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Influence of hydrogel composite applications and irrigation intervals on the yield and fruit quality of Valencia orange (*Citrus sinensis* L.) trees under semi-arid conditions

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ABSTRACT

Purpose: Under fluctuations in climatic conditions, sustaining production with excellent fruit quality is the main objective of citrus producers in the arid regions. This experiment was conducted on twelve-year-old Valencia orange trees (*Citrus sinensis* L) budded on Volkamer lemon rootstock (*Citrus volkameriana*), cultivated in sandy soil in the Eastern Desert of Egypt. **Research method:** This work studies the influence of hydrogel and irrigation intervals on the growth, yield, and fruit quality of Valencia orange trees. The experiment consists of four levels of hydrogel (0, 750, 1000, and 1250 g/tree) with three irrigation intervals (daily, day-by-day, and every 2 days) during three seasons (2020-2022). **Findings:** All applications affected tree canopy volume, shoot length, leaf number, yield (kg/tree), and the physical and chemical fruit characteristics. While, the application of 1000 g/tree hydrogel and every two-day irrigation interval produced the highest values when compared to other treatments during the experimental seasons. With respect to yield and fruit characteristics, treatment of 1250 g/tree hydrogel with irrigation day-by-day resulted in the highest tree yield (113.58 kg/tree) and total yield (18.74 tons/feddan) and improved various physical and chemical fruit characteristics. **Research limitations:** There was no limitation. **Originality/Value:** Hydrogel applications mitigated the impact of prolonging irrigation intervals on the vegetative growth, productivity, and fruit quality of the Valencia orange trees compared to untreated trees.

INTRODUCTION

Rising temperatures and water shortages are the main abiotic threats facing the agricultural sector in arid and semi-arid regions. Under these conditions, there is a greater need to reserve water consumption in the agricultural sector and increase water use efficiency for the future expansion of agriculture in the water-scarce arid region (Karandish et al., 2015). There is more interest in improving practice management that reserves water, i.e., adapting irrigation intervals, using advanced irrigation methods, and using hydrogel substances to increase soil water retention, which could save huge amounts of water and sustain agricultural production, particularly in fruit orchards (Rabbani & Kazemi, 2022).

Egypt, which is located in an arid region with limited water resources, is experiencing water scarcity conditions along with rising temperatures, which increase evapotranspiration in sandy soil. This crisis is considered one of the determining factors for the agricultural sector, especially fruit cultivation in desert areas (Gado & El-Agha, 2021).

Under such conditions, proper practice management, such as using polymeric substances and controlling irrigation quantity, must be used to reduce water loss in sandy soils in order to sustain citrus production and increase the productivity of the available water (Malik et al., 2022; Abd El-Aziz et al., 2020).

Deficit irrigation is a strategy that is more efficient in reducing water consumption than the water requirements of the crop without harming plant productivity, depending on the amount of water reduction, variety, and growth stage (Solanki et al., 2021; Abdelraouf et al., 2020). Using different irrigation intervals is considered a modified technique of deficit irrigation that aims to save water without having a harmful effect on tree growth and productivity (Galindo et al., 2018).

Citrus is an evergreen tree growing in a warm climate that requires a continuous water supply throughout the year. Under slight water stress, trees undergo physiological responses to adapt to water shortages and complete the growth season satisfactorily (Consoli et al., 2017). Therefore, in arid and semi-arid regions, the supply of adequate irrigation water is a determined factor for the economic production of citrus under these conditions (Abou Ali et al., 2023).

In citrus orchards, water shortages diminish vegetative growth, reduce yield, and produce poor fruit quality, causing significant economic losses. Sustaining citriculture with superb fruit quality is the main target of citrus growers worldwide, particularly in arid conditions such as the Mediterranean climate, which suffers from rainfall reduction and increases evapotranspiration.

Citrus is considered the most important fruit in Egypt and is regarded as a key pillar of the agricultural economy. Given the cultivated area, which reaches 519,788 Feddan, its annual productivity (about 4.7 million tons) represents 36.2% of total fruit production and its commercial value in both domestic and international markets, whereas citrus fruits occupy the first position in fruit export with a total of approximately 1,8 million tons in 2022. Moreover, orange exports accounted for about 25.07% of the total citrus production. Valencia orange occupies the second position as the most cultivated citrus variety in Egypt, with a fruitful area reaching 125,152 Feddan and producing 1,34 million tons (Annual Reports, 2022).

In arid and semi-arid areas, using hydrogel substances as soil applications improves soil-holding capacity and reserves water for a longer time, which could increase water intervals and enhance water productivity by reducing runoff (Alshallash et al., 2022). Furthermore, hydrogel retains nutrients and reduces leaching with drainage water, consequently enhancing the growth and productivity of fruit crops in sandy soil (Pattanaaik et al., 2015). Therefore, using hopeful practices such as control of irrigation intervals and hydrogel ingredients to maintain citrus productivity is necessary to sustain citriculture in such regions (AbdEl-Aziz et al., 2020).

This investigation was conducted during the 2020-2022 seasons to study the effect of combinations of irrigation intervals and rates of hydrogel composite on vegetative growth, productivity, and fruit quality of Valencia orange trees grown under arid region conditions.

MATERIALS AND METHODS

In Egyptian conditions with limited water resources, managing irrigation intervals could be a modified strategy to control water productivity without significant crop reduction.

This research was conducted in a private orchard located at Wadi-Almollak region of Ismailia Governorate, Egypt to assess the impact of two irrigation intervals and three rates of hydrogel composite on the growth and productivity of Valencia orange trees (*Citrus sinensis* L.) budded on Volkamer lemon (*Citrus volkameriana*) rootstock. Trees were planted at 5 × 5 m apart, for 165 trees/Feddan. The study was conducted for three consecutive years (2020, 2021, and 2022). Soil analysis, according to (Wild et al., 1979), was carried out at the department of soil sciences, faculty of Agriculture, Al-Azhar University (Table 1).

The quantity of hydrogel composite for each replicate was mixed with (1 kg) of fine sand and added under irrigation lines of 30 cm depth during mid-January each season. Trees were watered by a drip irrigation system with two adjustable emitters/trees (8 litter.h^{-1}) through two irrigation lines. Other agricultural practices were according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation. This field experiment aimed to evaluate the impact of hydrogel polymers with irrigation intervals on the growth and productivity of Valencia orange trees under arid regional conditions.

Twenty-one trees were selected and grouped into seven treatments; each treatment was represented by three replicates (tree/each).

Table 1. Chemical and mechanical analysis of the experimental soil.

Chemical analysis

Date	pH	EC	Soluble cations (meq / L)				Soluble anions (meq / L)			Macro elements (ppm)			Microelements (ppm)			
			Ca^{+2}	Mg^{+2}	Na^{+1}	k^{+1}	Cl^{-1}	HCO_3^{-2}	SO_4^{-2}	N	P	K	Fe	Mn	Zn	Cu
January 2020	7.90	1.93	3.8	1.8	1.45	0.27	6.3	1.6	3.97	980	0.66	200.5	3.6	2.7	7.8	22.74
October 2022	7.98	1.88	3.65	1.9	1.24	0.29	0.7	2.44	4.44	1204	50.77	7927	7.2	3.2	8.0	24.3

Mechanical analysis

Date	Rough sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Soil density
January 2020	33.5	36.5	18.4	11.6	1.53
October 2022	33.8	36.8	17.3	12.1	1.55

Treatments

T1: Control (Irrigation daily without hydrogel composite).
T2: Irrigation day-by-day (I1) + hydrogel composite (750 g /tree) (HC1).
T3: Irrigation every 2 days (I2) + hydrogel composite (750 g /tree) (HC1).
T4: Irrigation day-by-day (I1) + hydrogel composite (1000g/tree) (HC2).
T5: Irrigation every 2 days (I2) + hydrogel composite (1000 g /tree) (HC2).
T6: Irrigation day-by-day (I1) + hydrogel composite (1250 g /tree) (HC3).
T7: Irrigation every 2 days (I2) + hydrogel composite (1250 g /tree) (HC3).

The response of trees to the effects of the soil application of hydrogel and irrigation intervals was studied by comparing changes in growth, yield, and chemical agents. The following parameters were determined.

Vegetative growth parameters

Tree canopy volume (m^3) was calculated according to Zekri (2000) by the formula (1):

$$TV = 0.5236 \times HD^2 \qquad (1)$$

Where H = tree height and D = tree diameter.

Shoot length (cm), **e**ach season, in the spring, four main branches similar in length and diameter were chosen, one in each direction of each replicate was labeled for measuring shoot length from the 1st of March to the 1st of November during each season. At the end of spring cycle of each season, leaves number/ shoot was counted, then, ten leaves were calculated from tagged shoots to determine leaf area (cm^2) by using the equation of Chou (1966) (2)

$$\text{Leaf space} = 2/3\ (\text{length} \times \text{width}) \qquad (2)$$

Four branches (one-year-old) similar in growth were chosen, one branch in each original direction, and twelve shoots per main branch were tagged at the balloon stage of the flower each seasons. At blooming, all opened flowers/shoot were counted. At the end of fruit set, the number of fruitlets was recorded, and the fruit set percentage was calculated according to the following equation (3):

$$\text{Fruit set (\%)} = \text{Total fruit number/ Total flowers number} \times 100 \qquad (3)$$

Nutritional status

Ten leaves were taken from non-fruiting shoots on the outer canopy, washed with distilled water, dried at 70°C, and then digested according to (Wolf, 1982) to determine leaf mineral content.

Total nitrogen was determined by the semi-micro Kjeldahl methods (Bremner & Mulvaney, 1983). Phosphorus % was estimated colorimetrically by the method of (King, 1951). Potassium % was determined by the flame-photometer according to Jackson method (1969).

Yield parameters

Harvesting was achieved in mid-February every season, and yield was recorded as total fruit weight ($Kg.tree^{-1}$), average fruit weight (g), fruit number per tree, and yield efficiency ($Kg.m^3$) were calculated.

Fruit yield increment or reduction percentage was compared with the control was calculated according to equation of (Hifny et al., 2017) (4):

$$\text{Fruit yield increment or reduction (\%)} = \frac{\text{Fruit yield (kg)/treatment- Fruit yield (kg) / control} \times 100}{\text{Fruit yield (kg) / control}} \qquad (4)$$

Physical and biochemical fruit characteristics

Samples of ten fruits were picked at harvesting time from the outer canopy of each replicate and used to determine both physical and chemical fruit characters that include fruit weight (g), fruit volume (ml), peel thickness (mm), and flesh firmness (lb.inch^2). Furthermore, total soluble solids (TSS) was determined using a hand-held refractometer (Dorostkar et al., 2020). Titratable acidity percentage in fruit juice was determined as grams of citric acid per 100 ml of juice by titration against (0.1 N) NaOH in presence of phenolphthalein as an indicator, and Vitamin C (as mg/ 100 g pulp) was determined according to (AOAC, 1995), then TSS/acid ratio was calculated.

Soil analysis

Soil samples were collected from the experiment site in January 2020, before the start of the experiment, and at the end of the third season (October 2022), to determine the physical and chemical properties of the used soil, which are shown in Tables 1 and 2 according to Sparks et al. (2020).

Statistical analysis

A completely randomized block design was conducted on mature Valencia orange trees (14 years old). Twenty-one trees were organized into seven treatments with three replicates for each to investigate the aforementioned variables. All data obtained during experiment seasons were subjected to analysis of variance (ANOVA) according to (Ott & Longnecker, 2015), and significant differences among means were determined by L.S.D. at the level of 5% probability according to (Snedecor & Cochran, 1980).

RESULTS AND DISCUSSION

According to observational data on Valencia orange growth characteristics, treatments had a significant impact on growth parameters, including canopy volume, shoot length, and leaf area. Data obtained in Table 2, shows that trees exposed to T4 had the largest tree canopy volume (19.72, 23.55, & 29.48 m^3) throughout the trial seasons, followed by T7 (16.61 m^3) in the first season and T3 (22.87 & 27.50 m^3) during the second and third seasons, and control treatment showed the least significant values (14.68, 20.33, & 24.80 m^3). On the other hand, over the experiment's three years, the effectiveness of different therapies varied. While the control treatment had the lowest significant values during the experimental seasons, there was a fluctuation in the effect of other treatments during the three years of the experiment.

Regarding shoot length, T6 recorded the longest shoots in every growth cycle compared to control throughout the experiment (Fig. 1).

Data in Table 2 showed that, across seasons, the highest leaf area (42.13, 59.37, & 60.81 cm^2) and number of leaves per shoot values (13.30, 14.27, & 12.53) were recorded from trees subjected to T4, respectively. While T5 recorded the lowest values of both parameters whereas leaf area recorded (36.27, 38.36, & 39.78 cm^2) and number of leaves per shoot was (9.00, 9.67, & 10.00) in all seasons.

The outcome data showed that polymer applications improved growth parameters despite long irrigation intervals by enhancing nutrients and water use. Our findings are in agreement with Alshallash et al. (2022) on Mango trees, AbdEl-Aziz et al. (2020) on 'Murcott' mandarin trees, Abobatta and Khalifa (2019), and Zoghdan and Abo El-Enien (2019) on Navel orange, who reported that the application of hydrogel composite improves the vegetative growth parameters. Furthermore, Solanki et al. (2021) claimed that the scheduled irrigation water requirement of acid lime with polymer applications enhances canopy volume and increases vegetative growth.

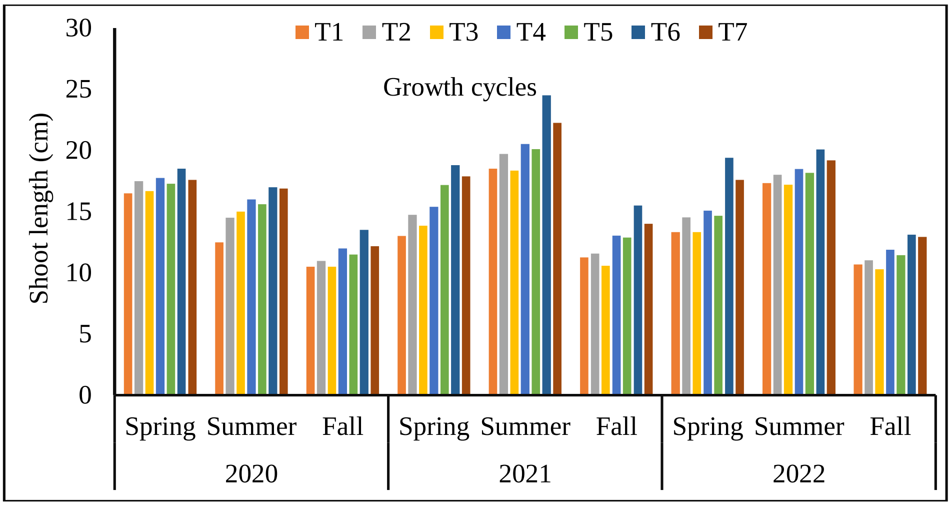

Fig. 1. Effect of various treatments on shoot growth of Valencia orange trees.
*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

Table 2. Effect of various treatments on vegetative growth parameters and leaf mineral contents of Valencia orange trees.

Treatment / Characters	Season	T1	T2	T3	T4	T5	T6	T7	LSD
Tree canopy	2020	14.68 b	14.94 b	15.61 a	19.72 a	14.75 b	15.40 b	16.61 b	2.06
	2021	20.33 d	20.80 cd	22.87 ab	23.55 a	20.92 cd	21.02 cd	21.95 bc	1.22
	2022	24.80 d	26.00 bcd	27.50 b	29.48 a	25.22 cd	26.58 bc	27.12 b	1.55
No. of leaves.shoot^{-1}	2020	10.57 b	101.10 bc	12.63 a	13.30 a	9.00 c	10.71 b	10.90 b	1.54
	2021	10.50 b	10.72 b	13.80 a	14.27 a	9.67 b	11.23 b	11.50 b	2.26
	2022	10.75 bc	10.13 c	10.73 bc	12.53 a	10.00 c	10.96 bc	12.00 ab	1.40
Leaf area (cm^2)	2020	36.36 b	38.94 ab	40.68 ab	42.23 a	36.27 b	39.45 ab	39.72 ab	5.67
	2021	41.25 c	44.94 bc	49.79 b	59.37 a	38.36 c	44.50 bc	45.73 bc	7.38
	2022	45.85 cd	46.27 cd	56.47 ab	60. a	39.78 d	49.27 bc	51.19 bc	7.54
N%	2020	2.12 ab	2.06 b	2.17 ab	2.22 a	2.13 ab	2.14 ab	2.18 ab	014
	2021	2.10 ab	2.08 b	2.14 ab	2.26 a	2.16 ab	2.17 ab	2.13 ab	0.18
	2022	2.13 b	2.11 b	2.15 b	2.29 a	2.14 b	2.18 ab	2.20 ab	0.12
P%	2020	0.15	0.14	0.14	0.13	0.13	0.13	0.12	N. S.
	2021	0.16	0.14	0.14	0.12	0.14	0.13	0.13	N. S
	2022	0.15 a	0.15 a	0.14 bc	0.12 d	0.14 bc	0.13 cd	0.12 d	0.013
K%	2020	2.00 ab	2.19 a	2.01 ab	2.03 ab	1.95 b	1.97 b	1.96 b	0.21
	2021	1.96 b	2.06 ab	2.08 ab	2.11 a	2.00 ab	1.99 ab	2.01 ab	0.13
	2022	1.99 c	2.09 ab	2.10 a	2.15 a	2.02 bc	2.01 c	2.03 bc	0.07

*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

The effect of different treatments on tree growth was monitored by estimating mineral elements in the leaves. A large variation in available nutrients in leaves was noticed through the investigation, viz., N% (2.22 to 2.06; 2.26 to 2.08; & 2.29 to 2.11 %), K% (2.19 to 1.95; 2.11 to 1.96; & 2.15 to 1.99 %), while in P% the variation was slight (0.15 to 0.12; 0.16 to 0.12; & 0.15 to 0.12%). These variations were statistically highly significant when compared with the responses of different treatments, except for P content in the first season.

Data in Table 2 showed that the lowest leaf N content was observed in the tree that was subjected to T2 (2.06, 2.08, & 2.11 %). Untreated trees recorded the highest leaf P content (0.15, 0.16, & 0.15 %). On contrary, T4 recorded the lowest values (0.12 & 0.12%) in the second and third seasons. also; T7 recorded the lowest P content in the first and third seasons (0.12 & 0.12%). Control treatment recorded the lowest K values (1.96 & 1.99%) in the second and third seasons, respectively. Furthermore, T4 recorded the highest concentrations of N (2.22, 2.26, & 2.29%) during the experiment and maximum values of K (2.11 & 2.15%) in the second and third seasons compared to the rest of the treatments.

The stimulating effect of the polymeric substances on the leaf mineral content may be due to improved plant nutrition status through increased availability of water and nutrients in the rhizosphere for a longer period, consequently enhancing the supply of nutrients and improving the nutritional status of the trees under arid conditions (Patra et al., 2022). Furthermore, outcome data from this work were consistent with the findings of (Abobatta & Khalifa, 2019), who claimed that hydrogel treatment improved the chemical composition of navel orange leaves. Furthermore Shirgure et al. (2014) on Nagpur mandarin claimed that treatment irrigation schedules recorded the highest leaf content of macronutrients (N, P, & K). Considering the impact of hydrogel and irrigation interval treatments on flowering and fruit set, it is quite evident that flowering and fruit set parameters responded positively to both investigated factor treatments.

The results obtained in Figure 2A showed that all treatments affected the number of opened flowers per shoot. T6 recorded the highest values (89.81, 91.47, & 115.17), followed by T7 (81.74, 85.07, & 110.98), the lowest values were recorded from trees subjected to T2 (78.68, 81.19, 84.60) throughout the experiment.

According to Figure 2B, data clearly showed that all treatments affected the fruit set ratio positively and had the same trend, whereas trees grown under T6 had the highest fruit set ratio (19.73, 23.39, & 20.98 %), followed by those under T7 (18.00, 22.09, & 19.23 %). The differences between both treatments and the other treatment were statistically significant. While T2 recorded the lowest values (13.45, 14.06, & 14.05 %), there were fluctuating responses in other treatments during the investigation.

Yield of trees treated with hydrogel at the most moderate intervals was much higher than that of other treatments due to the increased availability of water and nutrients for a longer time during various phenological stages. Consequently, stimulating fruit retention and increasing fruit weight in the trees that received polymers led to an increase in tree yield, consequently likely leading to a reduction in the effects of extending irrigation intervals. Our results concur with those of (Shirgure et al., 2014) who reported that irrigation schedules had a substantial impact on the yield and fruit quality parameters of Nagpur mandarin trees. The results in hand are in agreement with Solanki et al. (2021) on acid lime, Abd El-Aziz et al. (2020) on Murcott mandarin, and Zoghdan and Abo El-Enien (2019) on navel orange.

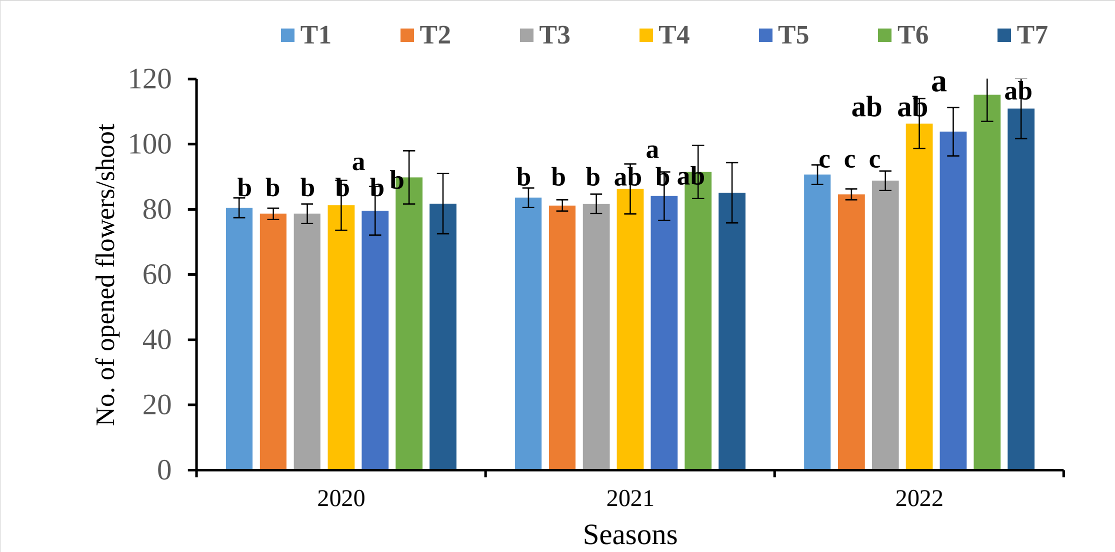

Fig. 2A: Flower number per shoot

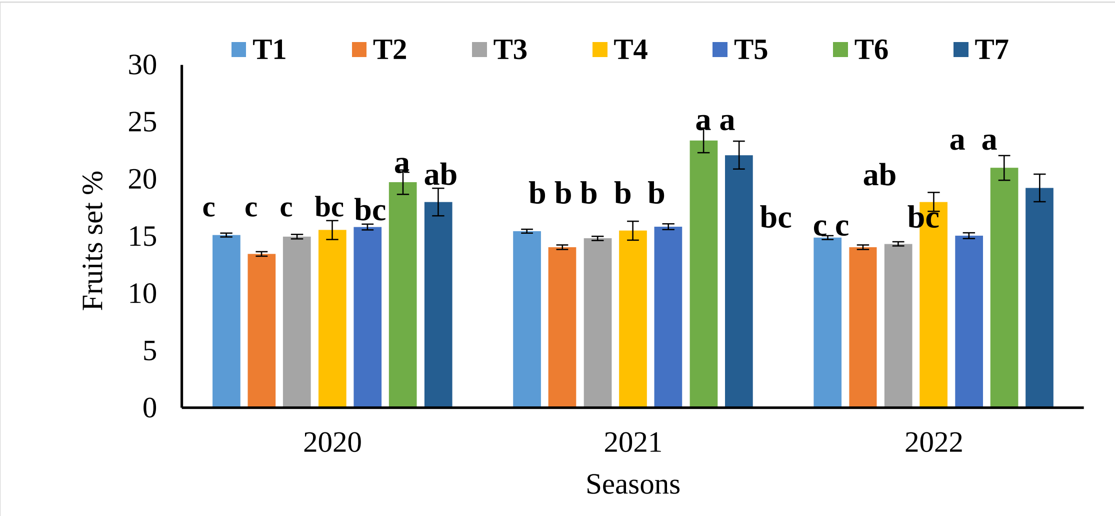

Fig. 2B: Fruit set %

Fig. 2. Effect of various treatments on flowering and fruit set of Valencia orange trees.
*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

Regarding yield efficiency, Figure 3 showed that T6 recorded the highest value (7.39, 5.69, & 5.04 kg/m^3), while T3 recorded the lowest value (4.78 kg/m^3) in the first season and control treatment recorded the lowest value (4.38 & 3.97 kg/m^3) in the second and third seasons.

Concerning fruit quality, Data in Table 4 illustrate a significant relationship that was identified in the number of fruits per plant, fruit weight, TSS, juice %, TSS/acidity ratio, and vitamin C during experiment. Data in hand showed a positive effect of various treatments on fruit weight, whereas the average fruit weight was 201.29 to 253.79 g across the seasons, heaviest fruits were produced from trees subjected to T5 (237.31 g), followed by T4 (227.77 g) in the first season. Trees subjected to T6 produced the heaviest fruit (214.02 & 253.79 g) compared to the rest of the treatments in the second and third seasons, followed by T4 (220.45 & 253.79 g), while the minimum fruit weight was recorded from untreated trees (209.91 & 201.29 g) in the first and third seasons and from T2 (203.26 g) in the second one. The results illustrate how different soil conditioner and irrigation interval treatments affect fruit quality parameters, which may be due to increasing soil moisture content in the rhizosphere of trees subjected to T6, which increases the availability of nutrients and reduces the effect of long irrigation intervals.

Table 3. Effect of various treatments on yield and yield parameters of Valencia orange trees.

Treatment		T1	T2	T3	T4	T5	T6	T7	LSD
Characters	Season								
Tree yield (Kg.tree^{-1})	2020	73.13 d	76.80 d	74.68 d	102.00 bc	94.40 c	113.58 a	108.73 ab	8.69
	2021	89.08 e	99.50 d	102.42 d	112.25 b	107.67 c	119.58 a	111.08 bc	3.47
	2022	100.00 e	114.17 cd	112.42 d	124.00 b	118.73 c	133.75 a	125.83 b	4.70
Total Yield (ton.fed^{-1})	2020	12.07 d	12.67 d	12.32 d	16.83 bc	15.58 c	18.74 a	17.94 ab	1.43
	2021	14.70 e	16.42 d	16.90 d	18.52 b	17.77 c	19.73 a	18.33 bc	0.57
	2022	16.50 e	18.84 cd	18.55 d	20.46 b	19.59 c	22.07 a	20.76 b	0.78
Fruit yield increasing %	2020	0.00 d	5.02 d	3.08 d	40.81 bc	30.34 c	56.67 a	50.02 ab	11.49
	2021	0.00 e	11.47 d	15.02 cd	26.04 b	20.92 bc	34.32 a	24.78 b	6.90
	2022	0.00 d	14.30 c	12.45 c	24.09 b	18.84 bc	33.80 a	25.91 ab	8.32
Yield Efficiency	2020	4.99 c	5.15 c	4.78 c	5.23 c	6.42 b	7.39 a	6.56 b	0.73
	2021	4.38 d	4.78 c	4.49 d	4.77 c	5.15 b	5.69 a	5.06 b	0.25
	2022	3.97 e	4.39 cd	4.09 de	4.21 de	4.79 ab	5.04 a	4.65 bc	0.32

*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

Table 4. Effect of various treatments fruit quality parameters of Valencia orange.

Treatment		T1	T2	T3	T4	T5	T6	T7	LSD
Fruit Parameters	Season								
Fruit weight (g)	2020	209.91 c	222.33 bc	224.00 abc	227.77 ab	237.31 a	220.31 bc	223.72 abc	14.39
	2021	212.97 b	203.26 c	203.90 c	220.45 a	208.94 bc	214.02 ab	207.36 bc	7.24
	2022	201.29 c	223.51 b	223.30 b	219.64 b	214.57 b	253.79 a	223.78 b	11.53
Fruit volume (ml)	2020	224.00 c	238.00 b	236.50 b	247.00 ab	257.70 a	238.80 b	238.30 b	10.76
	2021	227.20 bc	214.67 d	219.00 cd	240.60 a	218.00 cd	230.00 ab	218.27 cd	10.62
	2022	214.22 d	225.60 c	238.07 a	234.17 ab	232.83 abc	227.07 bc	237.67 a	8.29
Fruit firmness (lb/inch^2)	2020	8.53	8.91	8.56	8.86	8.75	8.57	8.42	N. S.
	2021	8.93	9.03	8.75	8.65	8.73	8.60	8.54	N. S.
	2022	8.73 ab	9.01 a	8.49 bc	8.64 abc	8.53 bc	8.47 bc	8.32 c	0.40
Juice volume (ml)	2020	42.57 c	44.23 bc	41.50 c	48.33 b	45.93 bc	54.77 a	48.70 b	4.90
	2021	49.37 bc	48.27 cd	45.80 d	52.27 ab	48.53 cd	54.53 a	52.77 ab	4.42
	2022	45.53 e	49.50 d	59.87 b	53.50 c	52.37 cd	65.17 a	59.50 b	3.80
TSS%	2020	11.43 ab	11.53 ab	11.67 a	11.37 ab	11.63 a	11.20 b	11.50 ab	0.350
	2021	9.95 e	11.11 c	10.81 d	11.58 a	11.24 b	11.60 a	10.90 d	0.127
	2022	11.44 b	11.41 b	11.49 b	11.55 ab	11.93 a	11.69 ab	11.72 ab	0.285
Total Acid %	2020	1.13 ab	1.01 cd	1.16 a	0.94 d	1.04 bcd	1.04 bcd	1.10 abc	0.117
	2021	1.16 a	1.05 bcd	1.08 b	1.01 d	1.06 bc	1.02 cd	1.07 b	0.040
	2022	1.15 a	1.09 bc	1.12 ab	1.04 d	1.08 c	1.03 d	1.09 bc	0.039
TSS/Acid ratio	2020	10.08 e	11.40 b	10.03 e	12.38 a	11.18 b	10.80 c	10.43 d	0.327
	2021	8.56 d	10.61 c	10.01 c	11.43 a	10.63 b	11.37 a	10.16 c	0.392
	2022	9.95 f	10.47 d	10.26 e	11.11 b	11.05 b	11.35 a	10.75 c	0.062
VC	2020	42.40 abc	43.60 a	42.43 abc	43.20 ab	42.83 abc	41.83 bc	41.43 c	1.67
	2021	42.07 ab	43.50 a	41.67 ab	40.25 b	41.50 ab	42.50 ab	40.25 b	2.46
	2022	42.43 abc	43.77 a	42.90 ab	41.97 bc	42.57 abc	42.63 abc	41.17 c	1.51

*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

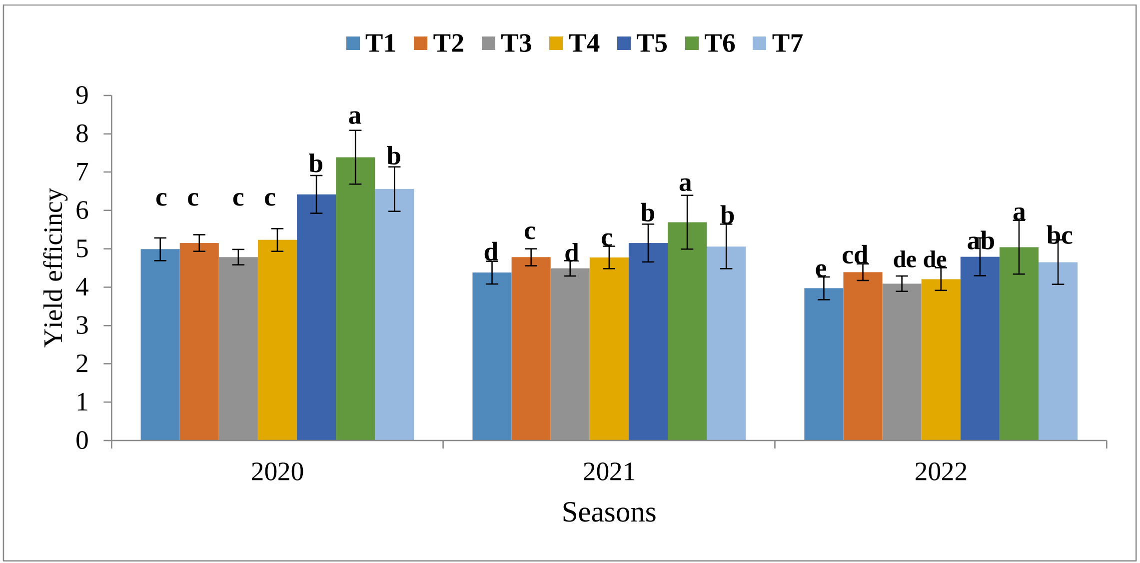

Fig. 3. Effect of various treatments on yield efficiency of Valencia orange trees.
*T1 (Control), T2 (I1+HC1), T3 (I2 +HC1), T4 (I1 + HC2), T5 (I2 + HC2), T6 (I1 + HC3), T7 (I2 +HC3).

Outcome data from Table 4 revealed that various treatments affected fruit volume. T5 had the biggest fruits (257.70 ml), followed by T4 (247.00 ml) in the first season, and T6 recorded the biggest fruits (240.60 & 237.07 ml) the second and third seasons. However, the control treatment produced the smallest fruits (224.00 & 214.22 ml) during the first and third seasons, while T2 recorded the lowest value (214.67 ml) in the second season.

Furthermore, the results obtained throughout the experiment showed that the differences between all coefficients of fruit firmness were non-statistical in 2020 and 2021, while they were statistically significant in 2022. Whereas, T2 recorded the highest significant values (9.01 lb/inch^2) compared to the rest of the treatments, and T7 recorded the lowest values (8.32 lb/inch^2), which may be due to higher soil moisture content throughout the investigation.

Data from Table 4 showed that there was a gradual increase in juice volume associated with the increased doses of the polymer during the experiment seasons, whereas T6 recorded the highest values (54.77, 54.53, & 65.17 ml) of juice volume. While, T3 recorded the least juice volume (41.50 & 45.80 ml) in the first and second seasons, and control treatment has the lowest value (45.53 ml) in the third season.

Data obtained in Table 4 showed that various treatments have a positive impact on TSS % compared to the control treatment, which had the lowest values (11.43, 9.95, & 11.44 %) during the experiment. Furthermore, the control treatment gave the highest total acidity (1.16 & 1.15 %) in the second and third seasons, while, T3 recorded the highest value (1.16 %) in the first season. In contrary, T4 recorded the lowest values (0.94 & 1.01%) in the first and second seasons, and T6 recorded the minimum acidity value (1.03 %) in the third season.

Regarding TSS/Acidity ratio, the differences between all treatments were statistical in 2020-2022, while the control treatment recorded the lowest significant values (10.08, 8.56, & 9.95 %). The differences in TSS/Acidity ratio may have stemmed from different acidity levels in fruit at harvest, such variation in TSS/Acidity ratio of fruits could be explained by differential available water for trees, particularly during the cell enlargement stage, which raises the acidity ratio in fruit juice from control trees.

The treatments carried out significantly affected fruit quality parameters and had a positive impact on most physical and chemical fruit parameters compared to the control, particularly T6. This could be due to the differential availability of water for trees during the fruit growth stages. Our findings are in the same line as those of Alshallash et al. (2022) on

Mango, Solanki et al. (2021) on acid lime, AbdEl-Aziz et al. (2020) on Murcott mandarin, Abobatta and Kahlifa (2019) and Zoghdan and Abo El-Enien (2019) on navel orange, Consoli et al. (2017) on orange and Shirgure et al. (2014) on acid lime.

Economic study

Data in Table 5 shows outstanding yield figures i.e. yield reaching 18.74, 19.73, and 22.07 tons of fruits in the recommended treatment, while it was 12.07, 14.70, and 16.50 tons in the control trees during the experimental seasons. Therefore, applying the suggested treatment (T6) in one feddan, the total expenses amounted to 16,160, 18,825, and 22,650 Egyptian pounds, while the total expenses for the control treatment amounted to 15,500, 18,00, and 22,000 Egyptian pounds.

Thus, total income per feddan with the recommended treatment reached 65,590, 78,920, and 88,280, while the untreated treatment reached 42,245, 58,800, and 66,000 L.E. during the investigation, respectively.

The expected net profit for the recommended treatment when applied in one feddan containing 165 Valencia orange trees reached 49,430, 60,095, and 64,630 L.E., while it reached 26.745, 40,800, and 44,000 L.E. in the control treatment during the experimental seasons, respectively.

Table 5. Economic study of productivity, total cost, and net profit per feddan.

Seasons	Control			Recommended treatment		
	2020	2021	2022	2020	2021	2022
Yield (ton)	12.07	14.70	16.50	18.74	19.73	22.07
Total cost (L.E.)	15,500	18,000	22,000	16,160	18,825	23,650
Total income	42,245	58,800	66,000	65,590	78,920	88,280
Net profit	26,745	40,800	44,000	49,430	60,095	64,630

CONCLUSION

Due to water shortage crises, citrus growers need to adapt new irrigation strategies to sustain citrus production in Egypt. The implementation of day-by-day irrigation with 1000 g of hydrogel composite/tree would be recommended to sustain Valencia orange production and save water. The results of this work could be recommended for citrus plantations in arid areas. Furthermore, vegetative growth parameters (tree canopy, shoot length, leaf area, and leaf number) demonstrate the unique role that polymer treatments play in regulating water and nutrient absorption. Finally, adopted irrigation schedules accompanied by soil application of hydrogel composite produced a clear differentiation within the other treatments.

Treatment of 1000 g/tree hydrogel composite and every two-days irrigation interval achieved the best results when compared to other treatments during the experiment. While application of 1250 g/tree hydrogel with irrigation day-by-day produced the highest tree yield (113.58 kg/tree) and total yield (18.74 tons/feddan) and improved various physical and chemical fruit characteristics, it could be a promising strategy for managing orange orchards in areas that are suffering from water shortages and are similar to the experiment area. More work is required to explain the different effects of hydrogel composite on plant physiology and soil characteristics.

Conflict of interest

The authors declare that there is no conflict of interest.

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