kg and 16.16 ton) for lemon, (34.05 Kg and 17.03 ton) for sour orange and (32.35 Kg and 16.17 ton) were recorded when one day irrigation per week was used. From the above mentioned results, it is clear that irrigation trees for three days weekly significantly increased yield as Kg per tree and ton per hectare for the four citrus species under investigation, this could be explain due to the increment of fruit numbers per tree comparing with the other irrigation treatments (one or two days per a week). These results are in harmony with those obtained by Juan *et al.* (2007) who reported that citrus yield is highly affected by the amount of water received in both current and previous growing seasons. In this concern, closing the irrigation period when the trees were irrigated for three days per week make stability in supplying citrus trees with irrigation water comparing with one or two days weekly and that might be due to increasing the soil moisture content through three days inside effective root zone and this is due to increasing AE_{IW} and increasing water storage capacity inside effective root zone and kept the wetted soil volume in effective root zone and then the roots of citrus trees would not suffer from water stress under IS3 compared with IS1.

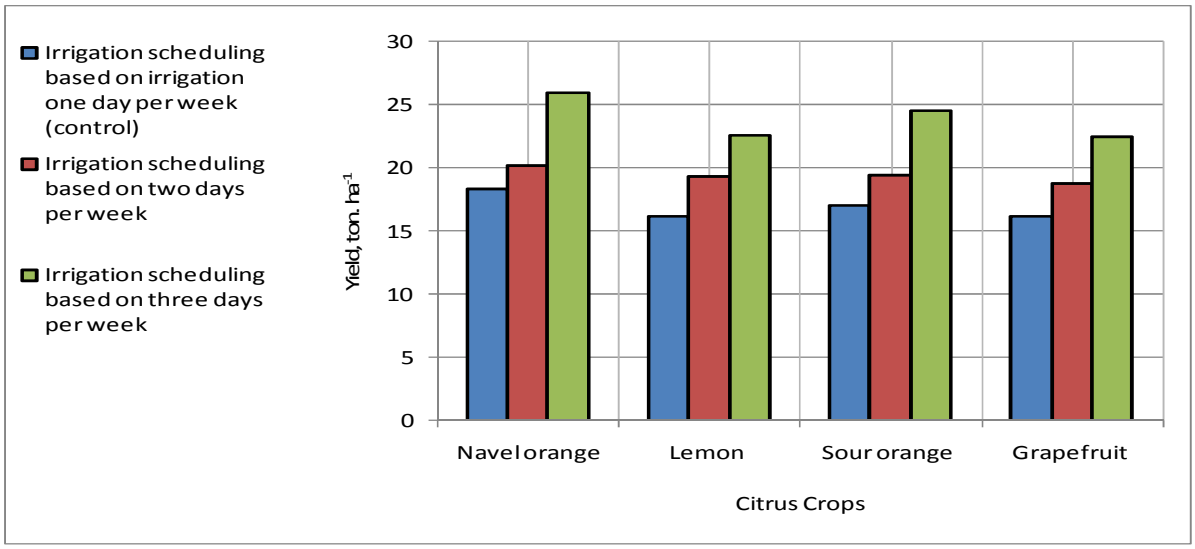


Fig. 4: Effect of irrigation scheduling under rotational irrigation systemon yield of citrus crops during average of seasons 2016 and 2017

Water productivity of citrus crops

The positive effect of the irrigation schedule WP_{citrus} with rotational irrigation system (tables 2, 3, 4 and 5) indicated the importance of increasing the days number of irrigation per week. The $WP_{citrus\ (Noval\ orange,\ Lemon,\ Sour\ orange\ and\ Grapefruit)}$ improved through seasons 2016 and 2017 where the highest values occurred with IS3 and the lowest values were occurred with IS1 as shown in figure (5).

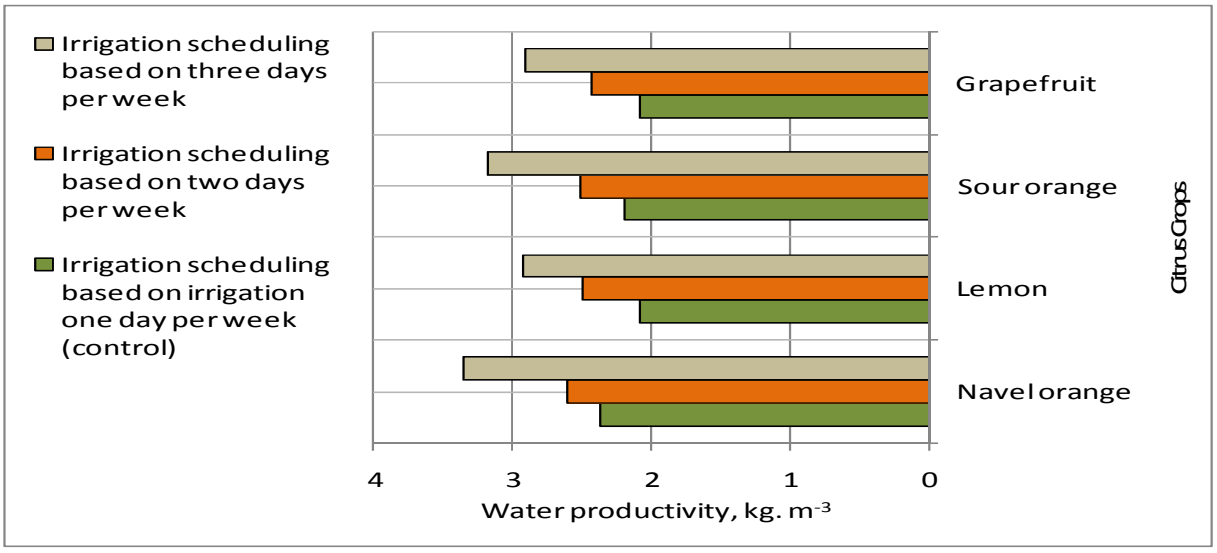


Fig. 5: Effect of irrigation scheduling under rotational irrigation systemon water productivity of citrus crops (Noval orange, Lemon, Sour orange and Grapefruit)during average of seasons 2016 and 2017.

Quality traits of citrus crops

Fruit physical properties:

The obtained results in tables (2, 3, 4 and 5) concerning fruit diameter, peel thickness, also fruit, peel and pulp weight show that irrigation treatments did not significantly affect fruit diameter of

any of navel orange, lemon, sour orange or grapefruit. Regarding peel thickness, irrigation treatments had a significant effect on peel thickness of both navel orange and sour orange, since irrigation trees as one day weekly recorded the highest value of peel thickness compared with the other irrigation treatments. On the other hand, irrigation treatments did not significantly affect peel thickness of both lemon and grapefruit. Concerning fruit, peel and pulp weight, the irrigation trees as one or two or three times per week did not show any significant effect on these parameters for all citrus species under investigation except that of lemon, where both fruit and pulp weight showed significant differences among the irrigation treatments. In this respect, irrigation trees either as one or two days a week recorded higher significant values than the three days.

Table 2: Effect of irrigation scheduling under rotational irrigation system on yield and fruit properties of navel orange (average of two years 2016 and 2017)

Variables / Treatments	No. fruit/tree	Yield/Tree, Kg	Yield, Ton/ha^{-1}	Water productivity, kg. m^{-3}	Fruit diameter cm	Peel thickness, cm	Fruit wt., gm	Peel wt., gm	Pulp wt., gm	TSS %	Acidity %	V.C mg/100 ml juice
IS1	125.70 b	36.69 b	18.34 b	2.37	8.90	0.92 a	293.67	101.00	192.67	10.33	0.54	50.67
IS2	172.70 b	40.44 b	20.22 b	2.61	7.87	0.53 b	247.00	76.67	170.33	11.26	0.63	55.47
IS3	248.00 a	52.01 a	26.00 a	3.36	7.27	0.48 b	210.00	62.67	147.33	11.76	0.61	44.80
LSD at 5 %	59.00	3.95	1.97		N.S	0.202	N.S	N.S	N.S	N.S	N.S	N.S

IS1: Irrigation scheduling based on irrigation one day per week (control), IS2: Irrigation scheduling based on two days per week, IS3: Irrigation scheduling based on three days per week.

Chemical properties:

Results of TSS% and V.C in fruit juice for the four citrus species are shown in tables (2, 3, 4 and 5). Generally, there were no significant differences for the irrigation treatments on TSS or V.C of the four citrus species. However, TSS tended to increase with grapefruit since irrigation trees for one time recorded the highest value. As for, V.C, although the differences lacked significance, the trees irrigated as two days show the highest value of V.C. this was true for the four species under the study. In respect to fruit juice acidity, there were significant differences for the irrigation treatments with sour orange and grapefruit only, since the intermediate treatment (two irrigation days) gave the lowest value compared with the other treatments. On the other hand, the irrigation treatments had no effect on acidity value of both navel orange and lemaon. Fruit properties in general, did not affect by different irrigation treatments.

Table 3: Effect of irrigation scheduling under rotational irrigation system on yield and fruit properties of lemon (average of two years 2016 and 2017)

Variables / Treatments	No. fruit/tree	Yield/Tree, Kg	Yield, Ton/ha^{-1}	Water productivity, kg. m^{-3}	Fruit diameter, cm	Peel thickness, Cm	Fruit wt., gm	Peel wt., gm	Pulp wt., gm	TSS %	Acidity %	V.C mg/100 ml juice
IS1	176.70 b	32.33 c	16.16 c	2.09	6.77	0.45	183.00 a	62.33 a	120.67	7.93	6.93	30.40
IS2	199.30 b	38.60 b	19.30 b	2.49	6.90	0.55	194.00 a	72.00 a	122.00	8.50	6.29	32.00
IS3	365.70 a	45.25 a	22.62 a	2.92	6.10	0.45	126.70 b	40.00 b	86.67	8.00	5.54	30.40
LSD at 5 %	98.72	4.50	2.25		N.S	N.S	48.26	15.42	N.S	N.S	N.S	N.S

IS1: Irrigation scheduling based on irrigation one day per week (control), IS2: Irrigation scheduling based on two days per week, IS3: Irrigation scheduling based on three days per week.

Table 4: Effect of irrigation scheduling under rotational irrigation systemon yield and fruit properties of sour orange (average of two years 2016 and 2017)

Variables / Treatments	No. fruit/tree	Yield/Tree, Kg	Yield, Ton/ha^{-1}	Water productivity, kg. m^{-3}	Fruit diameter cm	Peel thickness, cm	Fruit wt., gm	Peel wt., gm	Pulp wt., gm	TSS %	Acidity %	V.C mg/100 ml juice
IS1	201.70 b	34.05 c	17.03 c	2.20	7.83	0.88 a	171.67	81.33	90.33	10.83	4.22 b	23.47
IS2	265.00 a	38.93 b	19.47 b	2.51	7.57	0.75 b	147.67	72.33	75.33	11.03	3.79 b	23.47
IS3	290.30 a	49.13 a	24.56 a	3.17	7.77	0.77 b	170.33	76.00	94.33	11.03	4.69 a	21.33
LSDat 5 %	62.95	3.53	1.76		N.S	0.05	N.S	N.S	N.S	N.S	0.464	N.S

IS1: Irrigation scheduling based on irrigation one day per week (control), IS2: Irrigation scheduling based on two days per week, IS3: Irrigation scheduling based on three days per week.

Table 5: Effect of irrigation scheduling under rotational irrigation systemon yield and fruit properties of grapefruit (average of two years 2016 and 2017)

Variables / Treatments	No. fruit/tree	Yield/Tree, Kg	Yield, Ton/ha^{-1}	Water productivity, kg. m^{-3}	Fruit diameter cm	Peel thickness, Cm	Fruit wt., gm	Peel wt., gm	Pulp wt., gm	TSS %	Acidity %	V.C mg/100 ml juice
IS1	81.67	32.35 c	16.17 c	2.09	9.70	0.72	401.67	110.67	291.00	10.47	1.60 a	19.20
IS2	97.67	37.68 b	18.84 b	2.43	9.50	0.77	385.67	100.00	285.67	8.90	1.41 b	22.40
IS3	126.00	44.93 a	22.46 a	2.90	9.37	0.82	370.33	111.33	259.00	9.47	1.58 a	21.87
LSD at 5 %	N.S	3.87	1.93		N.S	N.S	N.S	N.S	N.S	N.S	0.143	N.S

IS1: Irrigation scheduling based on irrigation one day per week (control), IS2: Irrigation scheduling based on two days per week, IS3: Irrigation scheduling based on three days per week.

Conclusion

The obtained results indicate that, citrus yields under rotational irrigation system increased as a result of increasing the irrigation day numbers per week. In this respect, the application of weekly water requirements in three days induced variable values of citrus yields. The highest significant value was detected with irrigation in three days weekly concerning yield as ton ha^{-1} comparing with one or two irrigation days per a week. This was true for the four citrus species under the study. The increasing of citrus yields might be due to improving the application efficiency of irrigation water as resulted by increasing the number of irrigation days per week which means saving the total water amount that went out of effective root zone by deep percolation, thus, mitigating the water stress inside effective root zone in addition to enhancing the application of fertigation process.

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