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Washington Navel Orange Productivity as affected by Deficit Irrigation water and Potassium Application.

A: Effect on flowering behavior, fruiting, fruit splitting, amounts of applied water, and water use efficiency

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ABSTRACT

A field experiment was conducted in a private farm (30° 50′ 44.35″ N 30° 26′ 13.32″ E, and 3.35 m above mean see level) at Hamour village, El-Bustan area, El-Behiera governorate, Egypt during the 2016, 2017 and 2018 growing seasons to study the impact of three deficit irrigation and potassium foliar spry treatments on flowering behavior, fruit set, fruit yield, fruit splitting of Washington navel orange trees, amounts of applied water and water utilization efficiency. The trees under study were 25 years budded on sour orange rootstock and irrigated by surface drip irrigation system. A split plot experimental design with four replicates was used to implement the field experiment. The main plots included three irrigation treatments (I_1: irrigation at 100% ETo (control treatment), I_2: irrigation at 80% ETo, and I_3: irrigation at 60% of ETo). The sub-plots included two potassium foliar spry treatments (K0: without spry, and K1: with spry). The obtained results proved that deficit irrigation at 60% of ETo with or without foliar application of potassium mostly was efficient in increasing the total number of inflorescences (leafy plus leafless floral inflorescences) per branch. The data also revealed that irrigation rates at both 80 % and 100% (as a control) with foliar sprays of potassium produced the highest number and percentage of fruit set/branch compared to other treatments. These results were supported with significant differences. Moreover, irrigation treatment at 100% of ETo followed by irrigation at 80% of ETo with foliar potassium spray at 1% concentration, also, achieved the highest number of fruits/tree and increased fruit yield (as Kg/tree). On the other hand, the aforementioned two treatments significantly increased fruit splitting number and its percentage, yet irrigation at 60% of ETo significantly reduced fruit splitting, especially when accompanied by foliar potassium sprays.

Keywords: Deficit irrigation, Washington navel orange trees, potassium application, and fruit splitting.

Introduction

Citrus is one of the most important horticultural crops in Egypt due to its high economic value for the local markets and export as well. The total area occupied by citrus in 2016 was 533835 feddans and produced 4646579 tons of fruits. From such area, 156514 feddans are cultivated by Washington navel orange trees; representing about 29.32% of the total area producing 1697222 tons of fruits; representing about 36.53% of the total citrus production (Annual Book of Agricultural Statistics, 2015).

An adequate supply of irrigation water is a major limiting factor to agricultural production. Water is the most important environmental constraint determining growth and fruit yield of citrus trees in new reclaimed areas especially Boustan area (El-Behera governorate) which is considered as the main agricultural zone of citrus trees. The availability of water for irrigation is expected to be decreased in the future due to increased demands of water other sector, scarcity of water resources, increment of populations density and increasing agricultural area through water saving measures. Thus, in order to achieve a better water management, deficit irrigation strategy (Lorite *et al.,* 2004) could be employed. In sustained deficit irrigation, irrigation water is reduced during the whole growing season or during different growth stages of navel oranges (Holtz, 2004). Therefore, deficit irrigation (DI) strategy; involves the same total reduction in water supply throughout the year based on potential seasonal evapotranspiration (ETo), or regulated DI, which involves moderate or severe reductions in water supply during part or parts of the seasonal cycle of citrus tree development, coinciding with periods of low water stress sensitivity (Lampinen *et al.,* 1995). Deficit irrigation strategies are employed in semi-

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arid regions such Boustan zone to save water and to improve water-use efficiency with several Mediterranean crops including olives (*Olea europaea* L.) (Alegre *et al.,* 1999), almonds (*Prumus dulcis*, Mill. D. A. Webb.) (Girona *et al.,* 2005) and citrus [(Romero *et al.* (2006), Maria Gasque *et al.* (2016) and Panigrahi *et al.* (2012).

Thus, increasing water scarcity demands a more efficient and optimized use of irrigation water is considered as one of the most promising approaches for attaining this objective through deficit irrigation (RDI). RDI consists of reducing water supplies during certain stages of crop development, when yield and fruit quality might have a low sensitivity to water deficits, and providing normal irrigation doses during the rest of the season, especially during critical periods or phonological stages with a higher sensitivity to water deficits (Chalmers *et al.,* 1986). The present share of water in Egypt is less than 1000 m^3/capital/ year which is equivalent to the international standards of water poverty limit (El-Quosy, 1998).

Deficit irrigation can be profitable when irrigation costs are high or water supplies are limited, also deficit higher net incomes per unit of applied water than the fully irrigated farms (English *et al.,* 1990). In sandy soils, Koo and Smajstria (1985) reported that the greatest fruit set and yields of citrus occurred when about 80% of the area under the tree canopy was irrigated. Besides, Ali and Gobran (2002) concluded that irrigation when 50% of available soil moisture is depleting combined with potassium spray application improves growing, flowering, fruiting and water use efficiency of Washington navel orange trees.

During March-June; soil moisture promotes spring flushes (vegetative and floral flushes) and increases canopy size and fruit yield. Moreover, the plant water status regulates many physiological processes including leaf physiology; which affects crop productivity in citrus (Gomes *et al.,* 2004). Information on leaf physiological parameters such as net-photosynthesis, stomatal conductance and transpiration in response to irrigation offers a better understanding of tree-water relationship and its effect on crop performance under water deficit condition, and could be used for optimizing irrigation scheduling in navel orange trees.

The objectives of this work were to study the impact of deficit water and potassium foliar applications on flowering behavior, fruit set, fruit yield, fruit splitting of Washington navel orange trees, amounts of applied water and water use efficiency.

Materials and Methods

The present study was carried out in a private orchard farm (30°50′ 44.35″ N 30°26′ 13.32″ E, and 3.35 m above mean see level) at Hamour village, El-Bustan area El-Behiera governorate, Egypt during three successive years of 2016, 2017 and 2018 on twenty five years old navel orange trees (Citrus sinensis,Osheck L.) budded on sour orange rootstock grown in sandy soil. The main goals of this study was to assess the effect of deficit irrigation and foliar potassium spray treatments on flowering behavior, fruit set, fruit yield, fruit splitting, amounts of applied irrigation water and water use efficiency of the trees.

Physical and chemical characteristics of the soil at the experimental site:

Soil samples from two depths (0-30 and 30-60cm) were collected to determine the main physical and chemical characteristics of the soil at the experimental site.

A: Physical characteristics:

The following soil physical parameters were determined:

- Particle size distribution: Particle size distributions (sand, silt and clay percentages) of the soil at the experimental site were determined by the hydrometer according to FAO (1970). Also, soil texture class was identified.
- Soil bulk density: Bulk density values were determined in undisturbed soil samples using the core method (Black and Hartge, 1986).
- Hydraulic conductivity: Saturated hydraulic conductivity was measured in the laboratory according to Klute and Dirksen (1986).

B: Chemical characteristics:

Electrical conductivity (ECe) of soil paste extract, soil pH, soluble ions concentrations were measured in soil paste extract, and total calcium carbonate were determined according to Page *et al*. (1982).

The measured values are presented in Tables 1 & 2.

Table 1: Main physical properties of the soil at the experimental site.

Soil depth (cm)	Bulk density (g cm^{-3})	Hydraulic conductivity (cm h^{-1})	Particle size distribution			Texture class*
			Sand %	Silt %	Clay %	
0-30	1.63	212.46	92.2	4.0	3.8	Sand
30-60	1.64	228.60	94.2	2.4	3.4	Sand

Table 2: Main chemical properties of the soil at the experimental site.

Soil depth (cm)	ECe dS m^{-1}	pH 1:2.5	Total $CaCO_3$ g kg^{-1}	Soluble cations (mmolc L^{-1})				Soluble anions (mmolc L^{-1})			
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0-30	0.68	8.89	18.4	1.5	1.00	4.19	0.18	1.5	1.5	3.5	0.37
30-60	0.72	8.91	14.9	2.0	1.50	3.66	0.22	2.0	1.5	3.0	0.88

Experimental design and tested treatments:

A split plot design with four replicates was used to implement the field experiment. Three irrigation treatments represented the main plots, and two potassium treatments represented the sub-plots. The tested treatments were as follow:

Main plots (Irrigation):

I1: irrigation with amounts of water equal to 100% ET_o (as a control).
I2: irrigation with amounts of water equal to 80% ET_o.
I3: irrigation with amounts of water equal to 60% ET_o.

Sub-plots (Potassium):

K0: without foliar spry (control).
K1: with foliar spry.

Each tree received 5 liters of the spray solution, i.e. 30 g/tree of 1.0% concentration using commercial potassium product (60% K_2O).

Cultural practices:

Twenty four navel orange trees (Citrus sinensis, L.) budded on sour orange rootstock, spaced at 4 X 5m with total planting density of 210 trees fed^{-1}, were selected to conduct the field experiments. The trees were 25-yr old, nearly uniform in vigor and size and received the same cultural practices usually adopted for growing orange at El-Bustan area according to the recommendations of Ministry of Agriculture and Land Reclamation, Egypt.

The trees were irrigated daily with fresh water (from Nubaria Canal) using surface drip irrigation system. Irrigation treatments started in the second week of February and stopped after harvesting in October of the three seasons. Minimum amounts of irrigation water were applied during the rest of the season. The irrigation system includes an irrigation pump (50 hp) connected to sand and screen filters and a fertilizer injector tank. The conveying pipeline system consists of a 63 mm PVC main line connected to 50.8 mm PVC sub-main line and 38.1 mm PE manifold. The drip lateral lines of 16 mm diameter are connected to the manifold line. Each lateral line is equipped with built-in emitters of 4 L/h discharge rate spaced at 0.5 m. There were two drip lines per tree raw.

Plant measurements:

A. Flowering behavior:

During the period from April 10 to April 20 of the three seasons two branches, with circumference of 4 – 5 cm, in two different directions (north east to south west) were tagged from each tree, and the number of leafy and leafless inflorescences on each branch were recorded, then the total number of leafy and leafless inflorescences was calculated.

B. Fruit setting behavior:

During the three experimental seasons, number and percentages of fruit sets in each leafy and leafless inflorescence in two different dates i.e. May 5 and June 13. The fruit set percentage in each leafy or leafless inflorescence was calculated according to the following equation:

$$\%\ \text{Fruit set} = \frac{\textit{No. of fruit set in each infl.}}{\textit{Total No. of fruit set in each infl.}} \text{ X } 100$$

C. Fruit splitting:

During the period from August 15 to September 7 of the 2016, 2017 and 2018 seasons; number and percentages of the split fruits/tree were recorded.

D. Fruit number and yield:

In November of 2016, 2017 and 2018 seasons, number of fruits for each tree was listed. On December of each season, average fruit weight of 8 randomly selected mature fruits was estimated for each tree. Fruit yield of each tree was then calculated as kg per tree.

Soil water relations:

1- Amounts of irrigation water (AIW):

The AIW was calculated according to the equation given by Vermeiren and Jopling (1984) for drip system as follows:

$$AIW = ET_o * \frac{\pi}{4} * D^2$$

Where:

AIW = Daily of applied irrigation water (liter / day).

ET_o = Reference evapotranspiration (mm d^{-1}).

D = Diameter of the tree shade in the afternoon (m^2)

The reference evapotranspiration (ETo) values were calculated from class A pan measurements as follows:

$$ET_o = Epan \times Kpan. \quad \text{(Dorenbos and Pruitt, 1984)}$$

Where:

Epan is the measured pan evaporation values (mm/day).

Kpan is the pan coefficient that equals 0.75 for the experimental site.

Based on the actual emitter discharges, the irrigation time was calculated according to the equation given by Ismail (2002) as follows:

$$Ti = \frac{AIW\ (\frac{liter}{day})}{n\ x\ qx\ Ea}$$

Where:

AIW= Daily of applied irrigation water (liter / day).

Ti = irrigation time (hours/day).

n = number of drippers per tree.

q = emitter discharge (m^3/h).

Ea = Irrigation efficiency of the drip irrigation system, an average value of 0.9 was used as determined in the beginning of each season (Ismail, 2002).

2- Irrigation Water Use Efficiency (IWUE):

The IWUE values were calculated according to Jensen (1983) as follows:

$$IWUE = \frac{\textit{Orange fruit yield (Kg/fed.)}}{\textit{Applied irrigation water } (m^3/fed.)}$$

Statistical analysis:

The collected data were statistically analyzed using split plot design according to Snedecor and Cochran (1990). Averages were compared using the least significant difference (LSD) at 5% probability level.

Results and Discussion

I- Influence of deficit irrigations, potassium foliar application and their interactions on flowering behavior:

Results in Table (3) indicated that the deficit irrigation treatment at the rate of 60% ETo was significantly the highest in the number of leafy, leafless and total floral in florescence's ;especially in the first and third seasons, while in the second one, the differences were not statistically significant when compared to other irrigation treatments.

As for the influence of foliar spray with potassium on the number of leafy, leafless and total floral inflorescences; the data in Table (3) generally revealed that potassium spray at 1% was superior in this respect when compared to the control. Although the differences were not high enough to be significant yet; the differences were significant in number leafy inflorescence's and total number of inflorescences regarding the third season.

The interaction among deficit irrigation rates and foliar potassium application; the results in Table(3) revealed that irrigation rate at 60% with or without potassium spray resulted in the highest number of leafy, leafless and total number of floral inflorescences and the differences were significant, particularly in 1st and 3rd seasons. Moreover, interactions among irrigation rate at 80% ETo with foliar potassium spray at 1%; in the first and second seasons, resulted the highest interaction in the number of leafly and leafless inflorescences. Moreover, the interaction between this treatment without potassium spray produced significantly a higher total number of floral inflorescences when compared with the control (interaction at 100%). Conversely, interaction between irrigation rate at 80% of ETo with foliar potassium spray, resulted in a significantly the lowest interaction in number of leafy, leafless and total number of floral inflorescences during the third season (Table 3).

This result seem to be in agreement with those reported by Nir *et al.* (1972) who studied flower bud differentiation of Eureka lemon during drought treatments and before re-irrigation and suggested that the influence of water stress may inhibit production of GA3 gibberellin in water stressed root system, and that amount of stress is necessary to induce flowering. Likewise, Pire and Rojas (1999) studied the effect of drought stress on flowering of Tahiti lime. They found that the flowering response was increased by increasing the level of drought stress.

Influence of deficit irrigation rates, foliar application of potassium and their interactions on fruit set:

Results concerning the effect of deficit irrigation rates on number of fruit set/branch on each in florescence type through fruit set counting dates (on May, 5 and June, 13) showed that, in the three seasons, deficit irrigation rates at 80% of ETo; almost markedly increased number of fruit set on leafly floral inflorescences with significant differences when compared to control trees (irrigated at 100% of ETo) (Table 4). This result held true through two dates of set counting. Nevertheless, the numbers of fruit set on leafless inflorescences were not significantly affected by different deficit irrigation treatments.

Table 3: Effect of deficit irrigation, potassium foliar application of solution and their interactions on the number of leafy and leaf less inflorescences of Washington navel orange trees during 2016, 2017 and 2018 growing seasons

Treatments	First Season (2016)			Second Season (2017)			Third Season (2018)		
	Leafy inflor. number	Leafless inflor. number	Total number	Leafy inflor. number	Leafless inflor. number	Total number	Leafy inflor. number	Leafles s inflor. number	Total number
Main effect (Irrigation):									
I1: 100% ETo	59.94 ab	7.44 b	67.38 ab	67.25 a	8.50 a	75.75 a	63.59 a	7.94 b	71.53 a
I2: 80% ETo	51.31 b	7.94 ab	59.25 b	67.31 a	8.94 a	76.25 a	59.31 a	8.44 b	67.75 a
I3: 60% ETo	65.63 a	10.50 a	76.13 a	57.75 a	10.81 a	68.56 a	61.69 a	10.66 a	72.34 a
L.S.D at 0.05	**12.72**	**2.72**	**11.62**	**ns**	**ns**	**ns**	**ns**	**1.62**	**ns**
Sub effect (Potassium sprays):									
K0: without potassium	55.67 a	8.25 a	63.92 a	58.63 b	9.08 a	67.71 a	65.92 a	9.38 a	75.29 a
K1: with potassium	62.25 a	9.00 a	71.25 a	69.58 a	9.75 a	79.33 a	57.15 b	8.65 a	65.79 b
L.S.D at 0.05	**ns**	**ns**	**ns**	**9.16**	**ns**	**10.71**	**8.45**	**ns**	**8.23**
Irrigation × Potassium									
I1 × K_0	61.13 a	8.38 ab	69.50 a	66.63 a	8.63 ab	75.25 ab	63.13 ab	7.44 b	70.75 ab
I2 × K_0	42.50 b	3.50 b	46.00 b	61.13 ab	5.75 b	66.88 b	66.81 a	12.25 a	79.06 a
I3 × K_0	63.38 a	12.88 a	76.25 a	48.13 b	12.88 a	61.00 b	67.63 a	8.44 b	76.06 a
I1 × K_1	58.75 ab	6.50 b	65.25 a	67.88 a	8.38 ab	76.25 ab	63.88 ab	8.44 b	72.31 a
I2 × K_1	60.13 a	12.38 a	72.50 a	73.50 a	12.13 a	85.63 a	51.81 b	4.63 c	56.44 b
I3 × K_1	67.88 a	8.13 ab	76.00 a	67.38 a	8.75 ab	76.13 ab	55.75 ab	12.88 a	68.63 ab
L.S.D at 0.05	**17.32**	**5.43**	**17.50**	**15.71**	**4.79**	**18.19**	**14.667**	**2.16**	**14.56**

Means within a column with the same letter are not significantly different

Table 4: Effect of deficit irrigation rates, foliar application of potassium solution and their interactions on the number of fruit set on May, 5 and June, 13 of Washington navel orange trees during 2016, 2017 and 2018 growing seasons.

Treatments:	First Season (2016)				Second Season (2017)				Third Season (2018)			
	Fruit set number on May, 5.		Fruit set number on June, 13.		Fruit set number on May, 5.		Fruit set number on June, 13.		Fruit set number on May, 5.		Fruit set number on June, 13.	
	In leafy	In leafless	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor
Main effect (Irrigation rates).												
I1: 100% ETo	16.81 b	3.75 a	4.13 a	0.44 a	24.38 a	2.13 a	4.94 a	0.63 a	20.28 b	3.19 a	3.66 ab	0.50 a
I2: 80% ETo	26.69 a	2.63 a	4.38 a	0.50 a	24.49 a	2.94 a	4.56 a	0.88 a	25.53 a	2.22 a	4.28 a	0.69 a
I3: 60% ETo	20.75 ab	3.06 a	3.00 b	0.06 b	14.75 b	1.44 a	3.44 b	0.69 a	18.59 b	2.16 a	3.38 b	0.31 a
L.S.D at 0.05	**6.94**	**ns**	**1.01**	**0.29**	**5.37**	**ns**	**1.11**	**ns**	**4.63**	**ns**	**0.81**	**ns**
Sub effect (potassium sprays).(K)												
Without Potassium (K0)	16.88 b	2.38 b	3.71 a	0.21 b	20.87 a	2.00 a	3.29 b	0.58 a	23.75 a	2.33 a	4.67 a	0.50 a
With Potassium sprays at 1.0% (K1)	25.96 a	3.92 a	3.96 a	0.46 a	21.54 a	2.33 a	5.33 a	0.88 a	19.19 b	2.71a	2.88 b	0.50 a
L.S.D at 0.05	**5.66**	**1.45**	**ns**	**0.23**	**ns**	**ns**	**0.91**	**ns**	**3.78**	**ns**	**0.66**	**ns**
Irrigation rates × Potassium Sprays												
I1 × K_0	11.00 c	2.38 b	4.38 a	0.25 ab	24.50 ab	1.88 ab	4.38 bc	0.25 ab	23.00 ab	2.38 b	3.75 bc	0.38 ab
I2 × K_0	23.00 ab	2.00 b	4.63 a	0.38 ab	26.10 a	2.25 ab	3.00 cd	1.50 a	28.13 a	2.81 ab	5.38 a	1.06 a
I3 × K_0	16.63 bc	2.75 ab	2.13 b	0.00 b	12.00 c	1.88 ab	2.50 d	0.00 b	20.13 b	1.81 b	4.88 ab	0.06 b
I1 × K_1	22.63 ab	5.13 a	3.88 a	0.63 a	24.25 ab	2.38 ab	5.50 ab	1.00 ab	17.56 b	4.00 a	3.56 bc	0.63 ab
I2 × K_1	30.38 a	3.25 ab	4.13 a	0.63 a	22.88 ab	3.63 a	6.13 a	0.25 a	22.94 ab	1.63 b	3.19 cd	0.31 ab
I3 × K_1	24.88 ab	3.38 ab	3.88 a	0.13 b	17.50 bc	1.00 b	4.38 bc	1.38 ab	17.06 b	2.50 b	1.89 d	0.56 ab
L.S.D at 0.05	**9.28**	**2.53**	**1.61**	**0.43**	**7.60**	**2.28**	**2.04**	**1.41**	**7.58**	**1.48**	**1.54**	**0.98**

Means within a column with the same letter are not significantly different

With regard to the influence of foliar spray of potassium on number of fruit set/branch on different types of floral inflorescences, the data in Table (4) declared that foliar application with potassium at 1% resulted in the highest number of fruit set in both leafy and leafless in florescence's and the differences were significant; especially in the 1st and 2nd seasons. A vice-versa, trend held true in the third one.

As for interaction, the data in Table (4) revealed that; in general when deficit irrigation was performed at either of 80 or 100% with or without potassium spray, in the three seasons, achieved significantly the highest interactions for fruit set number in leafy and leafless floral inflorescences. On the contrary, interaction between irrigation rate at 60% ETo without foliar application with potassium had markedly the lowest interaction for fruit set number on both leafy and leafless floral inflorescences. This result is in agreement with those obtained by El-Abd (2005) and Abo El-Enein (2012) on Washington navel oranges, as the highest fruit set number and percentages was found with the trees irrigated with 4000 m^3/fed/year and irrigation 70% of FC. Besides, this treatment recorded the lowest fruit drop %. In addition, Zaghloul *et al.* (2015) showed that decreasing or increasing soil moisture content may subject roots to inefficient water which caused an increase in fruit drop% especially during June drop period, so to avoid that stress, soil must be kept fairly wet during summer months.

Influence of deficit water irrigation rates and foliar application of potassium solution and their interactions on fruit set percentages:

The results in Table (5) showed that in most cases, when deficit water irrigation rate at 80% ETo was employed; it produced the highest percentages of fruit set on leafy and leafless floral inflorescence through the date of fruit set counting (on May, 5 and June, 13) and the differences were statistically significant. This trend was similar to those of obtained in fruit set number.

With regard to the influence of foliar sprays of potassium on fruit set percentages (Table5), the results revealed that no significant differences were observed on fruit set percentages with or without foliar application of potassium during the dates of fruit set counting. This result was valid through the three seasons of the study. Conversely, foliar application with potassium at 1% applied resulted in the highest significant fruit set percentages as compared to control treatment.

The interactions among different irrigation rates with foliar potassium spray generally indicated that water irrigation rates at either 80 or 100% ETo with or without foliar potassium sprays were significantly superior in fruit set percentages on both leafy and leafless inflorescence. This result held true regarding fruit set counting during the three seasons of the study (Table 5).Conversely, the interactions among different deficit irrigation rates and foliar potassium sprays were not significant in fruit set percentages on both leafless and leafy inflorescences in 2nd and 3rd seasons, respectively.

These results are in agreement with the findings of Panigrahi *et al.* (2012) who reported that the maximum fruiting (fruit set and yield) of Nagpur mandarin was observed when drip irrigation (DI) applied at 80% (Ecp). They concluded that optimum quantity application of water through (DI) at (80%Ecp) was desirable water stress on Nagpur, mandarin trees; thus improving fruit yield and fruit quality without producing the higher vegetative growth. Likewise, Castel (2015) on Clementine mandarin trees; found that irrigation with 50% ET was insufficient in both seasons; producing high water stress and reducing tree growth; and that optimum growth of the trees was obtained with irrigation at 110% ETo. He also noticed that number of emitters per tree did not significantly affect tree water status neither tree growth, nor flowering, fruit set or yield. Yet, water irrigation amount, however, significantly affected all these variables. Koo and Smajstrla (1985) found that the greatest fruit set percentages and yield of citrus trees occurred when about 80% ET of the area under the tree canopy was irrigated. Moreover, Abdel-Missih *et al.* (1977) on Washington navel oranges reported that the growth rate of the fruits were generally enhanced by the addition of more water. They added that severe water stress decreased fruit set, yield and fruit quality and that irrigation at 2/3 available soil moisture resulted in the best results.

The increment in fruit set and fruit set percentages due to foliar application with potassium was reported by Ali and Gobran (2002) who studied the effect of foliar spray with potassium at 2% (potassium sulphate) on Washington navel orange performance they stated that this treatment significantly increased fruit characters like fruiting percentages. Moreover, Sanz *et al.* (1987) found that fruit set has been correlated to some extent with mineral levels in the leaves during the time fruit set especially potassium representing a limiting factor for fruit set.

Table 5: Effect of deficit irrigation rates, foliar application of potassium solution and their interactions on fruit set percentages on May, 5 and June, 13 of Washington navel orange trees during 2016, 2017 and 2018 growing seasons.

Treatments	First Season (2016)				Second Season (2017)				Third Season (2018)			
	Fruit set percentages on May, 5.		Fruit set percentages on June, 13.		Fruit set percentages on May, 5.		Fruit set percentages on June, 13.		Fruit set percentages on May, 5.		Fruit set percentages on June, 13.	
	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor	In leafy inflor	In leafless inflor
Main effect (Irrigation rates).												
I1: 100% ETo	29.71 b	49.62 a	6.56 ab	5.38 a	34.35 ab	25.95 a	5.84 a	10.76 a	32.03 b	37.79 a	6.08 a	4.94 ab
I2: 80% ETo	53.53 a	28.46 ab	9.14 a	9.18 a	36.35 a	20.81 ab	7.20 a	10.29 a	44.94 a	24.63 ab	7.86 a	9.73 a
I3: 60% ETo	31.62 b	21.96 b	4.63 b	0.60 b	27.75 b	13.15 b	6.63 a	5.64 a	29.56 b	17.55 b	6.25 a	3.12 b
L.S.D at 0.05	**14.88**	**21.64**	**3.24**	**4.56**	**7.35**	**10.78**	**ns**	**ns**	**10.76**	**13.32**	**ns**	**6.42**
Sub effect (potassium sprays).(K)												
Without Potassium (K0)	34.57 a	24.71 a	6.22 a	4.60 a	29.61 b	16.99 a	5.43 a	4.58 a	35.81 a	23.83 a	7.50 a	5.04 a
With Potassium sprays at 1.0% (K1)	42.00 a	41.98 a	7.33 a	5.50 a	36.02 a	22.94 a	7.68 a	13.21 a	35.21 a	29.48 a	5.95 a	6.82 a
L.S.D at 0.05	**ns**	**ns**	**ns**	**ns**	**6.00**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
Irrigation rates × Potassium Sprays												
I1 × K_0	19.19 d	36.75 ab	5.31 bc	2.70 bc	35.66 a	22.36 ab	6.31 ab	3.17 a	37.95 abc	33.15 ab	6.59 a	5.61 ab
I2 × K_0	57.31 a	17.07 b	10.46 a	11.10 a	35.17 a	13.76 ab	4.83 b	10.57 a	42.46 ab	22.46 ab	8.69 a	8.92 ab
I3 × K_0	27.20 cd	20.33 b	2.89 c	0.00 c	18.00 b	14.86 ab	5.15 b	0.00 a	27.02 c	15.88 b	7.23 a	0.60 b
I1 × K_1	40.22 abc	62.50 a	7.81 a	8.05 ab	33.03 a	29.54 a	5.38 ab	18.34 a	26.12 c	42.43 a	5.59 a	4.28 ab
I2 × K_1	49.75 ab	39.85 ab	7.81 a	7.25 abc	37.53 a	27.86 ab	9.57 a	10.01 a	47.42 a	26.81 ab	7.02 a	10.56 a
I3 × K_1	36.04 bcd	23.60 b	6.37 a	1.19 bc	37.49 a	11.44 b	8.10 ab	11.28 a	32.10 c	19.22 b	5.27 a	5.64 ab
L.S.D at 0.05	**19.36**	**28.93**	**4.66**	**7.73**	**11.14**	**17.42**	**4.36**	**ns**	**14.58**	**20.72**	**ns**	**8.94**

Means within a column with the same letter are not significantly different

Influence of deficit irrigation rates, foliar application of potassium and their interactions on the number of fruits per tree, average fruit weight, fruit yield and fruit splitting percentages:

Data in Table (6); generally revealed that when deficit water irrigation rate was applied at 100% of ETo followed by irrigation treatment at 80% of ETo produced fruit yield kg/tree; expressed as weight or number were markedly higher compared to irrigation at 60% of ETo with significant differences.

As for the influence of foliar spray with potassium on aforementioned parameters; the results in Table (6) indicated that foliar application with potassium at 1% achieved significantly the highest fruit yield expressed as weight or number during 1st, 2nd and 3rd seasons.

The interaction among different irrigation rates and foliar potassium application, generally indicated that the interactions between deficit irrigation treatments at either 100% or 80% ETo with foliar application with potassium at concentration of 1% significantly to the highest interaction for fruit yield (weight and number) compared with other interactions (Table 6). On the other hand, the worst interactions were observed when irrigation rate at 60% of ETo was applied with or without foliar potassium spray in this respect. The obtained results are in line with those reported by Panigrahi *et al.* (2012) on Nagpur mandarin trees harvested in drip irrigation (DI) at 100% ECP, followed by (DI) at 80% ECP. They explained the increment in number of fruits/tree with (DI) at 100% EC was due to smaller fruits in size and reduced its weight in this treatment. Also, observed that both fruit number/tree and its weight decreased with decreasing irrigation regimes from 80% Ecp to 40%Ecp. Besides, the highest fruit yield in DI at 80%Ecp followed by DI at 100% Ecp; also, fruit yield decreased with decreasing irrigation level from 80%Ecp to 40%Ecp. This result seem to be concomitant with our results.

The higher fruit yield under DI rates at 100% or 80%ETo might be explain that water deficit (15-20%) available soil water depletion) in root zone suppressed the vegetative growth of Washington navel orange trees via inhibiting gibberellic biosynthesis without bringing much effect on leaf photosynthesis and the trees invested higher quantity of photosynthates towards reproductive growth (fruiting) than vegetative growth. Pèrez- Pèrez *et al.* (2008) as well as Garcia-Tejero *et al.* (2010) on Lan late and Salustaina orange trees, found that fruit yield was markedly lower with a higher level of deficit irrigation rates. They concluded that a higher irrigation water productivity (IWP) resulted in DI at 80%Ecp was attributed to a higher increase in fruit yield with comparatively less increase in irrigation water use under this treatment over other treatments. Besides, Kanber *et al.* (1996) and Abu-Awaad (2001) on Washington navel orange trees and lemon trees; respectively, stated that irrigation based on pan coefficient that varied from 0.6 to 1.2 by 0.2 increments did not show any significant result in relation to yield performance of Washington navel orange trees comparing with the lemon trees performance under different irrigation regimes: 0.0%, 25%, 50%, 75%, 100% and 150% class-A pan evaporation. They stated that irrigation at 100% evaporation produced the maximum growth and highest fruit yield of lemon trees. Romero *et al.* (2006) concluded that deficit irrigation (DI) reduced trees yield on both Carrizo and Cleopatra rootstocks and significantly increased water-use efficiency (WUE). In addition, Wahbi *et al.* (2004) on olive trees; found that the partial root zone drying (PRD) at 25, 50% less applied water decreased fruit yield. They mentioned that olive yield reduction under PRD treatments was mainly due to a decrease in fruit number. PRD treatments affected significantly olive water relations.

Data concerning the effect of different deficit irrigation rates on number of fruit splitting are presented in Table (6) indicated that deficit irrigation at 60% (ETo); in three seasons, significantly reduced fruit splitting number compared with irrigation treatments at both 80% and 100% ETo (as control).

As for the effect of foliar spray with potassium solution on fruit splitting number; the results in Table (6) showed that the number of fruit splitting was not significantly affected by foliar potassium sprays through the three seasons of the experiment. No significant differences were observed between foliar potassium sprays and the control.

Concerning the interactions among the different deficit irrigation rates and foliar potassium sprays presented in Table (6); generally revealed that, in three seasons, interactions between deficit irrigation treatment at 60% ETo with or without foliar application of potassium resulted in significantly the lowest interaction for the number of fruit splitting compared with other interactions. Conversely,

Table 6: Effect of deficit irrigation rates, foliar application with potassium solution and their interactions on the number of fruit per tree, average fruit weight, fruit yield and both fruit splitting number and percentage of Washington navel orange trees during 2016, 2017 and 2018 growing seasons.

Treatments	First season (2016)					Second season (2017)					Third season (2018)				
	Total number of fruit /tree	Average fruit weight(gm.)	Fruit yield (Kg/tree)	No of Fruit splitting	Fruit splitting (%)	Total number of fruit /tree	Average fruit weight (gm.)	Fruit yield (Kg/tree)	No of Fruit splitting	Fruit splitting (%)	Total number of fruit /tree	Average fruit weight (gm.)	Fruit yield (Kg/tree)	No of Fruit splitting	Fruit splitting (%)
Main effect (Irrigation rates).															
I1: 100% ETo	239.38 a	261.38 a	62.26 a	7.75 a	3.20 b	258.63 a	257.63 a	66.23 a	11.50 a	4.50 a	254.63 a	249.13 a	63.07 a	9.63 a	3.73 a
I2: 80% ETo	229.63 ab	231.13 b	53.14 b	9.88 a	4.93 a	246.88 a	243.00 ab	59.99 a	9.50 a	3.97 ab	238.25 a	235.56 a	56.41 b	9.00 a	3.82 a
I3: 60% ETo	205.38 b	230.38 b	48.58 b	3.31 b	1.44 c	201.25 b	226.13 b	45.64 b	2.75 b	1.49 b	208.31 b	233.25 a	49.23 c	2.81 b	1.46 b
L.S.D at 0.05	31.46	17.48	8.09	3.25	1.68	41.48	29.82	9.33	5.42	2.49	22.29	ns	6.05	2.65	1.12
Sub effect (potassium sprays).(K)															
Without Potassium (K0)	201.50 b	228.75 b	46.15 b	6.33 a	3.25 a	208.83 b	237.25 a	49.88 b	6.83 a	3.21 a	208.92 b	229.25 b	48.17 b	6.83 a	3.21 a
With Potassium sprays at 1.0% (K1)	248.08 a	253.17 a	63.14 a	7.63 a	3.13 a	262.33 a	247.25 a	64.69 a	9.00 a	3.43 a	258.54 a	249.38 a	64.30 a	7.46 a	3.80 a
L.S.D at 0.05	**25.69**	**14.27**	**6.60**	**ns**	**ns**	**33.87**	**ns**	**7.62**	**ns**	**ns**	**18.20**	**17.09**	**4.94**	**ns**	**ns**
Irrigation rates × Potassium Sprays															
I1 × K_0	206.75 bc	265.25 a	54.66 bc	6.50 ab	3.20 ab	236.00 abc	263.75 a	61.84 ab	9.50 ab	4.00 ab	232.63 bc	253.75 a	58.77 a	8.00 a	4.46 ab
I2 × K_0	216.50 bc	213.50 b	45.97 cd	9.25 a	4.75 a	214.75 cd	229.75 ab	49.33 bc	7.25 abc	3.41 ab	215.63 c	218.63 b	47.07 b	9.00 a	4.16 a
I3 × K_0	181.25 c	207.50 b	37.93 d	3.25 b	1.81 b	175.75 d	218.25 b	38.49 c	3.75 bc	2.23 ab	178.50 d	215.38 b	38.67 b	3.50 b	2.01 bc
I1 × K_1	272.00 a	257.50 a	69.87 a	9.00 a	3.20 ab	281.25 a	251.50 ab	70.63 a	13.50 a	5.01 a	276.63 a	244.50 ab	67.37 a	11.25 a	4.00 a
I2 × K_1	242.75 ab	248.75 a	60.31 ab	10.50 a	5.12 a	279.00 ab	256.25 ab	70.67 a	11.75 a	5.54 a	260.88 ab	252.50 a	64.75 a	9.00 a	3.50 ab
I3 × K_1	229.50 abc	253.25 a	59.24 ab	3.38 b	1.08 b	226.75 bcd	234.00 ab	52.79 b	1.75 c	0.75 b	238.13 bc	251.13 a	59.80 a	2.13 b	0.90 c
L.S.D at 0.05	**50.63**	**26.00**	**12.72**	**4.49**	**2.21**	**53.07**	**42.70**	**13.24**	**7.20**	**3.30**	**34.43**	**31.22**	**9.23**	**4.06**	**1.63**

Means within a column with the same letter are not significantly different

interactions among deficit irrigation rates at 80 or 100% ETo with or without foliar potassium sprays; gave the highest interaction in number of fruit splitting.

Concerning the different deficit irrigation treatments on fruit splitting percentages; the data represented in Table (6), indicated that both irrigation rates at 100% and 80 % ETo significantly increased fruit splitting percentages when compared to water stress at 60%. This result held true during the three seasons of the study. Nevertheless, mostly, the differences were not statistically significant through the second and third seasons of the study.

Concerning the influence foliar potassium sprays on fruit splitting percentages, the results in Table (6) showed that no significant variation was observed in fruit splitting percentage resulted with foliar potassium application.

The interactions among different deficit irrigation treatments and foliar potassium sprays, revealed that deficit irrigation at either 100 or 80% ET with or without foliar application with potassium significantly raised fruit splitting % when compared with irrigation at 60% ETo. Conversely, irrigation at 60% ETo gave the worst interaction and reduced from splitting percentages (Table 4).

Our results agree with those obtained by Hossein *et al.* (2014) on Pomegranate who found that partial root zone drying (PRD) strategies decreased the fruit cracking compared to full irrigation (FI) that received 100% ETc. Kuriyama *et al.* (1981) reported that water stress decreased puffiness of Satsuma mandarins but increased blemishes of Temple. On the other hand, Zaghloul and Moursi (2017) reported that irrigation treatment at 100% of EP (I_2) scored the best results of decreasing splitting and creasing fruits with high significant differences during the two study seasons. Likewise, Rubino *et al.* (2004) showed that, physiological disorders (creasing, splitting and scald) are associated with water shortage and water irrigation quality.

Applied irrigation water (AIW) for Washington navel orange trees.

Measured pan evaporation values (mm/d) and applied irrigation water for Washington navel orange trees during the 2016, 2017 and 2018 seasons are presented in Table 7. Results indicated that average monthly amounts of irrigation water applied to the trees varied form 17.82 L/tree/d during January and reached its maximum value of 55.80 L/tree/d during Aug. (Table 7). Results indicated that, average applied irrigation water under the drip irrigation system was 2829.9 m^3/year/fed. This amount was 29.25 to 52.8% less than that of (4000-6000 m^3/fed) reported by El-boray *et al.* (1995b) for highest Washington navel orange production under surface irrigation system. Our obtained amount was 17% less than that of (3078 m^3/fed) reported by Hassan *et al.* (2001) for highest Washington navel orange production under drip irrigation system. Results of this study were in close agreement with those reported by Hoffman *et al.* (1984). They used one-third less water amount in drip-irrigated orange plots in Arizona, USA, han flood irrigation plots.

Table 7: Evapotranspiration values (mm/d) and applied irrigation water (AIW) for Washington navel orange trees during 2016, 2017 and 2018 seasons.

Month	2016 ETo (mm/d)	2016 AIW L/tree/d	2017 ETo (mm/d)	2017 AIW L/tree/d	2018 ETo (mm/d)	2018 AIW L/tree/d	Average AIW L/tree/d	Average AIW m^3/mon/fed
Jan.	3.43	20.58	2.97	17.82	2.74	16.44	18.3	119.0
Feb.	3.82	22.92	4.19	25.14	3.14	18.84	22.3	145.2
Mar.	4.86	29.16	5.36	32.16	4.89	29.34	30.2	196.7
Apr.	6.64	39.84	7.48	44.88	6.60	39.60	41.4	269.8
May	7.98	47.88	8.05	48.30	8.28	49.68	48.6	316.5
Jun.	8.34	50.04	7.62	45.72	9.12	54.72	50.2	326.5
Jul.	8.79	52.74	7.81	46.86	9.30	55.80	51.8	337.2
Aug.	8.99	53.94	7.71	46.26	8.37	50.22	50.1	326.4
Sep.	7.76	46.56	6.75	40.50	6.71	40.26	42.4	276.3
Oct.	5.52	33.12	5.46	32.76	5.61	33.66	33.2	216.0
Nov.	3.74	22.44	4.09	24.54	6.65	39.90	29.0	188.5
Dec.	2.71	16.26	2.87	17.22	3.00	18.00	17.2	111.7
Sum								**2829.9**

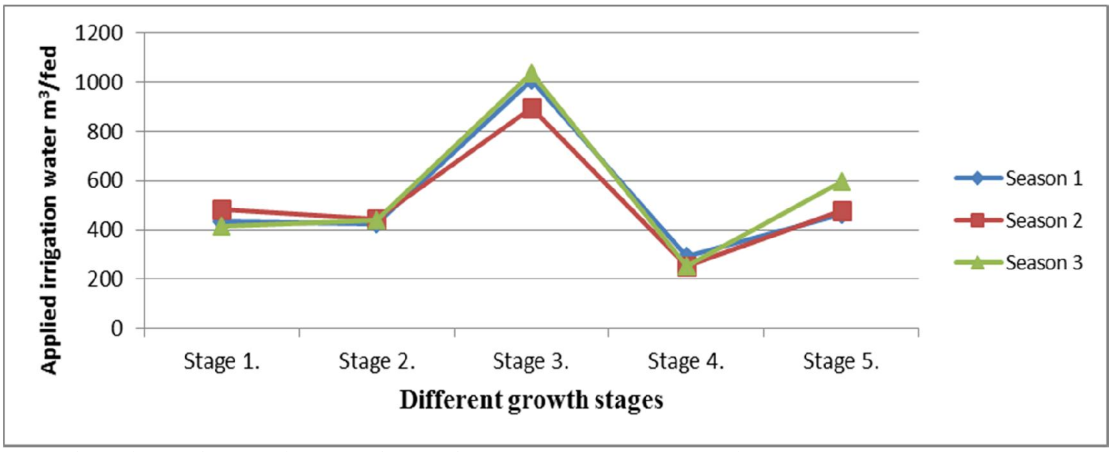
Applied irrigation water (AIW) during growth stages of Washington navel orange trees:

Data from Table (8) and fig (1); indicated that the highest values of applied irrigation water was observed through fruit growth stages from 30 May to 30 Aug. during the three years of the study. The values were 1009.17, 894.01 and 1034.70 m^3/fed. For 1st, 2nd and 3rd seasons, respectively. On the contrary, the lowest AIW was noticed in colour break stage (maturity stage). The values were 293.33, 255.15 and 253.64 m^3/fed. during 2016, 2017 and 2018 seasons.

The increment of applied irrigation water in fruit growth stage during 30 May to 30 Aug. might be attributed to that the fruits required a high amount of water for growth; addition the higher temperature degree, than that any other growth stage.

Table 8: Applied irrigation water (AIW) during growth stages of Washington navel orange trees through 2016, 2017 and 2018 seasons.

Different growth stages	2016 m^3/fed	2017 m^3/fed	2018 m^3/fed
1- Flowering and vegetative growth 25 Feb. to 15 Abr.	435.55	482.72	414.65
2- Fruit set stage 15 Apr. to 30 May.	427.14	445.66	437.72
3- Fruit growth stage. 30 May. to 30 Aug.	1009.17	894.01	1034.70
4- Fruit colour break stage 30 Aug. to 1 Oct.	293.33	255.15	253.64
5- Fruit ripening stage. 1 Oct. to 30 Dec.	462.84	479.97	594.19
Sum	**2628.03**	**2557.51**	**2734.90**



Stag1: Flowering and vegetative growth 25 Feb. to 15 Apr. Stage2: Fruit set stage 15 Apr to 30 May.
Stage3: Fruit Growth stage. 30 May. to 30 Aug. Stage4: Fruit color break stage 30 Aug. to 1 Oct.
Stage5: Fruit ripening stage. 1 Oct. to 30 Dec.

Fig.1: Applied irrigation water (AIW) during growth stages of Washington navel orange trees through 2016, 2017 and 2018 seasons

Irrigation water use efficiency (IWUE**).**

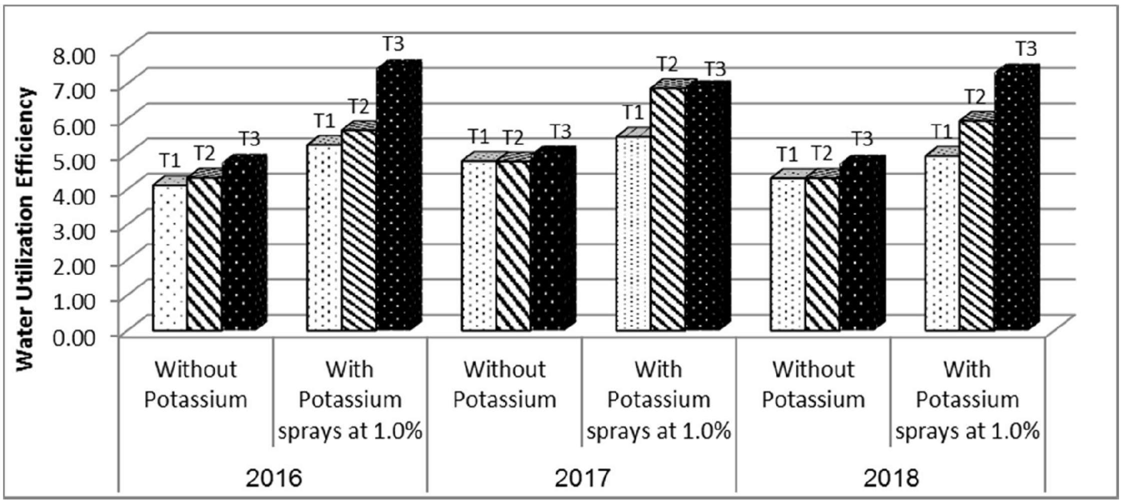
Results of average irrigation water use efficiency values obtained under the experimental conditions in Boustan area for T_1, T_2 and T_3 treatments with or without foliar application with potassium solution as shown in Table (9) and Fig. (2). proved that the highest values of IWUE (m^3 fed^{-1}) were noticed under drip irrigation at 100% of ETo with foliar application with potassium during three experimental seasons of study. On the contrary the lowest values of IWUE (m^3 fed^{-1}) were observed when irrigation was applied at 60% of ETo without potassium application during 1st, 2nd, 3rd seasons. Irrigation at 80% of ETo was intermediate in IWUE (m^3 fed^{-1}) with potassium spray.

Moreover, Zaghloul and Moursi (2017) found that the highest overall mean values of water use efficiency (kg/m^3) were recorded under irrigation treatments both at 80% (I_1) and 100% (I_2) EP compared to farmer irrigation treatment (I_0).

Table (9). Effect of tested treatments on applied irrigation water and irrigation water use efficiency with and without foliar potassium application of Washington navel orange trees through 2016, 2017 and 2018 seasons.

IRR Treatment	2016			2017			2018		
	AIW* (m^3 fed^{-1})	IWUE (kg m^{-3} water applied)		AIW* (m^3 fed^{-1})	IWUE (kg m^{-3} water applied)		AIW* (m^3 fed^{-1})	IWUE (kg m^{-3} water applied)	
		Without Potassium	With Potassium sprays at 1.0%		Without Potassium	With Potassium sprays at 1.0%		Without Potassium	With Potassium sprays at 1.0%
T1-Irrigation at (100% ETo)	2787.17	4.12	5.26	2699.74	4.81	5.49	2857.94	4.32	4.95
T2-Irrigation at (80% ETo)	2229.74	4.33	5.68	2159.79	4.80	6.87	2286.36	4.32	5.95
T3-Irrigation at (60% ETo)	1672.30	4.76	7.44	1619.84	4.99	6.84	1714.77	4.74	7.32

AIW: Applied irrigation water, **IWUE**: Irrigation water use efficiency.



T1-Irrigation at (100% ETo), T2-Irrigation at (80% ETo), T3-Irrigation at (60% ETo).

Fig. 2: Effect of deficit irrigation and potassium spray treatments on utilization efficiency (Kg fruits/m3 applied water) values.

Recommendation

It could be recommended that deficit water irrigation rates at either 100% or 80% of ETo were the efficient treatments to achieve the highest number of fruit/tree and increase of fruit yield (as Kg/tree); especially when applied with foliar application with potassium. Besides, these two previously treatments produced the highest number and percentages of fruit set per branch. Conversely, water stress treatment at 60% of ETo significantly reduced fruit splitting.

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