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Effect of some Drip Irrigation and Nano-Silicon Treatments on Growth, Yield and Water Relations of "Washington Navel" Orange Trees Grown in New Reclaimed Soils

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ABSTRACT

The deficiency of irrigation water is a main factor of limiting the growth and production of fruit trees, particularly in arid and semi-arid areas regions. So this study was conducted in order to assess the influence of applying silicon in the nano form to minimize the negative effects caused by water stress. A field trial was behaved in 2016 and 2017 seasons at Beheira Governorate to study the effect of three rates of drip irrigation viz. high irrigation rate (control=100%) and two deficit irrigation regimes (75 and 50% from the control), foliar application of nano- silicon (0, 100, 200 and 300ppm) and their interaction on growth, yield and water relations of "Washington Navel" orange trees grown in sandy soil and irrigated by drip irrigation method. The findings showed that, deficit irrigation treatment (I_3) was related with reduced vegetative growth aspects (canopy volume, No. of shoots /branch, Shoot length) as well as stomatal resistance, however transpiration rate was increased in both seasons, in addition, nano-silicon spraying at 300 or 200ppm caused a significant increase in previous growth aspects over the control. The combination between high or moderate irrigation rate (I_1 or I_2) with nano-silicon spray at 300 ppm (S_4) were more effective in enhancing growth parameters. In both seasons, deficit irrigation treatment (I_1) decreased leaf mineral contents and increased leaf proline content. However, high concentration of nano-silicon markedly increased leaf mineral contents but reduced leaf proline contents. Both low and high irrigation rates (I_2 and I_3) or high concentration of nano-silicon (S_4) and their interaction achieved the highest values of bound water and osmotic pressure and the lowest values of total and free water contents. Furthermore, the yield and components, water use efficiency and most of external and internal fruit properties were significantly increased under moderate irrigation (I_2) or high concentration of nano-silicon and their interaction (I_2 x S_4), while, the percentage of fruit splitting was decreased. Finally, trees irrigated with moderate irrigation rate combined with nano-silicon at (300 ppm) enhancement the growth, yield and fruit properties. On the contrary decreased fruit splitting(%) and applied irrigation water by 25% , whereas, increased water use efficiency compared to high irrigation rate (control) without nano-silicon spray.

Keywords: Irrigation regimes, Nano -silicon and Citrus trees

INTRODUCTION

Citrus is one of the most important types of fruit, which has economic advantages among other fruit types. It is considered the first popular fruit in Egypt due to its high nutritional value, cheap prices and the international reputation in the foreign markets for its excellent fruit qualities. In Egypt the total area of cultivated citrus reached 3237157 fed. with annual production 3438030 tons (FAO, 2016). Drought stress is the main aspect controlling the growth and productivity of fruit crops in arid and semiarid regions, (Todorov *et al.*, 1998). Under the circumstances of climate change and the reduction of water resources facing Egypt, we must do our utmost to effectively secure irrigation water at the orchards level.

Fertilization with mineral elements such as silicon affects the drought tolerance of many crops (Epstein,1999). Silicon application may therefore improves crop production under drought circumstance (Zhu and Gong, 2014) which deposits in cell walls of xylem vessels inhibit compression of the vessels under conditions of high transpiration rate caused by drought. However, the silicon–cellulose membrane in epidermal tissue also protects plants versus extreme loss of water by transpiration this action occurs for owing a reduction in the width of stomatal pores and then a reduction of leaves transpiration rate (Efimova, and Dokynchan, 1986). For this reason, application of silicon can improve the water and economic situation in droughts (Gong *et al.*,2003).

Silicon is a key component of its benefits to plants, improving vegetable growth, fruit productivity and quality, and photosynthesis in response to abiotic stresses such as drought and salinity (Abdel Gawad, 2015 and Helalya *et al.*, 2017). However, Asgharipour and Mosapour, (2016) who declared that silicon spraying improved growth and physiological indices hence could increase the ability of plants to resistance water stress which reduces transpiration leads to water stress tolerance.

Nano-fertilizers are used to control nutrient delivery, which is a powerful tool for achieving agriculture and sustainable environment. Using of Nano-fertilizers reduces soil pollution, decreasing the negative effects which associated with overdose of chemical fertilizers, reduces repeated use of fertilizers and improvement the use efficiency of fertilizers.(Naderi and Danesh-Shahraki, 2013) So, the topical of this study was to estimate the sensible effects of three irrigation regimes, foliar spray of nano-silicon which might help relieve the probable adverse effect of deficit irrigation and their interaction on vegetative growth, nutritional status, water relations, yield, fruit properties and water use efficiency of "Washington Navel" orange trees grown in sandy soil.

MATERIALS AND METHODS

The study was conducted in a commercial orchard in 2016 and 2017 growth seasons on eleven-year-old of "Washington Navel" orange trees (*Citrus sinensis* (L.) Osbeck) grafted on Volkamer lemon rootstock grown on a sandy soil (spaced at 4 x 6 m). The orchard was situated in El-Nubaria region (30° 66' N Latitude and 30° 06' E Longitude), Beheira Governorate, Egypt. Trees were cultivated under drip irrigation method and submitted to cultural practices ordinarily done in this region.

The characterization of soil and moisture constants (%) before beginning the experimental are given in Table 1.

The slected trees were vigour, symmetric and healthy as possible and arranged in split plot design as follows:

I. The main plots were assigned in three irrigation rate as:

I_1. Control (100%- as followed in the farm): each tree received 23.147 m^3 of water/year

I_2- Moderate irrigation treatment (75% from the control): each tree received 17.36 m^3 of water/year

I_3- Deficit irrigation treatment (50% from the control): each tree received 11.56 m^3 of water/year

Table 1. Soil characterize of the experimental location.

Ec (dSm^{-1})	O.M (%)	PH	Available (ppm) N	P		K
1.47	0.50	8.20	17.1	5.2		58.47
Particle size divisions (%)			Textural class	Soil moisture properties (%)		
Sand	Silt	Clay		FC*	WP*	AW*
88.57	4.73	6.70	Sandy	12.07	4.22	7.85

***, FC=Field capacity, WP=Wilting point, AW=Available water**

The rates of irrigation water (the control, moderate, deficit) were organized by 16, 12, 8 drippers /tree (4L/hr), respectively at two lateral JR line (dripper each 50 cm) for each row of the trees. The amount of irrigation water = No. of drippers x discharge of dripper (L/hr) x operating time. Irrigation water applied (litter $tree^{-1}$ and $m^3 feddan^{-1}$) were showed in Table 2.

Table 2. The quantity of irrigation water utilized in various irrigation rates in 2016 and 2017 seasons.

Treatment	I_1= Control (100%) (as followed in the farm) 2016	2017	Mean	I_2= Moderate irrigation (75% from control) 2016	2017	Mean	I_3= Deficit irrigation (50% from control) 2016	2017	Mean
l/tree/year	22235	24060	23147	16676.25	18045	17360	11117.5	12030	11573.7
m^3/tree/year	22.235	24.06	23.147	16.676	18.045	17.36	11.117	12.03	11.563
m^3/fed/year	3891.125	4210.5	4050.8	2918.34	3157.87	3038.10	1945.56	2105.25	2025.40

II. The sub plots were ranged for three foliar sprays of nano-silicon beside the control were applied at four times (the first week of March, April, May and June) as follow:

S_1= Control (Water spray)

S_2= Nano-silicon at 100ppm

S_3= Nano-silicon at 200ppm

S_4= Nano-silicon at 300ppm

The characterization and preparation of nano- silicon: Nano-silicon; 12-30 nm in diameters were prepared on Material Science and Nanotech. Dep. lab. Fac. Post-graduate studies for Adva. Sci., Beni-Suef Univ., Egypt.

The combinations between the two factors resulting twelve treatments (3 irrigation rates x 4 foliar applications) each treatment replicated three times with three trees in each replicate (3 replicate x 3 trees).

The following data were recorded:

1- **Vegetative growth aspects:** Number of shoots and shoot length in addition tree canopy volume (CV) was calculated according to Castle, 1983. Leaf area (cm^2) was estimated as stated by Chou, 1966. Stomatal resistance (s cm^{-1}) and transpiration rate (µg H_2O m^{-2} s^{-1}). Were defined on fully stretched leaves by a Portable Steady StatePorometer (LI – COR Model LI 1600).

2-Nutritional status:

Leaf mineral content. At the end of September from non-fruiting spring flush shoots 40 mature leaves/ tree were sampled, washed, dried at 70°C to constant weight ground and digested. The digested solution was used for the determination of N, P, K and Ca nutrients as described by A.O.A.C. (1995) while, leaf silicon content was determined according to Dai *et al*., (2005).

Leaf proline content (µ mole/g). was determined conferring to (Bates *et al*., 1973).

3-Water relations:

Total and free water contents in leaves tissues, also bound water content and osmotic of the cell sap of leaves were determined given to the method described by Koshirinko *et al.* (1970).

4- Yield and Water use efficiency (WUE):

At harvesting time (Mid-December in both seasons), No. of fruits/trees and yield as kg $tree^{-1}$ as well as $tonfed^{-1}$. were calculated. Water use efficiency (WUE) was calculated approving to Ali *et al*., (2007) as follow:

WUE = yield (kg/fed.) / water applied (m^3 /fed.)

5- Fruit properties:

A sample of 10 healthy fruits were taken at random from each tree at harvesting time and prepared for definition external (fruit weight (g), fruit height and diameter (cm), peel thickness (mm) and internal fruit properties. i.e. total soluble solids (TSS %) was determined by using hand refractometer, total acidity was determined as for Vit.C (mg/100 ml/juice) and TSS/acid ratio were analyzed (A.O.A.C., 1995). Number of splitting fruits was counted at weekly intervals from 15^{th} July till the time of harvesting and the percentage of splitting fruits was calculated as: No. of splitted fruits / Total No. of harvested fruits x 100.

Statistical analysis of variance (ANOVA) was implemented using MSTATC computer software program (Bricker, 1991). Differences among treatments means were examined by Duncan's Multiple Range Test (Snedecor and Cochran, 1990).

RESULTS AND DISCUSSION

1- Vegetative growth aspects:

a. Canopy volume, No. of shoots /branch, Shoot length and leaf area

Canopy volume, No. of shoots /branch, shoot length and leaf area were significantly affected by different drip irrigation rates (Table, 3). The maximum values of former mentioned growth aspects obtained from trees irrigated by the high irrigation rate (control-I_1) followed by moderate irrigation treatment (I_2), while the minimum values in this regard were found by trees subjected to deficit irrigation rate (I_3). Vegetative growth reduction under deficit irrigation treatment (I_3) could be attributed greatly to minimal assimilate availability through decrease net photosynthesis rate under water stress (Mpelascoka *et al*., 2001) In addition, the drought stress encouraged abcisic acid (ABA) production in root and transmission to the vegetative parts and increased consistence of reactive oxygen species (ROS) which reduction the vegetative growth (Atkinson *et al*., 2000).These results agree with the findings of Ennab and El-

Sayed (2014), Zayan *et al*., (2017) and Zaghdan and Abo El-Enien(2019) stated that the increase of vegetative growth parameters were remarkably decreased under irrigation water deficit of citrus trees. Related results were reported by Mikhael *et al*.,(2010) on peach trees and El-Zawily (2016) on "Washington Navel" orange trees.

For nano-silicon spraying treatments (Table, 3), the results showed that, spraying trees with 300 ppm nano-silicon (S_3) gave the higher values of the growth parameters than the other spraying treatments, compared with the least growth parameters were obtained in the sprayed trees with tap water (S_1) in both seasons. Foliar application of nano-silicon had positive effect on vegetative growth aspects might have attributed due to the effect of silicon in improving the tolerance of the trees to all stresses, increased photosynthetic activity of trees, water metabolism, chlorophyll content, antioxidant activities, protective enzymes under drought circumstance and enhancement uptake of necessary nutrients (Ma and Takahashi, 2002 and Roshdy, 2014). Similar results were noticed by Ibrahim and Al- Wasfy (2014), Abo El-Enien *et al*., (2017) and Kotb and Abdel-Adl (2017) on citrus trees and Helalya *et al*., (2017) on mango trees, who found that, using silicon effectively enhanced vegetative growth characters.

A significant interaction among drip irrigation rates and nano-silicon spraying was found to exist on the vegetative aspects (Table, 3). Moderate irrigation combined with nano-silicon at 300 ppm (I_2x S_4) had expressively greater growth values than those sprayed with water (control) under deficit irrigation treatment (I_3x S_1) in both seasons.

b. Stomatal resistance and transpiration rate:

Among the studied treatments of irrigation rate (Table, 3), the high irrigation rate (I_1) registered the lowest stomatal resistance values followed by (I_2) Whereas, deficit irrigation treatment (I_3) recorded the highest values in this regard. The transpiration rate markedly decreased with decreasing irrigation water rate, so the highest rate obtained with high irrigation rate (I_1) in the first season while in the second one (I_1) and (I_2) gave the highest rates without significant variations between them. Oppositely the lowest rate obtained by (I_3). A decline in transpiration under water deficiency associate with a stomatal mechanism, because the stomata are usually closed under water limited circumstances (De Sen *et al*., 2007). That findings are in concord with those declared by Mahmoud *et al*.,(2017) who found that water deficit decreased transpiration rate but, increased stomatal resistance values on basil plants. Spraying the trees with nano-silicon at 300 ppm or 200ppm significantly enhancement stomatal resistance values and decreased transpiration rate comparing with the control (S_1). The reduction of transpiration rate casing by foliar application of silicon could be attributed to silicon accumulates in the leaf, forming a doubled layer of cuticle. This accumulation supports a reduction in transpiration and decrease water loss by the plant (Freitas *et al*., 2011). Such result is in line with those of Mahmoud *et al*., (2017) and Pereira *et al*., (2013). The highest values of stomatal resistance belonged to (I_3 x S_4), meanwhile the least values recorded by the combination treatment of (I_1 x S_1). However, the transpiration rate was increase under (I_1 x S_1) combination treatments compared with the lowest rate obtained by (I_3 x S_4).

Table 3. Effect of drip irrigation rate, nano-silicon foliar application and their interaction on the growth aspects of "Washington Navel" orange trees in 2016 and 2017 seasons.

Treatment		Canopy volume (m^3)		No. of shoots /branch		Shoot length (cm)		Leaf area (cm^3)		Stomatal resistance (s/cm)		Transpiration rate ($\mu gH_2o/cm^{-2}s^{-1}$)	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate													
I_1		26.59a	28.57 a	27.99a	28.45a	9.49a	10.49a	28.49a	29.02a	2.81c	2.92c	4.11a	4.76a
I_2		25.28b	27.31 b	24.02b	23.69b	9.11b	9.42b	27.32b	27.61b	3.19b	3.30b	3.69b	4.85a
I_3		23.14c	25.24 c	20.31c	20.44c	7.37c	8.11c	25.57c	26.22c	3.68a	4.30a	2.99c	3.21b
Silicon rate													
S_1		23.84d	25.89d	23.06d	22.92d	7.89d	8.62d	25.88d	25.93d	3.01d	3.33d	3.78a	4.22a
S_2		24.80c	26.80c	23.81c	23.85c	8.70c	9.28c	26.86c	27.84c	3.13c	3.43c	3.69b	4.02b
S_3		25.43b	27.43b	24.19b	24.74b	8.92b	9.56b	27.45b	28.17b	3.25b	3.51b	3.57c	3.90b
S_4		25.95a	28.04a	25.42a	25.27a	9.11a	9.91a	28.31a	28.52a	3.52a	3.75a	3.35d	3.61c
Inter action (I x S)													
	S_1	25.33bc	27.33 de	27.40c	28.10c	9.26c	10.03bc	28.15d	28.32de	2.72i	2.80i	4.30a	5.18a
	S_2	26.11b	28.10 cd	27.70bc	28.16bc	9.53b	10.32b	28.20d	29.00bc	2.80h	2.85hi	4.20a	4.90b
I_1	S_3	27.13b	29.00 b	28.03b	28.53b	9.53b	10.74a	28.54b	29.21ab	2.83h	2.91h	4.03b	4.75b
	S_4	27.85a	29.86 a	28.85a	29.03a	9.63a	10.89a	29.10a	29.55a	2.90g	3.13g	3.91c	4.23c
	S_1	24.15d	26.18 f	22.50f	22.38f	8.21e	8.65e	26.30g	25.32h	2.92g	3.15g	3.85c	4.00cd
	S_2	25.06c	27.00 e	24.23e	23.19e	9.15d	9.32d	27.15f	28.03e	3.03f	3.25f	3.72d	3.95d
I_2	S_3	25.80bc	27.80cde	24.35e	24.51d	9.50b	9.71c	27.51e	28.50cde	3.25e	3.28f	3.70d	3.83de
	S_4	26.06b	28.26 bc	25.00d	24.69d	9.59a	10.00bc	28.33c	28.61cd	3.56c	3.55e	3.50e	3.62ef
	S_1	22.05e	24.16 g	19.11h	18.28i	6.21i	7.19g	23.20i	24.15i	3.40d	4.06d	3.20f	3.50f
	S_2	23.26d	25.32 f	19.51h	20.22h	7.43h	8.20f	25.23h	26.51g	3.55c	4.20c	3.15f	3.22g
I_3	S_3	23.36d	25.50 f	20.20g	21.18g	7.73g	8.23f	26.32g	26.82g	3.67b	4.35b	3.00g	3.12g
	S_4	23.90d	26.00 f	22.41f	22.10f	8.10f	8.85e	27.52e	27.41f	4.10a	4.59a	2.63h	3.00g

I_1,I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year

S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon, respectively.

2-Nutritional status:

a. Leaf mineral contents

Table (4) displayed that leaf N, P, K, Ca and Si responded specifically to drip irrigation rates. Hence, irrigated trees with I_1 (control) followed by I_2 (moderate irrigation) had statistically the highest mineral content in leaves, while the reverse was true with those watered with the lowest rate of irrigation water (I_3). The positive effects of moderate irrigation rate on mineral uptake could be led to its enhancing effect on transport of dissolved nutrients by mass flow also, the suitable balance of moisture in plant creates favorable conditions for photosynthesis and metabolites translocation, which accelerate the rate of nutrients uptake. On the other hand, the uptake of nutrients was retarded under irrigation deficit circumstances may be due to reduce active rooting. Analogous noting has been reported Abo El-Enien (2012) on Washington Navel orange trees, Panigrahi (2014) on mandarin trees and Helaly *et al*., (2017) on mango trees. They found that the percentage of mineral nutrition in the leaves were decreased under deficit irrigation treatments.

The highest leaf mineral contents belonged with foliar application of nano-silicon at 300 ppm (S_4) followed in decreasing order S_3 (200ppm), S_2(100ppm) and S_1 (control).The positive effects of Si on improving leaf mineral contents might be due to it is play an important role in lessen injurious of drought and improving water and nutrients uptake. Habasy (2016), Abo El-Enien *et al*., (2017) and Kotb and Abdel-Adl (2017) mentioned that silicon was associated with the enrichment of mineral content of orange trees.

High irrigation rate (I_1) combined with foliar application of nano-silicon at 300ppm S_4 (I_1x S_4) followed by combination treatment (I_1x S_3) and (I_2x S_4) significantly increased mineral contents of leaves compared to the other combination treatments (Table, 4).

Table 4. Effect of drip irrigation rate, nano-silicon foliar application and their interaction on mineral and proline contents of "Washington Navel" orange trees in 2016 and 2017 seasons.

Treatment		N (%)		P (%)		K (%)		Ca (%)		Si (%)		Proline (µ mole/gFW)	
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate													
I_1		2.44a	2.46a	0.28a	0.26a	1.54a	1.52a	2.37a	2.33a	0.74a	0.72a	0.39c	0.41c
I_2		2.39b	2.42b	0.27b	0.25a	1.50b	1.49b	2.27b	2.25b	0.68b	0.64b	0.46b	0.48b
I_3		2.34c	2.38c	0.25c	2.3b	1.43c	1.44c	2.20c	2.17c	0.61c	0.58c	0.57a	0.56a
Silicon rate													
S_1		2.35d	2.38d	0.25d	0.23d	1.46d	1.46d	2.18d	2.15d	0.40d	0.42d	0.52a	0.53a
S_2		2.38c	2.40c	0.260c	0.24c	1.48c	1.47c	2.27c	2.23c	0.71c	0.66c	0.49b	0.49b
S_3		2.40b	2.43b	0.29b	0.27b	1.50b	1.49b	2.30b	2.28b	0.77b	0.72b	0.46c	0.48c
S_4		2.44a	2.46a	0.30a	0.28a	1.51a	1.52a	2.38a	2.35a	0.83a	0.79a	0.43d	0.44d
Inter action (I x S)													
I_1	S_1	2.40e	2.42e	0.27e	0.25d	1.52d	1.50d	2.20h	2.17i	0.42j	0.45i	0.42efg	0.44g
	S_2	2.42d	2.44c	0.24g	0.22f	1.53c	1.51cd	2.35c	2.30d	0.75e	0.70e	0.40fgh	0.42h
	S_3	2.45b	2.47b	0.30b	0.28b	1.55b	1.53b	2.38b	2.35b	0.83b	0.82b	0.37h	0.41h
	S_4	2.49a	2.50a	0.32a	0.30a	1.58a	1.55a	2.55a	2.51a	0.96a	0.93a	0.38gh	0.38i
I_2	S_1	2.35h	2.38g	0.25f	0.23e	1.48f	1.46f	2.18i	2.15j	0.40k	0.42j	0.51c	0.55b
	S_2	2.38f	2.40f	0.27e	0.25d	1.50e	1.48e	2.27e	2.25f	0.72g	0.69f	0.47cde	0.49e
	S_3	2.40e	2.43d	0.29c	0.27c	1.50e	1.51cd	2.31d	2.29e	0.79d	0.72d	0.45def	0.48f
	S_4	2.44c	2.47b	0.30b	0.28b	1.52d	1.52c	2.35c	2.31c	0.81c	0.75c	0.40fgh	0.42h
I_3	S_1	2.30j	2.35i	0.23h	0.21g	1.40j	1.42i	2.15j	2.12k	0.38l	0.40k	0.62a	0.60a
	S_2	2.33j	2.37h	0.25f	0.23e	1.42i	1.43h	2.18i	2.15j	0.65i	0.60h	0.59ab	0.56b
	S_3	2.36g	2.40f	0.27e	0.25d	1.45g	1.45g	2.22g	2.20h	0.70h	0.63g	0.56b	0.54c
	S_4	2.40e	2.42e	0.28d	0.27c	1.44h	1.48e	2.25f	2.23g	0.73f	0.69f	0.50cd	0.53d

I_1,I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year
S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon, respectively.

b. Leaf proline contents

Irrigation regimes treatments showed significant variations in leaf proline content. The highest values in this respect (0.74 and 0.72 µ mole/g fw) recorded with deficit irrigation treatment (I_3) followed by moderate irrigation treatment (I_2),but the lowest values (0.39 and 0.41 µ mole/g fw) were recorded under high irrigation rate (I_1) in both seasons, respectively (Table, 4).These results exposed negatively correlation between irrigation rates and proline content this means under water stress the hydrolysis of proteins increase which increased accumulation of proline content in leaves. In the same line, Mikhael *et al*., (2010) and Ennab and El-Sayed (2014), who stated that prolinc content in leaves was increased under deficit irrigation conditions.

Leaf proline content was increased with decreasing nano-silicon concentrations from 0 up to 300ppm.The highest values in this respect recorded by the control (S_1) meanwhile the least values obtained with the high concentration of nano-silicon (S_4= 300ppm) in both seasons. the reduction of proline contents resulting to silicon spray may be led to the role of silicon to prevent hydrolysis of proteins in plant. Similar results were reported by Qin and Tian (2009), Helalya *et al*., (2017) and Hamed *et al*., (2017) on mandarin trees.

With regard to, the effect of interaction (I x S), the data of both seasons showed that, deficit irrigation treatment (I_3) combined with low concentration of nano-silicon (I_3 x S_1) resulted the highest values of proline content followed by (I_3 x S_2) . Furthermore, the lower values belonged with the combination treatment (I_1 x S_4) and (I_2 x S_4).

3- Water relations:

Results in Table (5) revealed that, total and free water contents in leaf tissues were markedly decreased by decreasing irrigation rates. Deficit irrigation treatment (I_3) recorded the least values and the variances were significant in 2016and 2017 seasons. The decrease in the total and free water content under deficit irrigation conditions (I_3) could be resulted from the reduction of water absorption by the roots. In contrast, the highest values of bound water content and osmotic pressure recorded with the lower irrigation rate (I_3). These results in partial agreement with findings of were obtained by Zayan *et al*,. (2002) on grapevine, Mikhael *et al*., (2010) on peach trees and Helalya *et al*., (2017) on mango trees. They found that, total and free water contents in leaf tissues were significantly decreased while bound water content and osmotic pressure were increased with deficit irrigation.

Total and free water contents in leaf tissues were increased with decreasing the concentration of nano silicon, and the greatest values was obtained with control treatment (S_1) comparing with the highest values recorded with nano-silicon spraying at 300ppm (S_4). On the contrary, spraying nano-silicon at 300 or 200ppm raised bound water content and osmotic pressure compared with the control in both 2016 and 2017 seasons. in the same line , El-Khawaga and Mansour (2014) on pomegranate trees and Pereira *et al*., (2013) on pepper plants.

The maximum and minimum values of water relations parameters (total and free water contents) and (bound water content and osmotic pressure) in leaf tissues, respectively belonged with the combined treatment of (I_1 x S_1) and (I_2 x S_4).

Table 5. Effect of drip irrigation rate, nano -silica foliar application and their interaction on water relations of "Washington Navel" orange trees in 2016 and 2017 seasons.

Treatment		Total water content %		Free water content %		Bound water content%		Osmotic pressure(atm)	
		2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate									
I_1		63.40a	63.84a	46.64a	45.83a	16.75c	18.00b	15.37c	15.77c
I_2		58.47b	60.76b	40.44b	39.19b	18.02b	21.86a	17.07b	18.05b
I_3		54.05c	54.91c	34.93c	32.68c	19.11a	22.23a	17.82a	18.56a
Silicon rate									
S_1		60.85a	61.77a	44.14a	42.89a	16.70d	18.87b	14.97d	15.99d
S_2		58.93b	60.92a	41.27b	40.06b	17.65c	20.86a	16.65c	17.09c
S_3		58.32c	58.90b	40.06c	38.14c	18.26b	20.75a	17.42b	18.07b
S_4		56.46d	57.76b	37.22d	35.83d	19.24a	21.92a	17.89a	18.69a
Inter action (I x S)									
I_1	S_1	65.20a	65.50a	49.10a	49.40a	16.10g	16.10d	13.50h	14.13k
	S_2	64.30b	64.00a	47.53ab	46.19b	16.76f	17.81cd	14.80g	15.32j
	S_3	62.40c	63.15a	45.80ab	44.20c	16.60f	18.95bcd	16.33f	16.50h
	S_4	61.70d	62.71ab	44.15bc	43.55d	17.55d	19.16bcd	16.86e	17.13g
I_2	S_1	61.10e	62.70ab	45.19b	43.10e	15.91g	19.60bcd	15.03g	16.32i
	S_2	58.32g	63.50a	41.20cd	40.00f	17.12e	23.50a	17.25d	17.95e
	S_3	59.28f	59.46bc	40.18d	38.13g	19.10b	21.33abc	17.80c	18.80d
	S_4	55.18i	57.40cd	35.21ef	35.53i	19.97a	21.86ab	17.94bc	19.13b
I_3	S_1	56.25h	57.12cd	38.15de	36.19h	18.10c	20.93abc	16.37f	17.53f
	S_2	54.18j	55.28de	35.10ef	34.00j	19.07b	21.28abc	17.91bc	18.00e
	S_3	53.28k	54.10de	34.20f	32.11k	19.08b	21.99ab	18.13b	18.92c
	S_4	52.52l	53.16e	32.30f	28.42l	20.22a	24.74a	18.88a	19.80a

I_1, I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year
S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon, respectively

4-Yield and water use efficiency (kg/m^3):

a. Number of fruits/ tree, Kg/ tree and ton / fed.

Data obtaining during both 2016 and 2017 seasons available in (Table, 6) stated that, the yield estimated in No. of fruits tree^{-1}, Kg tree^{-1} and ton fed^{-1}. were gradually decreased by decreasing drip irrigation rate. The maximum yield was attained by high drip irrigation rate (I_1) and moderate rate (I_2) without significant variances between them in most cases, while, the least values were resulted by deficit irrigation treatment (I_3).This results could be attributed to increase average fruit weight and number of fruit per trees. In this regard, El-Abd *et al*., (2012) and Conesa *et al*., (2018) in citrus trees.

Trees sprayed by nano- silicon had significant promotion on the fruit yield (Table, 6) expressed in No.of fruits tree^{-1}, Kg tree^{-1} and ton fed^{-1}. relative to the control (S_1). The promotion was associated with nano- silicon at 300 ppm (S_4) comparing to the other treatments in both seasons. Results in conformity with those obtained by Habasy (2016), Hamed *et al*., (2017), Abd-Elall and Hussein (2018) on citrus trees.

The highest fruit yield were obtained by (I_1 x S_4) and (I_2 x S_4) combined treatments without significant changes between them, even though, the combined treatment (I_1 x S_1) gave the lowest values in both seasons (Table, 6).

b. Water use efficiency (WUE)

The highest values of water use efficiency (Table, 6) were attained from trees irrigated under deficit irrigation (I_3) and moderate irrigation treatments (I_2) followed by trees irrigated with high irrigation rate (I_1). Similar results were achieved by Mikhael *et al*., (2010) on peach trees, Mali *et al*., (2015) on litchi and El-Zawily (2016) on Navel orange trees.

Concerning to the foliar application of nano-silicon, the results in Table (6) revealed that, spraying trees with high concentration (S_4) gave the highest significant values of water use efficiency followed by 200 ppm (S_3). El-Khawaga and Mansour (2014) on pomegranate trees and Mahmoud *et al*.,(2017) on basil plants, who found that silica nanoparticles sprayed at 60 ppm increased water use efficiency under deficit irrigation conditions.

About, the interaction between irrigation rate and foliar application of nano-silicon was significant in both seasons and the highest values of WUE belonged to (I_3 x S_4) combination treatment comparing with the lowest values achieved by (I_1 x S_1).

5-Fruit properties:

a. External properties

About external fruit properties (fruit weight and diameter and peel thickness) data in Table (7) showed that, the highest fruit weight and diameter obtained with the control (I_1) and moderate irrigation treatments (I_2) achieved the values of fruit weight and diameter without significant variances between them , but significantly lower values came with deficit irrigation treatment (I_3). Conversely, The highest values of peel thickness (4.71 and 4.72 mm) recorded by lower irrigation rate (I_3) followed in decreasing order moderate irrigation treatment (4.62 and 4.67mm) and control treatment (4.59 and 4.63mm) in both seasons, respectively. The lowering in fruit weight could be due to decrease fruit cell expansion under deficit irrigation through decreasing water content of cells (Behbudian *et al*., 1994). These results accorded with those stated by El-Abd *et al*., (2012), Moursi and Abo El-Enien (2015) and Conesa *et al*., (2018) on citrus trees.

Table 6. Effect of drip irrigation rate, nano-silicon foliar application and their interaction on yield of "Washington Navel" orange trees in 2016 and 2017 seasons.

Treatment		No. of fruits/tree		Yield(Kg/tree)		Yield (Ton/fed)		Water use efficiency (kg/m^3)	
		2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate									
I_1		254.2a	242.7a	66.75a	65.7a	11.6a	11.0a	3.0c	2.8c
I_2		249.5b	236.7a	65.5a	61.6b	11.4a	10.7a	3.8b	3.8b
I_3		207.3c	209.7b	51.1b	52.0c	8.9b	8.7b	4.7a	4.4a
Silicon rate									
S_1		219.5d	213.5d	55.64d	53.2d	9.3d	9.5d	3.5d	3.3d
S_2		235.2c	227.4c	60.2c	57.3c	10.0c	10.2c	3.8c	3.6c
S_3		243.6b	234.7b	63.0b	59.9b	10.4b	10.7b	4.0b	3.8b
S_4		249.5a	243.1a	65.62a	62.9a	11.0a	11.2a	4.2a	4.0a
Inter action (I x S)									
I_1	S_1	235.0e	226.3de	60.6e	57.9ef	10.6e	10.1ef	2.7j	2.6j
	S_2	251.0d	241.0bc	65.2d	62.3cd	11.4d	10.9cd	2.9i	2.8i
	S_3	263.0ab	247.6ab	69.1bc	64.7bc	12.1bc	11.3bc	3.1h	2.9h
	S_4	268.0a	256.0a	71.9a	68.0a	12.5a	11.9a	3.2h	3.1h
I_2	S_1	233.3e	219.3ef	60.1e	55.9fg	10.5e	9.7fg	3.5g	3.4g
	S_2	249.6d	235.0cd	64.9d	60.8de	11.3d	10.6de	3.8f	3.7f
	S_3	255.0cd	242.0bc	67.1cd	63.0cd	11.7cd	11.0cd	3.9ef	3.8ef
	S_4	260.3bc	250.3ab	69.8ab	66.3ab	12.2ab	11.6ab	4.0e	4.0d
I_3	S_1	190.0i	195.0h	46.1h	45.7j	8.0h	8.0i	4.2d	3.9de
	S_2	205.0h	206.3g	50.4g	48.8i	8.8.1g	8.5i	4.6c	4.3c
	S_3	213.0g	214.6fg	52.8f	51.9h	9.2f	9.0h	4.9b	4.5b
	S_4	220.3f	223.0ef	55.1f	54.5gh	9.6f	9.5gh	5.1a	4.7a

I_1,I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year
S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon, respectively

For nano-silicon treatments, the minimum values of external fruit properties were obtained by the control, (S1). Spraying trees with 300 or 200 ppm of nano-silicon recorded the higher values of fruit weight and diameter as well as peel thickness than the control in both seasons. The improvement of fruit properties can be determined by the application of nano-silicon to promote the transfer of certain elements and improve the absorption capacity of water and fertilizers, which in turn increases vegetative growth, yield and fruit characteristics. These findings was supported by those Ibrahim and Al-Wasfy (2014) and El- Gioushy (2016) revealed that using silicon successfully improved physical and chemical properties of citrus fruits.

A significant interaction between drip irrigation treatments and nano-silicon spraying was found to occur on external fruit properties. It was clear that under high rate of irrigation (I_1) and moderate rate (I_1) sprayed trees at 300ppm silicon (S_4) had remarkably weightiest fruit than the other combination treatments (Table,7). The maximum values of fruit diameter were created with (I_1 x S_4) and (I_2 x S_1) treatments in both 2016 and 2017 seasons, respectively. The higher thickness of peel resulted with the combination treatments of (I_3 x S_4) and (I_2 x S_4) without significantly differs between them.

b. Fruit splitting %

Under deficit irrigation treatment (I3) the percentage of fruit splitting was increased compared to the lowest percentage came from moderate irrigation treatment (I2) in both seasons (Table, 7).In this regard, Huang *et al* (2000) showed that, during fruit development the peel Ca content was decreased under decreasing irrigation water supply ,in turn has been associated with increased incidences of fruit splitting. The same results were also attained by Romero *et al*., (2006), Correa *et al*.,(2013), Zaghdan and Abo El-Enien(2109) on citrus trees.

All concentrations of nano-silicon (Table, 7) were significantly decreased fruit splitting (%) as compared to the control. Trees were sprayed with 300ppm nano-silicon belonged the lowest values. These findings may be due to that the silicon spray enhanced generally nutritional status and regular water balance which in turn of decrease fruit splitting (%). However, The lowest percentage of fruit splitting resulted by the combination treatment of (I2 x S4) comparing with (I3 x S1) treatment which recorded the highest values in this respect in both seasons.

Internal fruit properties

Results in Table (8) reveals that TSS(%), acidity(%) and Vitamin C contents in most cases were considerably increased by decreasing irrigation rate through 2016 and 2017 seasons, The highest values of internal fruit properties (TSS, acidity and Vit.C) belonged with moderate irrigation and deficit irrigation treatments comparing to control treatment. In contrast, TSS/acid ratio was increased under high irrigation rate (the control, I1). The same results were reported by Moursi and Abo El-Enien (2015), Conesa *et al*., (2018) on citrus trees.

Total soluble solids, acidity and Vitamin C contents in most cases were obviously increased by the examined nano-silicon treatments especially with 300 or 200 ppm nano-silicon at compared to the control. However, TSS/acid ratio was decreased with increasing the nano-silicon rate. The highest ratio in this respect belonged by the control (S_1). the present result goes partly with the findings of Ibrahim and Al-Wasfy (2014), Kotb and Abdel-Adl (2017), Abd-Elall and Hussein (2018) on citrus trees.

The interaction was significant and the highest values of internal fruit properties (TSS, acidity and Vit.C) were recorded with (I_2 x S_4) and (I_3 x S_4), while the combination treatment (I_1 x S_1) increased TSS/acid ratio.

Table 7. Effect of drip irrigation rate, nano-silicon foliar application and their interaction on external properties of "Washington Navel" orange fruits in 2016 and 2017 seasons.

Treatment		Fruit weight (g)		Fruit diameter(g)		Peel thickness(mm)		Fruit splitting (%)	
		2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate									
I_1		262.41a	260.41a	8.81a	8.88a	4.59b	4.63c	8.99b	8.51b
I_2		262.25a	259.92a	8.58b	8.69b	4.62b	4.67b	7.38c	7.71c
I_3		246.75b	239.50b	7.87c	7.88c	4.71a	4.72a	10.25a	10.29a
Silicon rate									
S_1		253.00b	248.55c	8.39b	8.55a	4.53d	4.55d	9.96a	9.51a
S_2		255.33b	251.44c	8.39b	8.41b	4.59c	4.64c	9.17b	9.22ab
S_3		258.00ab	254.66b	8.37b	8.45b	4.68b	4.69b	8.79c	8.89b
S_4		262.22a	258.44a	8.53a	8.52a	4.78a	4.80a	7.57d	8.06c
Inter action (I x S)									
I_1	S_1	258.00b	256.00c	8.85b	8.83c	4.50g	4.52f	9.87d	9.50bcd
	S_2	260.00b	258.66b	8.80c	8.87b	4.55fg	4.60de	9.20e	9.07cde
	S_3	263.00ab	261.33b	8.67d	8.89b	4.62de	4.62	8.84f	8.52de
	S_4	268.66a	265.66a	8.94a	8.90b	4.71bc	4.75bc	8.03g	7.97ef
I_2	S_1	258.00b	255.00c	8.53e	8.99a	4.53fg	4.55ef	8.84f	8.10def
	S_2	260.00b	259.00b	8.52e	8.53e	4.58ef	4.62d	7.50h	8.00ef
	S_3	263.00ab	260.66b	8.55e	8.56e	4.63de	4.70c	7.20i	7.75ef
	S_4	268.00a	265.00a	8.70d	8.69d	4.75b	4.80ab	5.97j	7.00f
I_3	S_1	243.00d	234.66f	7.80i	7.81i	4.55fg	4.58def	11.18a	10.92a
	S_2	246.00cd	236.66f	7.85h	7.84h	4.65cd	4.69c	10.81b	10.60ab
	S_3	248.00cd	242.00e	7.88g	7.89g	4.77b	4.75bc	10.31c	10.42abc
	S_4	250.00c	244.66d	7.95f	7.96f	4.89a	4.85a	8.70f	9.20cde

I_1,I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year
S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon ,respectively

Table 8. Effect of drip irrigation rate, nano-silicon foliar application and their interaction on internal properties of "Washington Navel" orange fruits in 2016 and 2017 seasons.

Treatment		TSS %		Acidity %		TSS /acid ratio		Vitamin C (mg /100 ml juice)	
		2016	2017	2016	2017	2016	2017	2016	2017
Irrigation rate									
I_1		11.34c	11.78b	0.99b	1.09b	11.45a	10.74a	49.72c	48.53c
I_2		11.52b	12.27a	1.10a	1.16a	10.46b	10.53b	50.09b	49.42b
I_3		11.78a	12.30a	1.43a	1.16a	10.33b	10.54b	50.54a	50.37a
Silicon rate									
S_1		11.51a	11.78d	1.01c	1.08b	11.45a	10.84a	49.30d	48.19d
S_2		11.60a	12.07c	1.07b	1.15a	10.86b	10.47b	49.55c	49.02c
S_3		11.60a	12.20b	1.09b	1.16a	10.69b	10.52b	50.19b	49.94b
S_4		11.48a	12.33a	1.15a	1.17a	9.99c	10.57b	51.44a	50.60a
Interaction (I x S)									
I_1	S_1	11.30c	11.52f	0.95c	1.00f	11.93a	11.50a	48.83h	47.20i
	S_2	11.32c	11.63ef	0.94c	1.13cde	11.93a	10.26d	48.92h	48.13h
	S_3	11.34c	11.75de	0.98c	1.11e	11.60a	10.53bc	50.00e	48.80g
	S_4	11.40c	12.00c	1.10b	1.13cde	10.36bc	10.60bc	51.13b	50.00d
I_2	S_1	11.45bc	11.83d	0.98c	1.14cd	11.66a	10.36cd	49.21g	48.17h
	S_2	11.48bc	12.35ab	1.13ab	1.15bc	10.13cd	10.66b	49.82f	49.00f
	S_3	11.50bc	12.40a	1.14ab	1.18ab	10.10cd	10.50bcd	50.20d	50.03d
	S_4	11.65abc	12.50a	1.17a	1.18ab	9.93cd	10.60bc	51.15b	50.51c
I_3	S_1	11.78ab	12.00c	1.10b	1.12de	10.76b	10.66b	49.85f	49.22e
	S_2	12.00a	12.25b	1.14ab	1.17ab	10.46bc	10.50bcd	49.92ef	49.95d
	S_3	11.96a	12.45a	1.15ab	1.18ab	10.40bc	10.53bc	50.38c	51.00b
	S_4	11.40c	12.50a	1.18a	1.19a	9.66d	10.50bcd	52.03a	51.31a

I_1,I_2 and I_3 = 23.147, 17.36 and 11.56 m^3 irrigation water /tree/ year
S_1, S_2, S_3 and S_4 = Foliar application with 0, 100, 200 and 300 ppm of nano-silicon, respectively

CONCLUSION

According to the results obtained under the study conditions it could be recommended that watering Washington Navel" orange trees planted in sandy soil under drip irrigation system by moderate irrigation rate (75% from actual irrigation practiced in the orchard) and spraying with nano-silicon at rate 300ppm this will improve the growth aspects, yield, fruit properties and decreased fruit splitting(%). Additionally, It increases the efficiency of water use by providing irrigation water by reducing the amount of water used by 25% compared to the high irrigation rate without nano-silicon spraying.

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تأثير بعض معاملات الرى بالتنقيط والنانو سيليكون على النمو و المحصول و العلاقات المائية لأشجار البرتقال ابوسرة النامية في الأراضي حديثة الاستصلاح

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يُعد نقص مياه الري من أحد العوامل الرئيسية التي تحد من نمو وإنتاجية اشجار الفاكهة وخاصة في المناطق الجافة وشبه الجافة لذلك أجريت هذه الدراسة لتقييم تأثير الرش بالسيليكون في صورة النانو لتقليل الآثار السلبية الناتجة عن نقص مياه الرى، حيث تم اجراء تجربة حقلية خلال عامي 2016 و 2017 في مزرعة خاصة بمنطقة النوبارية بمحافظة البحيرة - مصر. و ذلك لدراسة تأثير ثلاثة معدلات من مياه الري وهى 1- 100 % (الكنترول وهو الرى المتبع فى المزرعة I_1) 2-75 % من الكنترول (معدل الري المعتدل I_2) 3- 50% من الكنترول(معدل الرى المنخفض I_3) والرش بأربعة تركيزات من النانو سيليكون (صفرو100و200و 300 جزء فى المليون) على النمو والمحصول والعلاقات المائية لأشجار البرتقال ابو سرة المنزرعة في تربة رملية تحت نظام الري بالتنقيط . أوضحت النتائج التي تم الحصول عليها ان خفض معدل الرى (I_3) كانت مرتبطا بخفض معظم قياسات النمو الخضري وقيمة مقاومة الثغور في كلا الموسمين ، بينما الرش ، بالنانو سيليكون بمعدل 300 أو 200 جزء في المليون ادى الى زيادة معنوية فى قياسات النمو الخضري. عكست النتائج المتحصل عليها من التداخل بين كل من معاملة الكنترول أو الرى المعتدل (I_1 أو I_2) مع رش النانو سيليكون بمعدل 300 جزء في المليون (S_4) أكثر فعالية في تحسين قياسات النمو. في كلا الموسمين. كما اظهرت النتائج ان خفض معدل الرى الى50% من الكنترول (I_1) ادى إلى نقص محتوى الأوراق من العناصر مع زيادة فى محتواها من البرولين فى حين أدى التركيز العالي من السيليكون إلى زيادة معنوية في محتوى الأوراق من مع نقص محتواها من البرولين. سجلت كل من معاملة معدل الري المنخفض و المعتدل (I_2 و I_3) و التركيز الأعلى من السيليكون (S_4) وكذلك التفاعل بينهم أعلى القيم للماء المرتبط والضغط الأسموزي للعصير الخلوى وأقل القيم للماء الكلى والحر. اوضحت النتائج ان معاملة الري المعتدل (I_2) أو التركيز العالي من النانو سيليكون والتفاعل بينهما زيادة محصول الثمار(كجم/شجرة و طن/فدان) وكفاءة استخدام المياه(كجم/م^3) و خصائص الثمار الخارجية والداخلية ، في حين انخفضت النسبة المئوية لتشقق الثمار. وفقًا للنتائج التي تم الحصول عليها في ظل ظروف الدراسة ، يمكن التوصية برى أشجار البرتقال ابوسرة المنزرعة في التربة الرملية بمعدل الري المعتدل (75٪ من الري الفعلي في البستان) تحت نظام الرى بالتنقيط والرش باستخدام النانو سيليكون بمعدل 300 جزء في المليون مما يؤدى إلى تحسين النمو الخضري ، والمحصول ، جودة الثمار بالإضافة الى تقليل تشقق الثمار ، بجانب زيادة كفاءة استخدام المياه مع توفير مياه الري عن طريق تقليل كمية المياه المضافة بمقدار 25 ٪ مقارنة بمعدل الري العالي بدون رش النانو سيليكون.