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Influence of Irrigation methods and foliar application of Potassium silicate on the growth and productivity of Valencia orange trees (*Citrus sinensis* L.) grown under Delta conditions.

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ABSTRACT

In Egypt, water shortages increase annually due to various factors. In Delta region, most citrus growers use flood irrigation systems whereas irrigation water is frequently applied to each furrow leading to the loss of huge amounts of water. This work hypothesized that Valencia orange trees grown on raised beds irrigated with alternate floods or fixed furrows based on principles of partial root-zone drying could maintain tree vigour, yield, fruit quality, sustain citriculture, and save irrigation water in Delta region. To test this hypothesis an experiment was conducted in the 2021 and 2022 seasons at commercial orchards in Kalubia governorate to assesstree canopy, yields, fruit quality, leaf nutrient contents, and water productivity of Valencia orange trees budded on Sour orange rootstock. Five treatments were used in the investigation farmer's method as a control (both furrow irrigation), substitute furrow irrigation (SFI) with foliar application of 2000 ppm potassium silicate (K_2SiO_3), SFI + 4000 ppm (K_2SiO_3), irrigation with fixed furrows (IFF) + 2000 ppm (K_2SiO_3), and IFS + 4000 (K_2SiO_3). Obtained results indicated that various treatments were associated with a significant reduction in the tree canopy, leaf area, and leaf N content while increasing leaf P, K, Si, and free proline content compared to control and significantly improved fruit quality parameters. Treatment of (SFI with 2000 ppm K_2SiO_3), was regarded as the best combination treatment for enhancing tree canopy, yield, and fruit quality parameters and saving about 33% of irrigation water in both study seasons.

Keywords: Flood irrigation-Fruit quality- Potassium silicate- Valencia orange-Yield.

INTRODUCTION

The agricultural sector is the main consumer of water compared to other sectors, such as industrial and domestic. Due to the aridity conditions and rising temperature, which increase average evaporation and transpiration, there are huge quantities of lost water in agriculture (Golla, 2021). Citrus, as one of the evergreen perennial fruit crops, has high water requirements. Therefore, irrigation water is one of the main determinants of the success of economic citrus production in arid and semi-arid regions (Saitta et al., 2021). Citrus trees are considered to be one of the most important fruit crops worldwide. There is a prominent economic importance of citrus among fruit crops in Egypt, which is thesixth-largest citrus producer (about 4.5 million tons) in the world, produced from cultivated areas that reach 519,788 Feddan (Annual Reports, 2022). Moreover, citrus ranks as the first fruit export, with a total of 1.8 million tons in the 2023 season. Orange exports reached about 1,027,554 tons, representing 25.07% of the total citrus production. Valencia orange occupies the second position of cultivated citrus variety in Egypt, with a cultivated area reaching to (142,224 feddan), with (125,152 feddan) fruitful producing (1344125) tons with an average of 10.74 tons per feddan (Annual Reports, 2022).

The limited water supply worldwide and increased irrigation costs especially in arid and semi-arid areas demand a more efficient and optimized use of irrigation water to maximize water productivity and enhance yield and fruit quality. Due to the water scarcity crisis and the constant use of it in agriculture improving water efficiency through agricultural practices to obtain the largest amount of yield from a unit of water contributes to sustaining citriculture (Navarro et al., 2015).

In the southern Mediterranean region, citrus is often grown with a furrow irrigation system, particularly in clay and loamy soil, where irrigation water is frequently applied to each furrow. Such irrigation methods consume more water and reduce water productivity. Hence, managing irrigation water and crop production is the major challenge of agriculture in arid areas (Nikolaou et al., 2020) since excessive irrigation may decrease yield and affect the growth of root systems due to an increasing groundwater table, spreading pathogens, and leaching of nutrients which subject the plant to biotic stress and consequently reduce productivity.

Egypt is facing water scarcity, which is considered one of the major issues that affect productivity and the decline of variouscrops (Mostafa et al., 2021).

Moreover, agriculture in Egypt depends almost entirely on the waters of the Nile River, particularly in the Delta and the Valley regions with a trivial contribution from groundwater, and furrow irrigation is the main system used. Therefore, it isnecessary to adapt various crops to these conditions. Under this situation, researchers must develop novel approaches to crop and irrigation water management in order to save water and implement agriculture sustainability principles (Osman et al., 2016).

Partial irrigation(PI) is a modified form of deficit irrigation (DI) and is effective in saving water without a high reduction in yield depending on the crop, it is one of the most promising technologies that will help achieve this goal. Partial irrigation technique has become an accepted practice in fruit producingin arid and semi-arid regions (Jatet al., 2022and Mahmoud and Youssef, 2017). On the other side, soil characteristics and environmental factors affect the efficiency of PI (Jovanovic and Stikic,2018).

Therefore, sustaining limited water resources required adapting citrus orchardsto water shortages in order to sustain citriculture (Saitta, et al., 2021). From this perspective localized irrigation methods for citrus orchards should be adopted, particularly flooding irrigation, in combination with the optimization of irrigation water management methods such as PI and DI.

The practical application of the PI technique includes the partial drying of the root zone through two types: fixed and alternate partial root zones.

In the case of alternate irrigation whereas one furrow is watered while keeping the other one dry till the next occasion instead of completely watering them, thus both sides are watered alternately, which allows the wet side of the root system to dry down versus versa.

When using fixed irrigation, water is applied to half of the root system and the other half is left dry during the growing season (Levin and Supplant, 2018). Furthermore, previous studies claimed that watering one side of the tree could provide the water needs of the tree especially in clay and loamy soils due to soil characteristics that allow the water to spread crosswise (Mikhael et al., 2010). Otherwise, irrigating one side while the other side is subjected to drought during the whole season could be used to save water under clay and loamy soil(Jovanovic and Stikic, 2018).

The traditional surface irrigation techniques such asflood irrigation,consumed a huge amount of water particularly in clay soil. This method remains in use in the Delta region of Egypt for irrigation of various crops (AbdEl-Halim, 2015). Fruit trees such as citrus varieties traditionally grow on rising beds with flood irrigation systems in the Delta region, which increases the waste of large amounts of water (Fathi et al., 2020). So looking for new techniques to improve water use efficiency and saveavailable water is highly recommended (Koech and Langat, 2018).

Potassium silicate is a plant stimulant due to its components and their efficiency as anti-stress substances, which increase plant tolerance for stress conditions and reducethe hazards that accompany water deficits on plant growth consequently leading to increased yield and enhanced fruit quality (Dara, 2021). Moreover, foliar application of potassium silicate improved the yield and enhanced citrus fruit quality (Kheder and Abo-Elmagd 2021 and Mohamed and Kamar,2018). This investigation was carried out in order to explain the impact of irrigation methods and foliar sprays of potassium silicate on the growth, yield, and fruit quality of one of the main citrus varieties in Egypt, the Valencia orange. Furthermore providing information that is more reliable for citrus growers on the use of partial irrigation for enhancing water productivity particularly under clay soilconditions.

MATERIALS AND METHODS

This investigation was carried out during two successive seasons, 2021 and 2022 on a commercial orchard of matureValencia orange trees (*Citrus sinensis* L.) budded on sour orange (*Citrus aurantium*) rootstock in a private orchard at Qalyubiya Governorate. Trees were 18 years old, growing on rising beds spaced 5 × 5 m, and surface furrow irrigation was used.Irrigation water is pumped by using a Deutz irrigation machine with a water flow about 160 m^3/hour. Control treatment is watered for 3 hours at intervals. While partial irrigation treatments are watered for 2hours at each interval.

The trial considered three irrigation treatments with one row each, organized as three replicates (two trees in each). The selected trees are similar in vigor and size as possible, disease-free and subjected to the same agricultural practices during the experimental seasons.

The irrigation treatments applied were:

- Farmer irrigation (FI): treatment corresponding to local farmer's irrigation practices consisting of delivering fixed amounts everyinterval.
- Substitute furrow irrigation (SFI): water was added to the alternate groove while the other one keeps dry, on the subsequent irrigation, water is added to the other side}.
- Irrigation with fixed furrows (IFF): only one groove of the tree is irrigated and the other one remains dry throughout the season.

Potassium silicate (K_2SiO_3) was applied as a foliar application at two levels (2000 ppm and 4000 ppm) and applied two times in mid of May and mid of July each season, each tree received a seven Liter solution every time and spraying was done till runoff.

Treatments and Experimental Design:

Experimental design: A completely randomized block design was used and included five randomized blocks, each containing six trees for each treatment.

Treatments:

T1: Farmer irrigation (Control, water was applied to each furrow regularly and spraying with water).

T2: Substitute furrow irrigation (SFI) + foliar spraying of 2000 ppm (K_2SiO_3).

T3: Substitute furrow irrigation (SFI) + foliar spraying of 4000 ppm (K_2SiO_3).

T4: Irrigation fixed furrows (IFF) + foliar spraying of 2000 ppm (K_2SiO_3).

T5: Irrigation fixed furrows (IFF) + foliar spraying of 4000 ppm (K_2SiO_3).

Vegetative parameters:

The canopy volume was measured before the start of the experiment in February 2021 and again at the end of each season and was computed using the Zakri equation (2000) as follows: Canopy volume= 0.52 × tree height × (diameter^2).

Leaf sampling and analysis:

Yearly at the end of September, ten leaves were taken from the fourth or fifth position from newly flushed which nonfruiting twigs on the outer canopy to determine leaf area according to Ahmed and Morsy (1999),

Leaf area (cm2) = 0.46 (maximum length of leaf x maximum width of leaf) + 1.81.

Specific leaves weight was calculated as follows:

$$\text{Specific leaves weight} = \frac{\text{Leaves dry weight}}{\text{Leaves area}}$$

Total Nitrogen determined according to Kjeldahl method, P, K, and Si were determined by atomic absorption. Proline leaf content as per Bates et al.(1973) and expressed as (µg/ml) in leaves.

Yield parameters:

In the first week of March of each year, fruit is harvested for calculating tree yield, the fruits of each tree were weighed directly in the orchard. Yield efficiency as (kg /m^3) of the tree canopy and total yield (ton/feddan) were estimated theoretically in each season.

Water productivity (WP) corresponding to each irrigation method was calculated according to the equation of (Pereira et al., 2012) as follows: WP = Ya/ TWU

Whereas WP: Water productivity, Ya: yield (kg/ feddan), and TWU: Water quantity used per feddan. Water productivity is expressed as a ratio in kg/m^3.

At every harvest date, twenty fruits were collected randomly from different directions of the outer canopy of each tree toestimate physical and chemical parameters of fruit quality. An electric fruit juicer was used to squeeze the fruits, and the juice was then filtered through a sieve with a meshsize of 1 mm. The juice was used for determined chemical analysis i.e. total soluble solids, acidity, TSS/Acidity ratio, and ascorbic acid content expressed asgrams of citric acid per 100 ml of juice according to (A.O.A.C., 1995).

Soil analysis:

Before beginning the investigation, the soil's physical and chemical properties were determined by analyzing soil samples taken from the experimental site (Sparks et al., 2020).

Table (1). Some physical and chemical properties of the experimental soil.

Soil depth (cm)	Particle size distribution (%)			Texture	pH	EC (ppm)	Soluble cations (meq/L)				Soluble anions (meq/L)		
	Sand	Silt	Clay				Na^+	Ca^{++}	Mg^{++}	K^+	Cl^-	HCO_3^-	SO_4^{--}
0-45	8.30	43.30	48.40	Clay	8.10	950	7.4	3.19	3.91	0.15	8.11	3.40	3.31
45-90	8.50	42.00	49.50	Clay	8.00	910	7.35	4.10	3.80	0.17	10.4	3.51	1.50

Data analysis:

The plots were distributed following a randomized block design with 5 treatments. Three replications were used for each treatment for all parameters, and two treeper plot. Data were compared by statistical analysis of variance (ANOVA) according to Snedecor and Cochran (1990). The data were processed computerized using the Co- Stat program. Duncan's multiple-range test was used to differentiate between the main various treatments at a 5% level of probability according to (Gomez and Gomez, 1984).

RESULTS AND DISCUSSIONS

Data in **Table (2)** clearly show that irrigation methods with foliar application of potassium silicate at 2000 & 4000 ppm significantly affected tree canopy, leaf area, and specific leaf weight in the spring growth cycle. Regarding tree canopy, the maximum vegetative growth (20.17 & 24.81 m^3) recorded by full irrigation treatment compared to all other treatments in both seasons followed by T2 (17.08 & 20.38 m^3) while T5 had the lowest values of canopy volume (14.95 & 18.76 m^3) in both seasons.

Canopy volume was affected by different treatments while T2 recorded the lowest reduction of canopy volume (15.23 & 17.83 %) followed by T3 (17.65 & 18.48 %) while, T5 recorded the maximum reduction (24.36 &9.19 %) comparing to control treatment.

Leaf area had the same trend whereas, the largest leaf area (11.22 & 11.32 cm^2) values were obtained from the control treatment followed by trees subjected to T2 (9.82 &9.76 cm^2), while T5 had the lowest values (9.19 &9.12 cm^2) in both seasons.

Furthermore, there is a notable change in specific leaf weight due to various treatments during the experiment. Data in **Table (2)** showed that T5 achieved the highest values (0.530& 0.510) in both seasons and was found superior to the control treatment that scored the lowest values (0.333 & 0.337) in both seasons. These could be due to the positive impact of potassium that stimulate soluble solute formation that preserves cell balance and acts as an osmosis agent in controlling stomata conductivity, a crucial process for saving plant water under partial irrigation(Khalil et al., 2022).

The reduction in vegetative growth parameters under partial irrigation treatments could be due to a less wetted area of soil and available water and nutrients for the root system on the dried side of the tree, which leads to poor stomata conductivity and reduced photosynthesis, consequently, decreasing dry matter synthesis, consequently, reduced growth and productivity (Jovanovic and Stikic, 2018).

Our results are consistent with Miranda, et al, (2021) who reported a reduction in leaf dry matter and leaf area of Valencia oranges grafted on Swingle citrumelo under water-deficient conditions. Furthermore, Slamini et al. (2022) on clementine trees, Mossad et al. (2020) on Valencia orange trees and Consoli et al. (2017) on orange trees found that a low irrigation rate reduces the vegetative growth of the trees.

It also agrees with Mohammad and Al-kamar (2018) on Valencia orange and Habasy (2016) on Navel orange who found beneficial effects of using potassium silicate on vegetative growth, where the use of potassium silicate stimulates tree growth and improves fruit characteristics especially ripening parameters.

Table (2). Effect of irrigation methods and foliar application of Potassium silicate on vegetative growth parameters of Valencia orange trees.

Treat.	Tree canopy (m^3)		Canopy reduction (%)		Leaf area (cm^2)		Specific leaf weight	
	2021	2022	2021	2022	2021	2022	2021	2022
T1	20.17 A	24.81 A	0.00 A	0.00 A	11.22 A	11.32 A	0.333 E	0.337 D
T2	17.08 B	20.38 B	15.23 B	17.83 B	9.82 B	9.76 B	0.433 D	0.417 C
T3	16.61 B	20.23 B	17.65 B	18.48 B	9.56 C	9.17 D	0.477 B	0.463 B
T4	15.07 C	19.98 C	25.32 C	23.47 C	9.76 BC	9. 35 C	0.453 C	0.450 B
T5	**14.95 C**	**18.76 C**	**25.89 C**	**24.36 C**	**9.19 D**	**9. 12 D**	**0.530 A**	**0.510 A**

*Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level.

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

Nutritional status of Valencia orange trees

Some leaf content of Valencia orange trees was determining such as N, P, K,and Si under all treatments during the experiment. Various treatments caused a noticeable enhancement of average leaf P & K content compared to control treatment. Data in our hands **(Table 3)** shows that the highest N leaf content (2.39 & 2.36%) was always obtained in the control treatment (T1), while T5 recorded the lowest values (2.15 &2.09 %). Regarding P leaf content T4 was more effective (0.161 & 0.164%), while, control treatment recorded the lowest values (0.130 & 0.142 %). Other treatments had intermediate values of studied nutrient in both seasons.

Regarding leaf content of potassium, data in **Table (3)** shows that trees subjected to T5 recorded the highest values of K (2.35 & 2.38%), followed by T3 (2.24 & 2.36 %). In contrast, untreated trees had the lowest K values (1.96 & 2.00%) compared to other treatments in both seasons.

Tabulated data in **Table (3)** showed that T5 recorded the highest significant level of Si content (1.360 & 1.383m mol g^{-1} DW) compared to the control, which recorded the lowest values (0.987 & 1.007m mol g^{-1} DW), and there was a fluctuation of other treatment effects in both seasons.

Data in **Table (3)** showed that various treatments affect proline content during the experimental seasons (2021 and 2022). It could be noticed that proline content increased with PI treatments, whereas T4 recorded the highest values (0.587 & 0.620 mg/ g FW) followed by trees subjected to T5 (0.563 & 0.600 mg/ g FW), in contrast control treatments recorded the lowest values (0.473 & 0.490 mg/ g FW).

Improving leaf nutrient contents in trees subjected to PI treatment could be due to the stimulation of mineralization of organic compounds in soil and increased soil aeration because of the release of N & P (Dodd et al., 2015). Furthermore, potassium silicate improves nutrient and water uptake, consequently increasing the leaf mineral contents of Valencia orange trees (Mohamed and Al-Kamar, 2018).

Under stress conditions, plants form various osmolytes solutes that play a significant role in tolerating abiotic stressand protecting cells against reactive oxygen species produced by drought, such as proline (Abobatta, 2020).

Partial irrigation treatments reduce vegetative growth, which increases light penetration into the canopy and increases the formation of amino acids such as proline, which act as osmoprotectants in plant cells under stress to maintain the metabolic in the cell under drought conditions (Pérez-Álvarez, et al., 2021 and Zhong et al., 2019). Furthermore, Mohamed and Al-Kamar, (2018) reported that potassium silicate reduces proline content in the leaves of Valencia orange trees.

Table (3). Effect of irrigation methods and foliar application of Potassium silicate on some leaf mineral contents of Valencia orange trees.

Treat.	N+ (%)		P+ (%)		K+ (%)		Si m mol g-1 Dw		Proline mg/g FW	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T1	2.39 A	2.36 A	0.130 B	0.142 B	1.96 B	2.00 C	0.987 D	1.007 D	0.473 B	0.490 C
T2	2.22 AB	2.27 AB	0.156 AB	0.155 AB	2.12AB	2.21 B	1.097 CD	1.183 C	0.547 AB	0.567 A-C
T3	2.19 AB	2.23 AB	0.150 AB	0.160 AB	2.24AB	2.36 A	1.297 AB	1.370 AB	0.513 AB	0.523 BC
T4	2.17 BC	2.21 BC	0.161 A	0.164 A	2.10AB	2.15B	1.167 BC	1.277 BC	0.587 A	0.62 A
T5	2.15 C	2.09 C	0.159 AB	0.160 AB	2.35 A	2.38 A	1.360 A	1.383 A	0.563 A	0.600 AB

*Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level.

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

Yield and its attributes were reduced due to the effects of partial irrigation conditions **(Table 4).** When water regimes were kept constant, the application of (T3) SFI with a foliar application of 4000 ppm (K_2SiO_3) gave the highest values compared to other partial irrigation treatments, in this respect in both seasons. At harvest time, tree yield was estimated, along with fruit quality and water productivity. Data in **Table (4)** revealed significant differences in yield parameters among treatments. Regardingtree production, it is noticed that untreated trees (T1) produced the maximum yield (52.01 & 53.06 kg/tree) followed by trees subjected to T3 (50.10 & 51.97 kg/tree). While trees subjected to T4 produced a list significant yield (43.47 kg/tree) in the first season and T5 (46.42 kg/tree) in the second one.

Total yield (Ton/Fed) has the same trend, whereas T1 has the highest values (8.58 &8.75 ton/fed), followed by T3 (8.27 & 8.58 ton/fed), and T4 recorded the lowest values (7.17 ton/fed) in 2021 season and T5 (7.66 ton/fed) in 2022 season. While, there is a fluctuated effect for other treatments on yield parameters during the experiment.

A reduction in yield per feddan may be due to low water availability for trees and reduction in vegetative growth, consequently, decreasing fruit weight. Continuous partial irrigation during the growing seasons resulted in yield reduction, whereas T3 recorded the least reduction (3.21 & 1.86 %) followed by T2 (3.46 & 3.37%), while T4 recorded the highest yield reduction (16.14%) in the first season andT5 (12.44%) in the second one compared to the control.

Results presented in **(Fig.1)** showed that various treatments affected the yield efficiency during experimental seasons, whereas T5 recorded the highest value (3.16 kg/m^3) in the first season and T3 (2.57 kg/m^3) in the second one. In contrast, the control treatment recorded the lowest significant values (2.58 & 2.14 kg/m^3) inboth seasons.

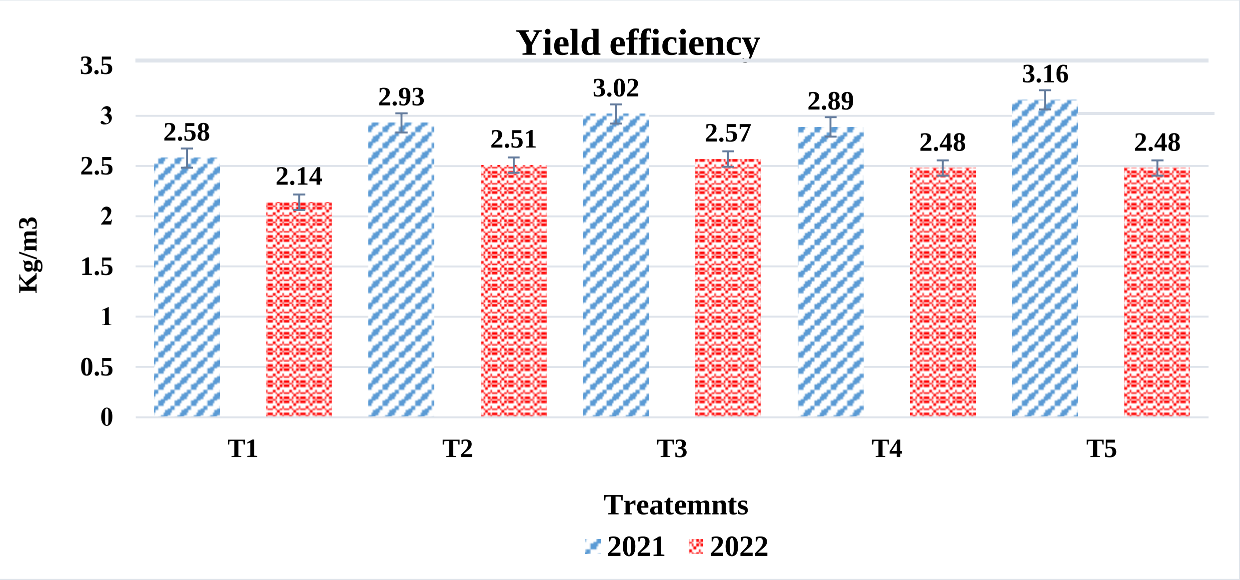

Fig. (1). Effect of irrigation methods and foliar application of Potassium silicate on yield efficiency of Valencia orange trees

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

This is mainly due to the reduction of fruit weight in all treatments. Although a decrease in tree yield was observed, a significant increase in water productivity was achieved in treatments during the experiment compared to the control **(Table 4).**

Regarding the effect of different treatments on physical fruit characters during the experiment, there is a notable change in fruit weight was cleared. Data in hand **(Table 4)** showed that, fruit weights (g), fruit volume (ml) juice ratio were significantly reduced by decreasing irrigation water and the smallest fruit were produced under T5 (FI). The reduction in weight and volume of fruits from trees subjected to T5 may be due to the reduced available water content during the cell enlargement stage.

Whereas, the heaviest fruit (201.53& 200.95 g) were obtained from the control treatment (T1) and found superior to other treatments, followed by T3 (194.40 g) in the first season and T2 (199.33 g) in the second one. the partial irrigation significantly decreased average fruit weights, so, fruits from trees subjected to T5 had the lowest significant average fruit weight (162.23 & 170.03 g) in both seasons.

Concerning fruit volume (size), Data in Table 4 illustrate a significant effect of various treatments on fruit volume, whereas there is a regular reduction was identified in the fruit volume as a result of PI treatments during the experiment. Untreated trees produced the largest fruit (182.87 & 185.50 cc) followed by T3 (176.90 & 182.50 cc) whereas T5 recorded the lowest significant values (157.83 & 163.67 cc) comparing to control, and there is a fluctuated effect for other treatments on yield parameters during the experiment.

Regarding juice percentage (% by weight) data in hand showed that juice percentage has the same trend, whereas T1 recorded the highest value (58.34& 57.01 %), followed by T3 (56.78 & 51.97%), while, T5 recorded the lowest values (45.02 & 44.14 %) in both seasons. The variation in juice percentage may be due to low water absorption and reduced fruit volume, which corresponds to the reduction in the available amount of irrigation water.

The different effects of various treatments when applied during the experiment on the fruit yield, could be due to the impact on the availability of water and nutrients which affect the production of vegetative-reproductive parts in response to drought stress (Kusakabe et al., 2016, Faber and Lovatt ,2014 on navel orange and Pérez-Pérez et al., 2009).

Table (4). Effect of irrigation methods and foliar application of Potassium silicate on yield and physical fruit parameters of Valencia orange trees.

Treat.	Yield (kg/tree)		Total yield (Ton/fed)		Yield reduction (%)		Fruit weight (g)		Fruit volume (cc)		Juice (%) (W/W)	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
T1	52.01 A	53.06 A	8.58 A	8.75 A	0.00 A	0.00 A	201.53 A	200.95A	182.87 A	185.50 A	58.34 A	57.01 A
T2	49.97 AB	51.21 A	8.24 AB	8.45 A	3.46 AB	3.37 A-C	191.00 B	199.33 AB	173.78 B	179.00 A	55.39 AB	47.94 C
T3	50.10AB	51.97 A	8.27 AB	8.58 A	3.21 A	1.86 AB	194.40 B	196.07 BC	176.90 AB	182.50 A	56.78 AB	51.97B
T4	43.47 C	47.06 B	7.17 C	7.76 B	16.14 B	11.22 BC	176.00 C	194.33 C	161.67 C	180.50 A	52.95 B	45.34 CD
T5	47.21 B	46.42 B	7.79 B	7.66 B	9.98 AB	12.44 C	162.23 D	170.03 D	157.83 C	163.67 B	45.02 C	44.14 D

*Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level.

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

Fig. (2) showed that there is a significant increase in water productivity was noticed with partial irrigation methods during the experiment. For the using amounts of irrigation water between 6240m^3 and 4160 m^3, the average water productivity was 1.39,2.01, 2.02, 1.80, & 1.86 kg m^{-3}, with the highest values observed in treatment 3 (2.02 kg m^{-3}) and the lowest from the trees subjected to the farmer irrigation method (1.39 kg m^{-3}).

The main effect of the T3 strategy was a significant increase in yield parameters and water productivity compared to other treatments.

These results may be due to that control trees were more vigorous than trees from other treatments, which has smaller canopy volume and more fruit number. Furthermore, potassium silicate application had positive effects on fruit weight that increase yield efficiency in treated trees.

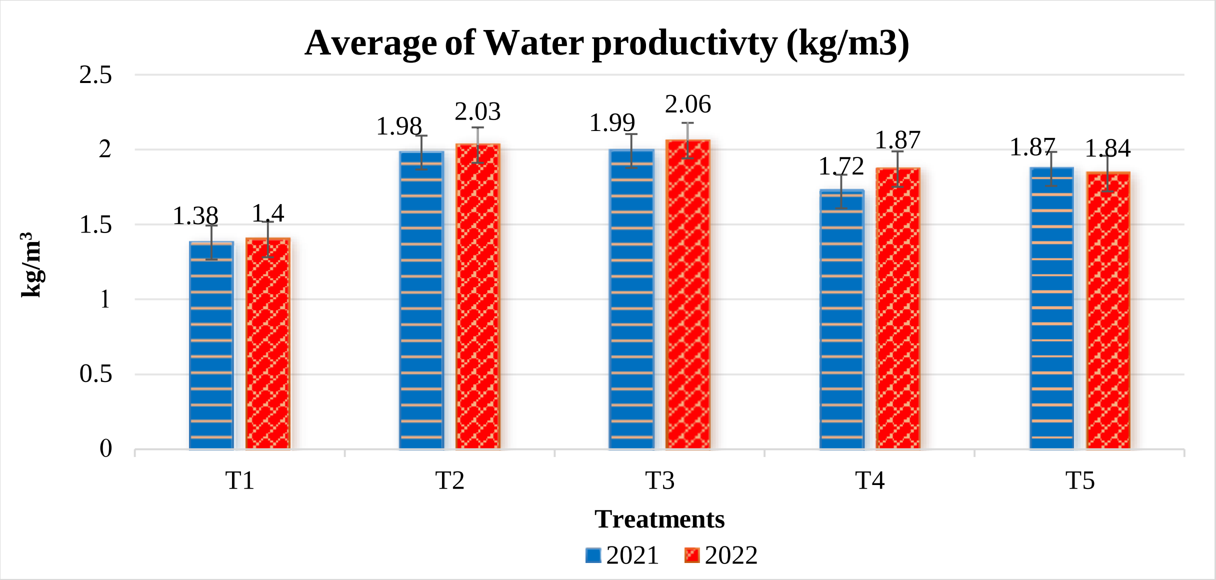

Fig. (2). Effect of irrigation methods and foliar application of Potassium silicate on average water productivity of Valencia orange trees

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm(K_2SiO_3).

Internal fruit parameters such as total soluble solids, acidity, and V.C levels increased progressively with the different treatments compared to the control, and this trend was true during both seasons, as T5 recorded the highest values of TSS%, acidity%, and V.C. As shown in **Table (5).**

Several studies found a correlation between higher acidity and total soluble solids (TSS) and a decreased water supply. Our findings closely match theirconclusion. Data in hand showed that there is a positive effects of various treatments on juice TSS, whereas the highest juice TSSwas obtained from T5 (12.83& 13.00) followed by T3 & T4 (11.78) in the first season and by T4(12.35) in the second one. While the control fruits recorded the least significant values (11.29& 11.11) compared to T5 in both seasons.

The juice of T5 fruits showed the highest acidity (1.183& 1.150 %) compared to other treatments, on the contrary, the lowest values of juice acidity (1.033& 1.043 %) were recorded from control for 2021 and 2022 seasons.

Increased TSS and acidity in juice under water-deficient conditions is a well-established reaction in citrus, particularly when water deficiency occurs during the whole season (Mossad et al., 2020 and Hutton and Loveys, 2011). Furthermore, the positive effects on fruit quality may be due to the effect of potassium silicate, which stimulates the synthesis of more sugars and increases TSS.

Regarding the effect of various treatments on TSS/acidity ratio, **Fig. (3)** shows that T1 had the highest value (10.93%) followed by T5 (10.85%) and T4 recorded the lowest value (10.56%) in the first season. In the second one, T5 achieved the maximum TSS/acidity ratio (11.31%),followed by T4 (10.87%) while, T2 recordedthe lowest value (10.47%) during the experiment.

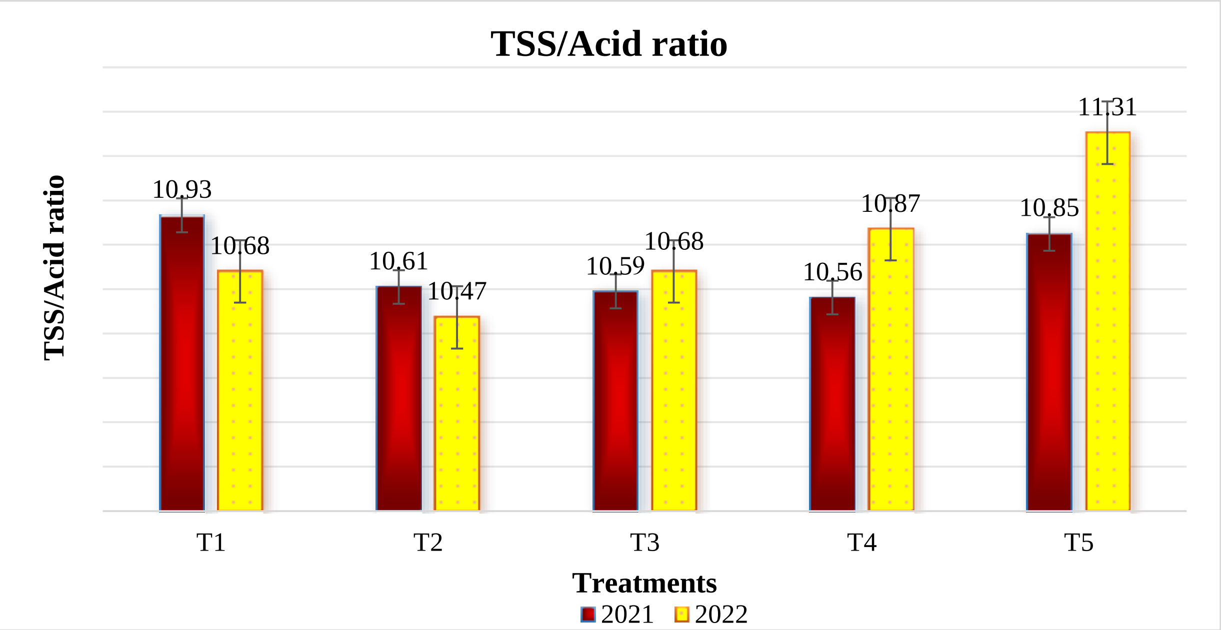

Fig. (3). Effect of irrigation methods and foliar application of Potassium silicate on TSS/acid ratio of Valencia orange fruits

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

Data in **Table (5)** showed a positive effect of various treatments on Vitamin C content, whereas the average vitamin C was 39.53 to 48.05 across the seasons. Fruits from trees subjected to T5 were rich in V.C. content and had the highest values (46.55 & 48.05 mg/100g) followed by T4 (43.44 & 44.13 mg/100g) while control treatments recorded the lowest values (39.53 & 40.34 mg/100g) in both seasons.

Under partial irrigation (either alternate between the two sides of the tree or fixed irrigation of only half of the root zone, while the other half remains dry). Plants emitted biochemical signals from the roots in the dry part to the vegetative organs to adapt to the environment, by regulating stomata conductance and reducing transpiration, which reduces CO_2 assimilation and dry matter formation (Wahab et al., 2022).

Moreover, PI increases the translocation of metabolic solutes from leaves to fruits, consequently increasing the accumulation of total soluble contents in the fruit (Zhong et al., 2019, Mohamed and Al- Kamar, 2018, Consoli et al., 2017and Francaviglia et al., 2013). Furthermore, there is a positive result of the application of potassium silicate, which enhances the fruit's physical parameters, stimulates the formation of more sugars, and accelerates the translocation of sugars into fruits that have cumulativesoluble solutes, which in turn results in increasing the juice's TSS content and improving the TSS/Acidity ratio.

Generally, the TSS/acidity ratio was increased in fruits from trees subjected to water stress particularly, fixed irrigation treatment due to the reduction of available water, which stimulates the forming of soluble solutes in the plant compared to non-stressed trees (control). Numerous studies have demonstrated that the fruit quality of citrus trees improves under deficit irrigation. Chen et al., (2022) on mandarin, Morianou et al, (2021) and Navarro et al., (2015) on grapefruit, Silveira et al., (2020) and Nagaz et al., (2017) on orange. Moreover, the improvement in fruit characteristics can be attributed to the effect of water deficiency on fruit quality such as fruit ripening and solid solute formation. In addition to the effect of potassium silicate, which increases the soluble solutes in the plant.

The results of the present investigation are close to those of Kheder and Abo-Elmagd (2021), Mounika et al., (2021), Mohamed and Al-Kamar (2018) and Habasy (2016), who stated that the application of potassium silicate enhances tree productivity and fruit quality, maximizes TSS, and reduces acidity of citrus trees.

Table (5). Effect of irrigation methods and foliar application of Potassium silicate on internal fruit parameters of Valencia orange trees.

Treat.	T.S.S (Brix°)		Acidity (%)		Vit C (mg/100g)	
	2021	2022	2021	2022	2021	2022
T1	11.29 B	11.11 C	1.033 C	1.043 C	39.53 C	40.34 C
T2	11.98 AB	11.35 BC	1.117 B	1.083 BC	42.37 BC	42.66 BC
T3	11.78AB	12.03 A-C	1.113 B	1.127 AB	42.49 BC	43.63 BC
T4	11.78 AB	12.35 AB	1.147 AB	1.137 AB	43.44 AB	44.13 B
T5	12.83 A	13.00 A	1.183 A	1.150 A	46.55 A	48.05 A

*Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level.

* T1 Farmer irrigation (Control), T2 (SFI +2000 ppm (K_2SiO_3), T3 (SFI +4000 ppm (K_2SiO_3), T4 (IFF) +2000 ppm (K_2SiO_3), T5 (IFF) +4000 ppm (K_2SiO_3).

Conclusions:

Valencia orange (*Citrus sinensis* L.) is one of the most profitable citrus varieties in Egypt. However, it requires more irrigation rates to produce an economic crop and high-quality fruits due to extending the growing season particularly under clay soil conditions. This fact drives us to investigate the effect of different irrigation methods andspraying with potassium silicate on the total yield, fruit quality parameters and irrigation water consumption.

This study demonstrated that different irrigation methods and foliar applications of potassium silicate on Valencia oranges affect fruit quality significantly and reduce the quantity of irrigation water compared to the farmer’s irrigation method.

Using substitute furrow irrigation (4160 m^3) with spraying potassium silicate at 4000 ppm (T3) achieved the maximum water productivity (2.025k/m^3), produced the highest yield (8.27 ton/feddan) while improved the quality of fruits, juice parameters and saved 33% of irrigation water approximately in both study seasons compared to other partial irrigation methods. This is considered a positive issue to improve water productivity and save irrigation water in clay soil during the water crisis in Egypt. The effects of irrigation methods and foliar application of potassium silicate on crop yield require further studies and research to evaluate the impact of this irrigation practice.

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الملخص العربى

تأثير طرق الري والرش الورقي بسليكات البوتاسيوم في نمو وإنتاجية أشجار برتقال فالنسيا (*Citrus sinensis L*) المزروعة تحت ظروف الدلتا.

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في مصر يتزايد نقص المياه سنويًا بسبب عوامل مختلفة. وفي منطقة الدلتا، يستخدم معظم مزارعى الموالح نظام الرى بالغمر، حيث يتم الرى بشكل متكرر على كل بتن، مما يؤدى الى فقدان كميات هائلة من المياه. نظرية هذا العمل أن أشجار البرتقال الصيفى النامية على مصاطب، وتروى بالبتون المتبادلة أو البتن الثابت، اعتمادا لنظام التجفيف الجزئى لمنطقة الجذر، يمكن ان تحافظ على حيوية الأشجار وانتاجيتها، وجودة الثمار، واستدامة زراعات الموالح، وتوفير مياه الرى فى منطقة الدلتا. ولاختبار هذه النظرية، تم اجراء تجربة فى موسمى 2021و 2021 فى بستان تجارى بمحافظة القليوبية لتقييم حجم المجموع الخضرى للاشجار والانتاجية، وجودة الثمار، ومحتويات الاوراق من العناصرالغذائية، وانتاجية المياه، لأشجار البرتقال الصيفى المطعومة على أصل النارنج. تم استخدام خمس معاملات فى الدراسة، طريقة المزارع كعامل مقارنة (رى كلا البتنين)، والرى التبادلى للبتون (SFI) مع الرش الورقى ب 2000 جزء فى المليون من سيلكات البوتاسيوم (K_2SiO_3)، SFI + 4000 جزء K_2SiO_3 ، ورى بتن ثابت (IFF) + 2000 جزء فى المليون (K_2SiO_3)، ورى بتن ثابت (IFF) + 4000 جزء فى المليون (K_2SiO_3). أشارت النتائج التى تم الحصول عليها الى أن المعاملات المخلتفة سببت انخفاض فى حجم المجموع الخضرى للشجرة ومساحة الورقة ومحتوى الورقة من النيتروجين، مع زيادة محتوى الورقة من الفوسفور والبوتاسيوم والسيلكون، والبرولين الحرمقارنة بالمقارنة. وتحسين معايير جودة الثمار بشكل ملحوظ. واعتبرت معاملة (SFI مع 2000 جزء فى المليون K_2SiO_3) أفضل معاملة اتعزيز حجم المجموع الخضرى للأشجار والانتاجية وجودة الثماروتوفير حوالى 33% من مياه الرى فى كلا موسمى الدراسة.