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Effect of foliar application of different concentrations of salicylic acid on Washington navel orange trees under water stress

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Abstract

Background A field experiment was performed from 2021 to 2022 on 10-year-old Washington navel orange trees (*Citrus sinensis*) budded on sour orange rootstock (*Citrus aurantium*) under sandy loam soil conditions in the region of Belbeis—El Sharkia Governorate, Egypt. This study was carried out to increase water use efficiency, maximize water utilization and determine the most effective treatment of Washington navel orange trees by using different concentrations of salicylic acid (control, 250, 500, and 750 ppm) under some levels of water stress (100, 75 and 50% of estimated crop water requirement).

Results In this scenario, the water use efficiency increased with 750 ppm of salicylic acid under 75% of the estimated crop water requirement, which produced 2.27 and 3.09 kg of fruit for each cubic meter of irrigation water in the first and second seasons, respectively. In addition, using salicylic acid treatment with 750 ppm under 75% of the estimated crop water requirement had a high economic return through increasing water unit return, while using less water irrigation amount by 25% at the same time, which reached 9.06 and 12.38 EGP per every cubic meter of irrigation water in the first and the second seasons, respectively.

Conclusion In summary, the data cleared that the irrigation water quantity could reduce by 25% while maintaining the production and the possibility of increasing it by using salicylic acid with the highest concentration. Thus, we recommend applying the treatment of the estimated crop water requirement with 75% combined with salicylic acid 750 ppm to Washington navel orange trees budded on sour orange rootstock to gain a high economic return.

Keywords Orange, Salicylic, Irrigation, Evapotranspiration, Water stress

Background

Citrus is a sensitive crop to water scarcity, which is one of the major causes of low productivity and the decline of citrus orchards. Water deficit in citrus diminishes vegetative growth, yield, and sometimes quality, causing economic losses (Romero et al. 2006). In Egypt, citrus trees are the most important fruit crop. They have outstanding economic importance among fruit crops, particularly for exportation. The total area under citrus trees is 493,925 feddan,[1] of which 440,210 feddan is fruitful to produce 4,503,226 tons (38.73% of the total production of fruit trees) with an average of 10.23 tons per feddan. The total area of Washington orange trees is 152,806 feddan, of which 145,645 feddan is fruitful to produce 1,608,806 tons with an average of 11.05 tons per feddan (Ministry of Agriculture 2022). Previous studies under Egyptian conditions exhibited a wide range of irrigation rates needed for orange orchards that could sometimes reach 8000 m^3/feddan/year or more (Abd-El Aziz 2004; Mahmoud 2012). The general

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[1] Feddan = (0.42 hectare).

Table 1 Reference crop evapotranspiration rate (ETo) calculated with CROPWAT V.8.00 computer program from meteorological data under Sharkia Governorate conditions using FAO—Penman–Monteith equation according to Admasu et al. 2014 (season 2021)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
ETo (100%)	2.17	2.73	3.69	5.24	6.76	6.79	6.77	6.27	5.05	3.89	2.75	2.07	
Crop coefficient	0.61	0.64	0.67	0.72	0.78	0.81	0.80	0.97	0.46	0.51	0.64	0.58	
ETc (100%)	1.32	1.75	2.47	3.77	5.27	5.50	5.42	6.08	2.32	1.98	1.76	1.20	
W.R (m^3/fed./Day)	5.56	7.34	10.38	15.85	22.15	23.10	22.75	25.54	9.76	8.33	7.39	5.04	
W.R (m^3/ fed. Month)	166.79	220.15	311.26	475.37	664.37	692.99	682.42	766.32	292.70	249.97	221.76	151.28	4895.36
ETo (75%)	1.63	2.05	2.77	3.93	5.07	5.09	5.08	4.70	3.79	2.92	2.06	1.55	
ETc (75%)	0.99	1.31	1.86	2.83	3.95	4.12	4.06	4.56	1.74	1.49	1.32	0.90	
W.R (m^3/fed./Day)	4.18	5.51	7.79	11.88	16.61	17.32	17.07	19.15	7.32	6.25	5.54	3.78	
W.R (m^3/ fed. Month)	125.28	165.31	233.84	356.53	498.28	519.49	512.06	574.43	219.67	187.64	166.12	113.27	3671.93
ETo (50%)	1.09	1.37	1.84	2.62	3.38	3.40	3.39	3.14	2.53	1.95	1.38	1.04	
ETc (50%)	0.66	0.88	1.23	1.89	2.64	2.75	2.71	3.05	1.16	0.99	0.88	0.60	
W.R (m^3/fed./Day)	2.79	3.68	5.18	7.92	11.07	11.57	11.39	12.79	4.89	4.18	3.71	2.53	
W.R (m^3/ fed. Month)	83.78	110.48	155.33	237.69	332.19	347.00	341.71	383.77	146.64	125.31	111.28	76.00	2451.18

ETo, reference crop evapotranspiration rate; ETc, estimated crop water requirement

trend in those studies showed that increasing irrigation rate caused promotions in many characteristics, which leads to an increment in both vegetative growth and fruiting as well as profitable yield (Wassel et al. 2007; Panigrahi and Strivastava 2011; Mahmoud 2012).

The River Nile, as a major source of water in Egypt (55.5 billion cubic meters), puts it under enormous pressure, especially because of the competitive situation with neighboring countries, many steps need to be taken to conserve both the quantity and quality of water, and appropriate strategies will have to be developed to avoid risk to future water supplies. Water irrigation accounts for over (40.2 billion cubic meters) 72.43% of the total water use in Egypt according to statistics from Central Agency for Public Mobilization and Statistics (2019), and then the main efficiency gains must come from reducing the amount of water used for irrigation.

One of the ways that can reduce the total water used for irrigation is to employ practices that improve crop yield per unit volume of water used (i.e., water productivity or water use efficiency) is using growth regulators like salicylic acid. The increasing number of studies in crop plants revealed a potential role of salicylic acid (SA) as a growth regulator and in the activation of abiotic stress tolerance apart from their role in biotic stress resistance. The endogenous level of salicylic acid in plants increased during abiotic stress (Saxena et al. 2019).

This study aimed to improve water use efficiency, maximize water utilization, and determine the most effective treatment of Washington navel orange trees by using different concentrations of salicylic acid (SA) (control, 250, 500, and 750 ppm) under some levels of water supply (100, 75, and 50% of ETc, i.e., estimated crop water requirement).

Methods

Material preparation and characterization

The present investigation has been carried out during two successive seasons (2021 and 2022) to improve water use efficiency and increase water unit return for citrus by studying the effect of salicylic acid (SA) (control, 250, 500, and 750 ppm) under different levels of water stress (100, 75, and 50% of estimated crop water requirement (ETc)) on growth, flowering, fruit set and yield of Washington navel orange trees (*Citrus sinensis)* budded on sour orange (*Citrus aurantium*) rootstock. The experimental trees were 10 years old and grown at 4×5 m in sandy loam soil under a drip irrigation system using River Nile water in a private orchard in Belbeis region, El Sharkia Governorate, Egypt.

All the trees in this study received the same horticultural practices except for experimental treatments. The experimental design was a split-plot arrangement of a randomized complete block with three replicates and two trees for each replicate. The main plot (first factor) comprised three irrigation levels (100, 75, and 50% of ETc), and the sub-plot (second factor) was salicylic acid (control, 250, 500, and 750 ppm), which were applied three times in every season in the first week of March, May, and July. The tested irrigation levels based on different rates of irrigation water, i.e., 4895, 3671, and 2451 m^3/feddan/year for the first season and 4720, 3543, and 2362 m^3/feddan/year for the second season as shown in Tables 1, 2 and Fig. 1. These values resulted from the CROPWAT (2012) version 8.0.1.1

Table 2 Reference crop evapotranspiration rate (ETo) calculated with CROPWAT V.8.00 computer program from meteorological data under Sharkia Governorate conditions using FAO—Penman–Monteith equation according to Admasu et al. 2014 (season 2022)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
ETo (100%)	2.10	2.57	3.39	5.46	6.12	6.82	6.49	5.82	5.00	3.85	2.62	2.18	
Crop coefficient	0.61	0.64	0.67	0.72	0.78	0.81	0.80	0.97	0.46	0.51	0.64	0.58	
ETc (100%)	1.28	1.64	2.27	3.93	4.77	5.52	5.19	5.65	2.30	1.96	1.68	1.26	
W.R (m^3/fed./Day)	5.38	6.91	9.54	16.51	20.05	23.20	21.81	23.71	9.66	8.25	7.04	5.31	
W.R (m^3/ fed. Month)	161.41	207.24	286.18	495.33	601.47	696.05	654.19	711.32	289.80	247.40	211.28	159.31	4720.99
ETo (75%)	1.58	1.93	2.54	4.10	4.59	5.12	4.87	4.37	3.75	2.89	1.97	1.64	
ETc (75%)	0.96	1.24	1.70	2.95	3.58	4.15	3.90	4.24	1.73	1.47	1.26	0.95	
W.R (m^3/fed./Day)	4.05	5.19	7.15	12.40	15.04	17.42	16.36	17.80	7.25	6.19	5.30	4.00	
W.R (m^3/ fed. Month)	121.44	155.64	214.43	371.95	451.11	522.55	490.90	534.10	217.35	185.71	158.86	119.85	3543.88
ETo (50%)	1.05	1.29	1.70	2.73	3.06	3.41	3.25	2.91	2.50	1.93	1.31	1.09	
ETc (50%)	0.64	0.83	1.14	1.97	2.39	2.76	2.60	2.82	1.15	0.98	0.84	0.63	
W.R (m^3/fed./Day)	2.69	3.47	4.78	8.26	10.02	11.60	10.92	11.86	4.83	4.13	3.52	2.66	
W.R (m^3/ fed. Month)	80.70	104.03	143.51	247.67	300.74	348.02	327.60	355.66	144.90	124.02	105.64	79.66	2362.15

ETo, reference crop evapotranspiration rate; and ETc, estimated crop water requirement

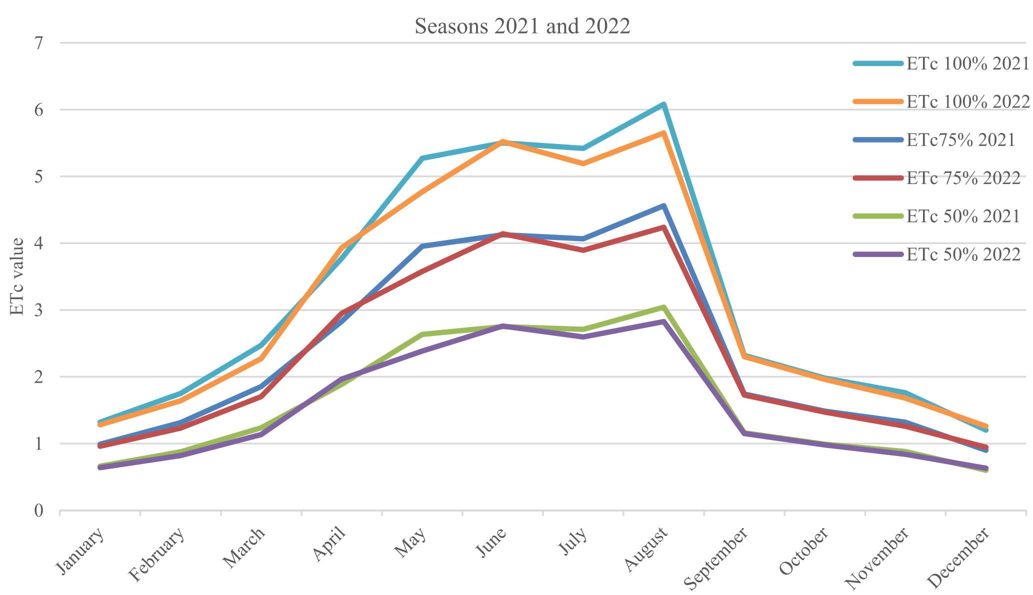

Fig. 1 Monthly estimated crop water requirement (ETc) at the experimental site during the two growing seasons (2021 and 2022)

computer program using the region meteorological data (2020 and 2021 years). Moreover, the estimated crop water requirement (ETc) is obtained by multiplying the specific crop coefficient (Kc) by reference evapotranspiration (ETo), i.e., ETc = ETo × Kc.

The tested treatments were evaluated through the following parameters

Tree volume leaf area and roots behavior (length of fibrous roots)

The tree height (m), tree circumference (m), and tree canopy volume (m^3) were determined in both investigation seasons. The tree canopy volume was calculated according to the following equation: canopy volume $(m^3) = 1.33 \times 0.5 \times \text{circumference (m)} \times 3.14 \times 0.5 \times \text{height (m)}$ (Turell 1965). Tree volume increment had been calculated by subtracting tree volume at the beginning and the end of the season. In addition**,** the total length of fibrous roots in 500 cm^3 of soil samples was taken from the layers of 0–30 cm from the soil surface at the beginning of the experiment and then at the end of each season (December). Moreover, leaf area (cm^2) was determined using disks of the leaf blades according to Bremner and Taha (1966).

Flowering and fruit set

Sixteen twigs per tree (four twigs on each side) had been chosen to collect the data. The number of leafy and leafless inflorescences per twig were counted and recorded, and then leafy inflorescences percentages were calculated according to the following equation: $\text{Leafy inflorescences (\%)} = 100 \times \frac{\text{Leafy inflorescences}}{\text{Total inflorescences}}$.

In addition, the total number of flowers per twig was counted and recorded at full bloom. At the same time, the numbers of set fruitlets per twig were counted and recorded after the fruit set stage. Finally, the fruit set percentage was calculated according to the following equation:$\text{Fruit set (\%)} = 100 \times \frac{\text{Number of set fruitlet}}{\text{Number of total flowers}}$.

Leaf photosynthetic pigments, proline, cell sap osmotic pressure, opened stomata percentage and leaf‑bound water percentage

The photosynthetic pigment contents (mg/100 g of fresh weight) were determined in fresh samples of leaf blades collected in August, according to Von-Wettestein (1957). Moreover, the proline content of fresh leaves (μ moles/g fresh weight) was determined following the method adopted by Bates et al. (1973). The leaf osmotic pressure of the cell sap of leaf blades and leaf-bound water percentage were determined following the method of Gosov (1960). The total numbers of stomata and the number of opened stomata/cm^2 of leaf area were determined using the method of Stino et al. (1974), and the percentage of opened stomata was calculated according to the following equation: $\text{Opened stomata} = 100 \times \frac{\text{Number of opened stomata}}{\text{Number of total stomata}}$.

Fruit physical properties

Samples of 32 fruits per replicate (16 fruits per tree) were randomly selected, and the studied parameters involved fruit weight (g) and juice volume.

Chemical constituents of the fruit juice

The following parameters were considered: total soluble solids percentage (TSS) was determined using a hand refractometer; total titratable acidity (g citric acid per 100 ml of juice) was determined by titration against 0.1 N sodium hydroxide in the presence of phenol phthalin as an indicator; values of the TSS/acid ratio were calculated; ascorbic acid content (mg per 100 ml of juice) was determined by titration against 2,6-dichlorophenol indophenol (mg per 100 ml) following the method illustrated in the AOAC (1985).

Yield, water use efficiency, and water unit return

The quantity of fruits collected from each tree at harvest (December) was tallied, the weight of all the fruits from each tree (kg) was determined and noted, and the hypothetical yield per feddan [based on 210 trees per feddan (4 × 5 m apart)] was computed.

Water use efficiency (WUE) values were calculated according to the following equation (Jensen 1983) $\text{WUE} = \frac{\text{Yield (kg per feddan)}}{\text{Seasonal ET} (m^3 \text{perfeddan})}$.

Water unit returns (WUR) were calculated according to the following equation: Water unit return = WUE × price of 1 kg orange (4 EGP).

Statistical analysis

The experimental design was a split-plot arrangement of a complete randomized block (factorial experiment with split-plot design) with three replicates and two trees for each replicate. The main plot contained three water irrigation levels (100, 75, and 50% of ETc), and the sub-plot comprised salicylic acid (control, 250, 500, and 750 ppm). The data obtained were statistically analyzed using the analysis of variance method as reported by Snedecor and Cochran (1980). The differences between means were differentiated by using Duncan's range test (Duncan 1955).

Results

The obtained data showed that salicylic acid treatments had a great effect on all morpho-phenological parameters displayed in Table 3 starting with tree canopy volume, leaf area, and leafy inflorescences percentage that are considered as a preliminary predictor of yield status, fruit set, and length of fibrous roots which also reflected in the increase in the number of fruits per tree.

The highest significant value for tree canopy volume was 62.76 m^3 with 100% of ETc, while the lowest significant value was 40.56 m^3 with 50% of ETc. For salicylic acid (SA), the highest significant value for tree canopy was 55.80 m^3 with SA 750 ppm, while the lowest significant value was 46.91 m^3 with the control (SA 0 ppm); this came true in the two seasons. For the interaction between water rates and salicylic acid, the most significant

Table 3 Water stress levels and salicylic acid concentrations influence on morpho-phenological (growth, fruit set, and number of fruits per tree) parameters of Washington navel orange trees (2021–2022 seasons)

	Tree canopy volume (m^3)	Leaf area (cm^2)	Total length of fibrous roots (cm)/500 cm^3 soil in 0–30 cm soil layer	Percentage of leafy inflorescences per twig	Overall fruit set percentage per twig	Number of fruits per tree
First season (2021)						
ETc 100%	62.76^{a}	19.36^{a}	176.40^{a}	80.82^{a}	8.60^{a}	147.87^{a}
ETc 75%	51.43^{b}	17.75^{b}	143.91^{b}	78.20^{a}	6.88^{b}	111.67^{b}
ETc 50%	40.56^{c}	16.05^{c}	113.33^{c}	61.50^{b}	5.08^{c}	73.80^{c}
SA 0 ppm	46.91^{d}	16.86^{c}	128.63^{d}	68.49^{c}	6.10^{c}	97.04^{d}
SA 250 ppm	50.33^{c}	17.46^{b}	142.25^{c}	72.44^{b}	6.60^{b}	105.58^{c}
SA 500 ppm	53.31^{b}	18.06^{a}	150.91^{b}	76.17^{a}	7.22^{a}	116.44^{b}
SA 750 ppm	55.80^{a}	18.49^{a}	156.38^{a}	76.92^{a}	7.48^{a}	125.40^{a}
ETc 100% × SA 0 ppm	57.28^{e}	18.33^{c}	152.79^{cd}	78.31^{ab}	7.41^{c}	131.38^{c}
ETc 100% × SA 250 ppm	62.26^{b}	19.34^{b}	176.32^{b}	79.15^{ab}	8.31^{b}	144.78^{b}
ETc 100% × SA 500 ppm	65.53^{a}	19.81^{a}	186.64^{a}	82.23^{a}	9.22^{a}	156.99^{a}
ETc 100% × SA 750 ppm	65.98^{a}	19.96^{a}	189.85^{a}	83.57^{a}	9.45^{a}	158.35^{a}
ETc 75% × SA 0 ppm	45.68^{f}	17.24^{de}	133.71^{f}	75.27^{b}	6.35^{e}	97.69^{e}
ETc 75% × SA 250 ppm	49.13^{e}	17.45^{d}	140.12^{ef}	79.37^{ab}	6.63^{e}	104.06^{de}
ETc 75% × SA 500 ppm	52.37^{d}	17.63^{d}	144.79^{de}	79.38^{ab}	7.03^{d}	110.87^{d}
ETc 75% × SA 750 ppm	58.56^{c}	18.66^{c}	157.00^{c}	78.78^{ab}	7.50^{c}	134.03^{c}
ETc 50% × SA 0 ppm	37.76^{h}	15.01^{h}	99.38^{i}	51.90^{e}	4.55^{g}	62.03^{g}
ETc 50% × SA 250 ppm	39.59^{h}	15.58^{g}	110.32^{h}	58.79^{d}	4.86^{g}	67.90^{g}
ETc 50% × SA 500 ppm	42.02^{g}	16.75^{f}	121.32^{g}	66.90^{c}	5.42^{f}	81.46^{f}
ETc 50% × SA 750 ppm	42.86^{g}	16.86^{ef}	122.29^{g}	68.41^{c}	5.48^{f}	83.81^{f}
Second season (2022)						
ETc 100%	80.99^{a}	22.24^{a}	184.79^{a}	85.28^{a}	12.02^{a}	184.03^{a}
ETc 75%	66.07^{b}	19.95^{b}	148.68^{b}	77.16^{b}	10.72^{b}	139.42^{b}
ETc 50%	49.30^{c}	16.79^{c}	117.12^{c}	62.04^{c}	7.84^{c}	90.58^{c}
SA 0 ppm	58.97^{d}	18.58^{c}	133.75^{d}	69.14^{c}	9.44^{c}	117.47^{d}
SA 250 ppm	63.27^{c}	19.45^{b}	143.14^{c}	73.25^{b}	10.03^{b}	129.57^{c}
SA 500 ppm	67.64^{b}	20.02^{a}	158.97^{b}	78.96^{a}	10.52^{a}	148.37^{b}
SA 750 ppm	71.93^{a}	20.61^{a}	164.94^{a}	77.96^{a}	10.78^{a}	156.63^{a}
ETc 100% × SA 0 ppm	73.74^{c}	20.80^{b}	166.86^{c}	81.88^{b}	11.55^{b}	166.50^{c}
ETc 100% × SA 250 ppm	79.58^{b}	22.25^{a}	180.03^{b}	85.15^{ab}	11.88^{ab}	180.90^{b}
ETc 100% × SA 500 ppm	84.79^{a}	22.91^{a}	194.55^{a}	87.07^{a}	12.29^{a}	193.07^{a}
ETc 100% × SA 750 ppm	85.84^{a}	23.00^{a}	197.74^{a}	87.03^{a}	12.36^{a}	195.64^{a}
ETc 75% × SA 0 ppm	59.24^{e}	18.93^{d}	133.74^{ef}	68.94^{d}	9.78^{e}	111.35^{f}
ETc 75% × SA 250 ppm	63.01^{d}	19.72^{c}	137.29^{e}	73.86^{c}	10.39^{d}	125.64^{e}
ETc 75% × SA 500 ppm	66.25^{d}	19.91^{c}	155.24^{d}	84.07^{ab}	11.07^{c}	150.35^{d}
ETc 75% × SA 750 ppm	75.78^{c}	21.24^{b}	168.43^{c}	81.78^{b}	11.63^{b}	170.34^{c}
ETc 50% × SA 0 ppm	43.93^{g}	16.00^{f}	100.64^{h}	56.60^{g}	6.99^{h}	74.57^{h}
ETc 50% × SA 250 ppm	47.21^{g}	16.39^{f}	112.10^{g}	60.72^{f}	7.82^{g}	82.17^{h}
ETc 50% × SA 500 ppm	51.87^{f}	17.23^{e}	127.12^{f}	65.75^{de}	8.19^{fg}	101.67^{g}
ETc 50% × SA 750 ppm	54.17^{f}	17.57^{e}	128.64^{f}	65.07^{e}	8.35^{f}	103.92^{fg}

ETc, estimated crop water requirement; SA, salicylic acid

Mean followed by the same letter/s within each column is not significantly different from each other at the 0.5% level

treatments were 100% of ETc combined with SA 500 or 750 ppm, which gained 65.53 and 65.98 m^3, respectively. Generally, leaf area, the total length of fibrous roots, leafy inflorescences percentage, and the fruit set percentage as well as the number of fruits per tree have the same trend as tree canopy volume; this came true in the two seasons.

Table 4 Water stress rates and salicylic acid concentrations influence on photosynthetic pigments and proline contents, cell sap osmotic pressure, opened stomata percentage and bound water content percentage of Washington navel orange leaves (2021–2022 seasons)

	Leaf chlorophyll a content (mg/100 g of leaf F. W.)	Leaf chlorophyll b content (mg/100 g of leaf F. W.)	Leaf proline content (µg/moles of leaf F. W.)	Leaf cell sap osmotic pressure (atm.)	Opened stomata percentage	Leaf-bound water content percentage
First season (2021)						
ETc 100%	0.224[a]	0.103[a]	50.72[c]	25.96[c]	90.96[a]	44.44[c]
ETc 75%	0.209[b]	0.097[b]	78.67[b]	27.55[b]	85.79[b]	46.29[b]
ETc 50%	0.193[c]	0.092[c]	118.72[a]	29.30[a]	79.03[c]	48.37[a]
SA 0 ppm	0.202[c]	0.094[a]	96.93[a]	28.29[a]	82.61[c]	47.09[a]
SA 250 ppm	0.207[b]	0.097[a]	89.26[b]	27.77[a]	84.43[b]	46.69[b]
SA 500 ppm	0.212[a]	0.099[a]	75.97[c]	27.33[a]	86.52[a]	46.25[b]
SA 750 ppm	0.215[a]	0.100[a]	68.65[d]	27.03[a]	87.49[a]	45.43[c]
ETc 100% × SA 0 ppm	0.216[a]	0.099[a]	64.04[g]	26.68[a]	88.77[b]	45.97[d]
ETc 100% × SA 250 ppm	0.221[a]	0.104[a]	60.16[g]	26.01[a]	90.66[b]	44.87[e]
ETc 100% × SA 500 ppm	0.228[a]	0.105[a]	42.78[h]	25.59[a]	92.02[a]	44.23[e]
ETc 100% × SA 750 ppm	0.230[a]	0.105[a]	35.89[i]	25.56[a]	92.40[a]	43.42[f]
ETc 75% × SA 0 ppm	0.203[a]	0.095[a]	92.09[d]	28.38[a]	82.36[c]	46.61[c]
ETc 75% × SA 250 ppm	0.207[a]	0.096[a]	82.63[e]	27.89[a]	84.18[c]	46.27[c]
ETc 75% × SA 500 ppm	0.211[a]	0.098[a]	76.87[f]	27.38[a]	87.35[b]	46.19[c]
ETc 75% × SA 750 ppm	0.216[a]	0.100[a]	63.06[g]	26.55[a]	89.29[b]	45.23[d]
ETc 50% × SA 0 ppm	0.188[a]	0.089[a]	134.65[a]	29.80[a]	76.69[e]	49.31[a]
ETc 50% × SA 250 ppm	0.192[a]	0.092[a]	125.00[b]	29.42[a]	78.45[e]	49.01[a]
ETc 50% × SA 500 ppm	0.196[a]	0.094[a]	108.25[c]	29.02[a]	80.19[d]	48.55[b]
ETc 50% × SA 750 ppm	0.197[a]	0.094[a]	106.99[c]	28.96[a]	80.77[d]	46.74[c]
Second season (2022)						
ETc 100%	0.225[a]	0.103[a]	43.98[c]	26.72[c]	91.67[a]	43.45[c]
ETc 75%	0.212[b]	0.096[b]	82.47[b]	28.79[b]	86.09[b]	44.56[b]
ETc 50%	0.197[c]	0.091[c]	125.70[a]	30.69[a]	81.32[c]	46.49[a]
SA 0 ppm	0.205[c]	0.094[a]	101.22[a]	29.54[a]	83.54[c]	45.77[a]
SA 250 ppm	0.209[b]	0.096[a]	90.26[b]	28.98[a]	85.45[b]	45.38[a]
SA 500 ppm	0.214[a]	0.098[a]	77.18[c]	28.44[a]	87.78[a]	44.43[b]
SA 750 ppm	0.216[a]	0.100[a]	67.53[d]	27.96[a]	88.67[a]	43.75[c]
ETc 100% × SA 0 ppm	0.216[a]	0.099[a]	58.83[g]	27.73[e]	88.19[c]	44.32[c]
ETc 100% × SA 250 ppm	0.224[a]	0.102[a]	47.64[h]	27.02[e]	91.51[b]	44.21[c]
ETc 100% × SA 500 ppm	0.229[a]	0.105[a]	37.31[i]	26.18[f]	93.40[a]	43.06[d]
ETc 100% × SA 750 ppm	0.230[a]	0.106[a]	32.14[j]	25.95[f]	93.56[a]	42.14[e]
ETc 75% × SA 0 ppm	0.207[a]	0.094[a]	102.87[d]	29.56[c]	84.46[e]	44.91[c]
ETc 75% × SA 250 ppm	0.210[a]	0.095[a]	94.36[e]	29.15[c]	84.77[e]	44.50[c]

Table 4 (continued)

	Leaf chlorophyll a content (mg/100 g of leaf F. W.)	Leaf chlorophyll b content (mg/100 g of leaf F. W.)	Leaf proline content (µg/moles of leaf F. W.)	Leaf cell sap osmotic pressure (atm.)	Opened stomata percentage	Leaf-bound water content percentage
ETc 75% × SA 500 ppm	0.213[a]	0.097[a]	75.83[f]	28.79[d]	86.41[d]	44.36[c]
ETc 75% × SA 750 ppm	0.218[a]	0.100[a]	56.81[g]	27.64[e]	88.72[c]	44.30[c]
ETc 50% × SA 0 ppm	0.192[a]	0.090[a]	141.96[a]	31.33[a]	77.95[h]	47.84[a]
ETc 50% × SA 250 ppm	0.194[a]	0.091[a]	128.79[b]	30.78[b]	80.07[g]	47.33[a]
ETc 50% × SA 500 ppm	0.200[a]	0.092[a]	118.40[c]	30.35[b]	83.54[f]	45.86[b]
ETc 50% × SA 750 ppm	0.201[a]	0.093[a]	113.64[c]	30.28[b]	83.72[f]	45.17[b]

ETc, estimated crop water requirement; SA, salicylic acid

Mean followed by the same letter/s within each column is not significantly different from each other at the 0.5% level

The data in Table 4 demonstrate the role of salicylic acid treatments on water relations parameters such as leaf chlorophyll a, leaf chlorophyll b, leaf proline, leaf cell sap osmotic pressure, opened stomata percentage, and leaf-bound water content under water stress. Generally, chlorophyll a, leaf chlorophyll b, and opened stomata percentage parameters were increased when the water amount or salicylic acid concentrations increased. On the contrary, leaf proline, leaf cell sap osmotic pressure, and leaf-bound water content were decreased when the water amount increased at the same time they increased when salicylic acid concentrations decreased. This came true in both seasons.

Regarding, the highest significant value for leaf chlorophyll a was 0.224 (mg/100 g of leaf F. W.) with 100% of ETc, while the lowest significant value was 0.193 (mg/100 g of leaf F. W.) with 50% of ETc. For salicylic acid (SA), the highest significant values for leaf chlorophyll a were 0.215 and 0.212 (mg/100 g of leaf F. W.) with SA 750 and 500 ppm, respectively, while the lowest significant value was 0.202 (mg/100 g of leaf F. W.) with the control (SA 0 ppm); this came true in the two seasons. For the interaction between water rates and salicylic acid, there are no significant results through the treatments. The leaf chlorophyll b and opened stomata percentage parameters take the same trend as chlorophyll a; this came true in the two seasons.

In the conversed direction, the lowest significant value for leaf proline was 50.72 (µg/moles of leaf F. W.) with 100% of ETc, while the highest significant value was 118.72 (µg/moles of leaf F. W.) with 50% of ETc. For salicylic acid (SA), the lowest significant values for leaf proline were 68.65 (µg/moles of leaf F. W.) with SA 750 ppm, while the highest significant value was 96.93 (µg/ moles of leaf F. W.) with the control (SA 0 ppm); this came true in the two seasons. For the interaction between water rates and salicylic acid, the lowest significant value was 35.89 (µg/moles of leaf F. W.), which was gained by 100% of ETc combined with SA 750 ppm treatment. The leaf cell sap osmotic pressure and leaf-bound water content take the same trend to leaf proline; this came true in the two seasons.

Data presented in Table 5 show a strong effect of ETc treatments on all physical and chemical fruit parameters with significant differences in both seasons, while salicylic acid did not affect most of the parameters except TSS/acid ratio and Ascorbic acid.

The highest significant value for fruit weight was 327.59 g with 100% of ETc, while the lowest significant value was 289.32 g with 50% of ETc. For salicylic acid (SA), there is no effect of the salicylic acid application on all physical and chemical fruit parameters except TSS/acid ratio and Ascorbic acid. For the interaction between water rates and salicylic acid, the most significant treatments were 100% of ETc combined with SA 500 or 750 ppm, which gained 336.03 and 337.69 g, respectively.

Generally, most of all physical and chemical fruit parameters take the same trend to fruit weight except for TSS/acid ratio and Ascorbic acid. The TSS/acid ratio and ascorbic acid parameters effect by ETc or salicylic acid concentration, while the ascorbic acid parameter did not affect by the interaction between water rates and salicylic acid at all, but the TSS/acid ratio parameter was affected. This came true in the two seasons.

Data in Table 6 and Figs. 2, 3, 4 summarize the benefits of this study. The highest significant increment in hypothetical yield per feddan (ton/feddan) was gained by using 100% of ETc, which produced 10.20 tons/feddan, while 50% of ETc treatment recorded only 4.49 tons/feddan. For salicylic acid, the highest significant increment

Table 5 Water stress rates and salicylic acid concentrations influence on weight, juice volume, TSS, acidity, TSS/acid ratio and ascorbic acid of Washington navel orange fruits (2021–2022 seasons)

	Fruit weight (g)	**Juice volume (cm^3)**	**TSS (%)**	**Acidity (%)**	**TSS/acid ratio**	**Ascorbic acid (mg/100 ml)**
First season (2021)						
ETc 100%	327.59^{a}	184.64^{a}	10.96^{c}	0.77^{a}	14.27^{c}	37.05^{c}
ETc 75%	303.91^{b}	175.00^{b}	11.78^{b}	0.70^{b}	16.73^{b}	41.78^{b}
ETc 50%	289.32^{c}	166.85^{c}	12.77^{a}	0.69^{c}	18.54^{a}	45.74^{a}
SA 0 ppm	297.31^{a}	171.73^{a}	11.49^{a}	0.70^{a}	16.49^{d}	39.91^{d}
SA 250 ppm	305.91^{a}	173.93^{a}	11.66^{a}	0.73^{a}	16.02^{c}	40.97^{c}
SA 500 ppm	310.66^{a}	177.15^{a}	11.96^{a}	0.73^{a}	16.50^{b}	41.91^{b}
SA 750 ppm	313.87^{a}	179.18^{a}	12.23^{a}	0.73^{a}	16.71^{a}	43.29^{a}
ETc 100% × SA 0 ppm	308.27^{d}	180.45^{c}	10.74^{d}	0.72^{a}	14.91^{e}	35.85^{a}
ETc 100% × SA 250 ppm	328.37^{b}	183.46^{b}	10.80^{d}	0.78^{a}	13.83^{f}	36.02^{a}
ETc 100% × SA 500 ppm	336.03^{a}	186.53^{a}	10.94^{d}	0.79^{a}	13.90^{f}	37.23^{a}
ETc 100% × SA 750 ppm	337.69^{a}	188.12^{a}	11.37^{c}	0.78^{a}	14.52^{e}	39.10^{a}
ETc 75% × SA 0 ppm	298.01^{d}	170.67^{e}	11.31^{c}	0.68^{a}	16.53^{d}	39.08^{a}
ETc 75% × SA 250 ppm	301.69^{d}	172.19^{e}	11.69^{c}	0.70^{a}	16.63^{d}	41.78^{a}
ETc 75% × SA 500 ppm	304.29^{d}	176.44^{d}	11.95^{b}	0.70^{a}	17.00^{d}	42.55^{a}
ETc 75% × SA 750 ppm	311.63^{c}	180.71^{c}	12.17^{b}	0.73^{a}	16.74^{d}	43.69^{a}
ETc 50% × SA 0 ppm	285.64^{d}	164.07^{e}	12.43^{b}	0.69^{a}	18.13^{b}	44.81^{a}
ETc 50% × SA 250 ppm	287.68^{d}	166.12^{e}	12.50^{b}	0.70^{a}	17.85^{c}	45.11^{a}
ETc 50% × SA 500 ppm	291.66^{d}	168.50^{e}	13.00^{a}	0.69^{a}	18.96^{a}	45.96^{a}
ETc 50% × SA 750 ppm	292.28^{d}	168.71^{e}	13.15^{a}	0.69^{a}	19.17^{a}	47.08^{a}
Second season (2022)						
ETc 100%	328.92^{a}	182.53^{a}	11.49^{c}	0.77^{a}	14.93^{c}	38.91^{c}
ETc 75%	310.86^{b}	171.21^{b}	12.43^{b}	0.75^{b}	16.50^{b}	42.74^{b}
ETc 50%	292.56^{c}	161.32^{c}	13.30^{a}	0.74^{c}	18.02^{a}	48.95^{a}
SA 0 ppm	300.98^{a}	167.02^{a}	12.04^{a}	0.75^{a}	16.12^{d}	41.61^{d}
SA 250 ppm	308.12^{a}	169.82^{a}	12.23^{a}	0.76^{a}	16.20^{c}	42.30^{c}
SA 500 ppm	315.30^{a}	173.81^{a}	12.51^{a}	0.76^{a}	16.55^{b}	44.22^{b}
SA 750 ppm	318.73^{a}	176.08^{a}	12.83^{a}	0.76^{a}	16.97^{a}	46.01^{a}
ETc 100% × SA 0 ppm	315.42^{c}	176.50^{c}	11.15^{d}	0.75^{a}	14.91^{g}	37.34^{a}
ETc 100% × SA 250 ppm	325.86^{b}	180.44^{b}	11.21^{d}	0.77^{a}	14.51^{g}	37.88^{a}
ETc 100% × SA 500 ppm	336.33^{a}	185.58^{a}	11.60^{c}	0.78^{a}	14.89^{g}	39.46^{a}
ETc 100% × SA 750 ppm	338.09^{a}	187.58^{a}	12.01^{b}	0.78^{a}	15.38^{f}	40.96^{a}
ETc 75% × SA 0 ppm	306.79^{c}	165.83^{d}	11.94^{c}	0.76^{a}	15.80^{f}	40.72^{a}
ETc 75% × SA 250 ppm	308.66^{c}	168.41^{d}	12.40^{b}	0.76^{a}	16.38^{e}	41.89^{a}
ETc 75% × SA 500 ppm	311.28^{c}	173.02^{c}	12.58^{b}	0.75^{a}	16.72^{e}	43.40^{a}
ETc 75% × SA 750 ppm	316.73^{c}	177.57^{c}	12.78^{b}	0.75^{a}	17.15^{d}	44.96^{a}
ETc 50% × SA 0 ppm	280.73^{e}	158.73^{d}	13.03^{a}	0.74^{a}	17.71^{c}	46.79^{a}
ETc 50% × SA 250 ppm	289.86^{d}	160.62^{d}	13.09^{a}	0.74^{a}	17.77^{c}	47.11^{a}
ETc 50% × SA 500 ppm	298.28^{c}	162.84^{d}	13.36^{a}	0.74^{a}	18.11^{b}	49.78^{a}
ETc 50% × SA 750 ppm	301.36^{c}	163.08^{d}	13.70^{a}	0.74^{a}	18.51^{a}	52.13^{a}

ETc, estimated crop water requirement; SA, salicylic acid

Mean followed by the same letter/s within each column is not significantly different from each other at the 0.5% level

in hypothetical yield per feddan (ton/feddan) was gained by using salicylic acid treatment (SA 750 ppm), which produced 8.38 tons/feddan, while SA 0 ppm treatment (control) recorded only 6.11 tons/feddan. In addition, the interaction between water rates and salicylic acid showed that 100% of ETc combined with SA 500 or 750 ppm recorded 11.08 and 11.23 tons/feddan, and 100% of ETc combined with SA 0 ppm (control) produced 8.51

Table 6 Water stress rates and salicylic acid concentrations influence on tree yield, hypothetical yield per feddan, water use efficiency and water unit return of Washington navel orange trees (2021–2022 seasons)

	Tree yield (kg)	Hypothetical yield per feddan (ton)	Water use efficiency (kg fruit/m^3 water)	Water unit return (EGP/m^3 of water)
First season (2021)				
ETc 100%	48.57^a	10.20^a	2.07^a	8.28^a
ETc 75%	34.01^b	7.14^b	1.94^b	7.75^b
ETc 50%	21.38^c	4.49^c	1.85^c	7.40^c
SA 0 ppm	29.12^d	6.11^d	1.80^d	7.21^d
SA 250 ppm	32.83^c	6.89^c	1.78^c	7.10^c
SA 500 ppm	36.76^b	7.72^b	2.01^b	8.06^b
SA 750 ppm	39.92^a	8.38^a	2.19^a	8.76^a
ETc 100% × SA 0 ppm	40.51^c	8.51^c	1.74^f	6.95^f
ETc 100% × SA 250 ppm	47.54^b	9.98^b	1.97^d	7.86^d
ETc 100% × SA 500 ppm	52.76^a	11.08^a	2.19^b	8.75^b
ETc 100% × SA 750 ppm	53.47^a	11.23^a	2.28^b	9.13^b
ETc 75% × SA 0 ppm	29.12^f	6.11^f	1.86^g	7.46^g
ETc 75% × SA 250 ppm	31.40^e	6.59^e	1.74^f	6.95^f
ETc 75% × SA 500 ppm	33.74^d	7.09^d	1.88^e	7.54^e
ETc 75% × SA 750 ppm	41.79^c	8.78^c	2.27^a	9.06^a
ETc 50% × SA 0 ppm	17.72^h	3.72^h	1.78^h	7.14^h
ETc 50% × SA 250 ppm	19.54^h	4.10^h	1.62^g	6.49^g
ETc 50% × SA 500 ppm	23.77^g	4.99^g	1.97^d	7.89^d
ETc 50% × SA 750 ppm	24.51^g	5.15^g	2.02^c	8.08^c
Second season (2022)				
ETc 100%	60.65^a	12.74^a	2.69^a	10.74^a
ETc 75%	43.43^b	9.12^b	2.55^b	10.22^b
ETc 50%	26.61^c	5.59^c	2.39^c	9.57^c
SA 0 ppm	35.88^d	7.53^d	2.30^d	9.21^d
SA 250 ppm	40.52^c	8.51^c	2.25^c	9.02^c
SA 500 ppm	47.37^b	9.95^b	2.66^b	10.66^b
SA 750 ppm	50.49^a	10.60^a	2.91^a	11.65^a
ETc 100% × SA 0 ppm	52.53^c	11.03^c	2.33^e	9.34^e
ETc 100% × SA 250 ppm	58.95^b	12.38^b	2.55^d	10.20^d
ETc 100% × SA 500 ppm	64.96^a	13.64^a	2.81^b	11.25^b
ETc 100% × SA 750 ppm	66.16^a	13.89^a	2.93^b	11.73^b
ETc 75% × SA 0 ppm	34.16^f	7.17^f	2.31^g	9.23^g
ETc 75% × SA 250 ppm	38.79^e	8.15^e	2.18^e	8.73^e
ETc 75% × SA 500 ppm	46.81^d	9.83^d	2.63^c	10.52^c
ETc 75% × SA 750 ppm	53.96^c	11.33^c	3.09^a	12.38^a
ETc 50% × SA 0 ppm	20.94^h	4.40^i	2.27^h	9.10^h
ETc 50% × SA 250 ppm	23.82^h	5.00^h	2.03^f	8.12^f
ETc 50% × SA 500 ppm	30.34^g	6.37^g	2.55^d	10.20^d
ETc 50% × SA 750 ppm	31.33^g	6.58^g	2.71^c	10.85^c

ETc, estimated crop water requirement; SA, salicylic acid

Mean followed by the same letter\s within each column is not significantly different from each other at the 0.5% level

tons/feddan, which means that salicylic acid treatment increased yield about 31.96 and 31.19% by using the same amount of irrigation water; this trend was true in both seasons.

With a more comprehensive view, these results cannot be evaluated without reference to WUE (water use efficiency—kg fruit/m^3 water) and WUR (water unit return—EGP/m^3 water) to translate these results

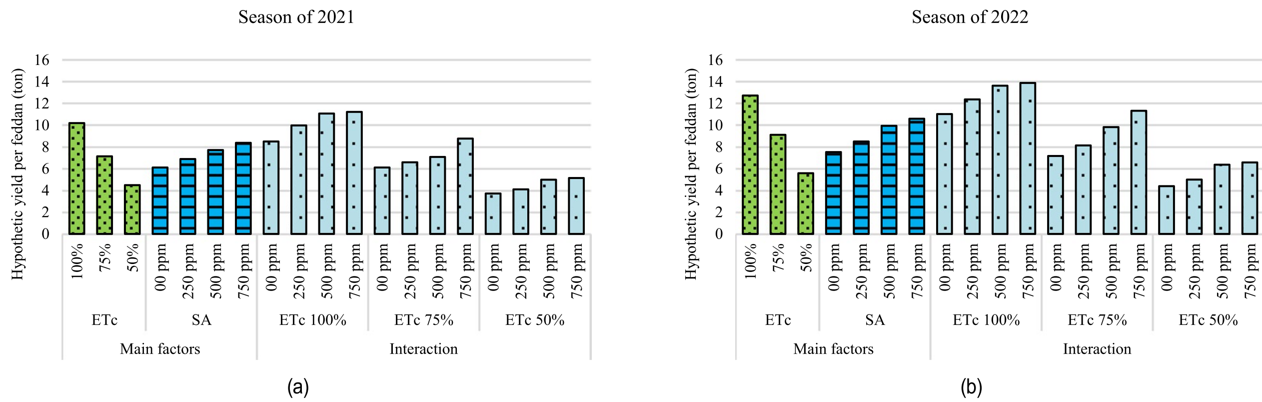

Fig. 2 **a**–**b** Water stress rates and salicylic acid concentrations influence on hypothetical yield per feddan of Washington navel orange trees (2021–2022 seasons)

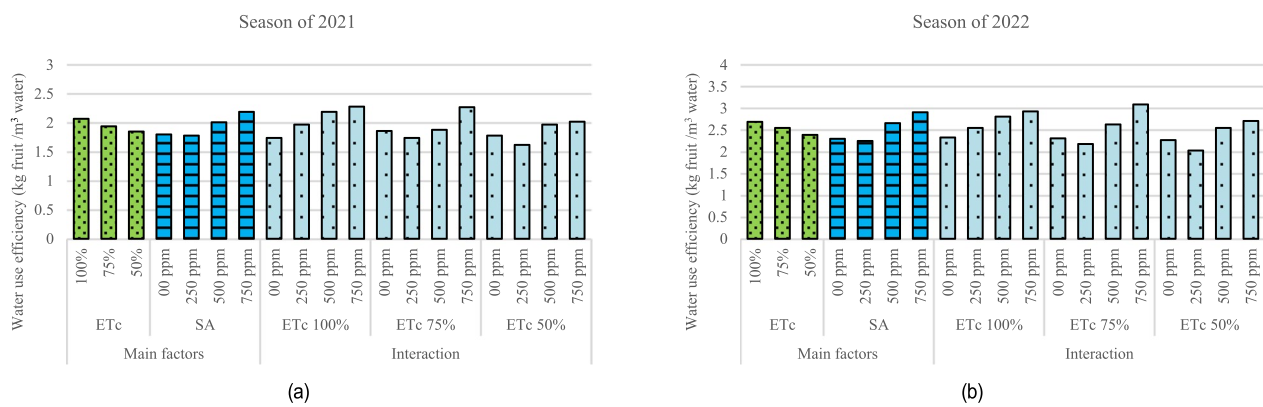

Fig. 3 **a**–**b** Water stress rates and salicylic acid concentrations influence on water use efficiency of Washington navel orange trees (2021–2022 seasons)

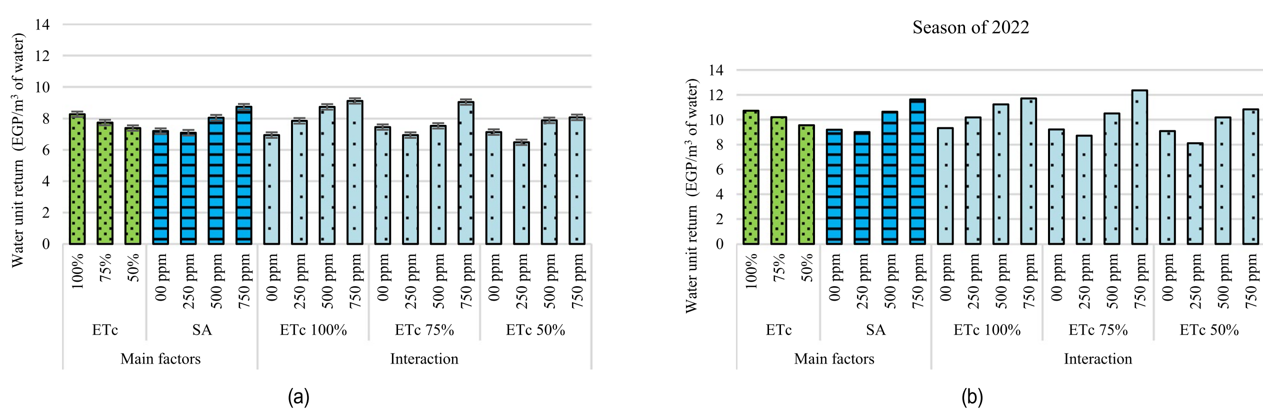

Fig. 4 **a**–**b** Water stress rates and salicylic acid concentrations influence on water unit return of Washington navel orange trees (2021–2022 seasons)

economically as a monetary product of the water unit, so, if the results have generally shown the superiority of salicylic acid treatment in WUE and WUR but the interaction clarified that the salicylic acid treatment (750 ppm) combined with 75% of ETc was better than the control combined with 100% of ETc where the values recorded for 75% of ETc combined with salicylic acid treatments (750 ppm) were 2.27 and 3.09 for WUE and 9.06 and 12.38 for WUR while 100% of ETc combined with salicylic acid 0 ppm treatments (control) recorded 1.74 for WUE and 6.95 for WUR with obvious and high significant differences, it was better in water use efficiency and the economic return from using the water unit. This trend was also confirmed in the second season.

Discussion

Table 3 demonstrates that salicylic acid treatments significantly affected all of the morpho-phenological parameters beginning with tree canopy volume, leaf area, and the percentage of leafy inflorescences that are taken into consideration as a preliminary predictor of yield status, fruit set, and length of fibrous roots, which also manifested in an increase in the number of fruits per tree.

The highest significant value for tree canopy volume was gained by 100% of ETc, while the lowest significant value was gained by 50% of ETc. For salicylic acid (SA), the highest significant value for tree canopy was recorded by SA 750 ppm, while the lowest significant value was recorded by the control (SA 0 ppm); this came true in the two seasons.

For the interaction between water rates and salicylic acid, the most significant treatments were 100% of ETc combined with SA 500 or 750 ppm. Generally, leaf area, the total length of fibrous roots, leafy inflorescences percentage, and the fruit set percentage, as well as the number of fruits per tree have the same trend as tree canopy volume; this came true in the two seasons.

Particularly, the parameters were increased by increasing ETc rates possibly due to the increase in soil moisture availability, moderate evaporation from the soil surface, temperature, *N*, *P*, and *K* values (Kumar et al. 2014; Falivene et al. 2016; Mahmoud and Youssef 2017a, b; Mahmoud et al. 2018). Results regarding conserving water supply levels were in agreement with those mentioned by Mahmoud (2012), Mahmoud and Youssef (2017a, b), Mahmoud et al. (2018).

Moreover, it can be noticed that salicylic acid gained the highest significant values compared with the control. In this connection, this increase may be due to the role of salicylic acid in activating cell division, biosynthesis of organic foods, and availability as well as the movement of mineral nutrients toward the leaves (El-Shazly et al. 2015; Metwaly and El-Shatoury 2017). These results are agreeable with those reported by Yildirim et al. (2008), Ben Ahmed et al. (2009), Cornelia et al. (2010), El-Shazly et al. (2015), Khoshbakht and Asgharei (2015), Metwaly and El-Shatoury (2017), Zaky et al. (2018).

The data presented in Table 4 show how salicylic acid treatments affected water relations parameters like leaf chlorophyll a, chlorophyll b, proline, osmotic pressure in leaf cell sap, the percentage of open stomata, and leaf-bound water content under water stress. In general, parameters measuring chlorophyll a, leaf chlorophyll b, and the percentage of opened stomata increased as water content or salicylic acid concentrations increased. On the contrary, leaf proline, leaf cell sap osmotic pressure, and leaf-bound water content were decreased when the water amount increased at the same time they increased when salicylic acid concentrations decreased. This came true in both seasons. The results presented in lead us to believe that the use of salicylic acid at the aforementioned concentrations reduced the harmful effects of lack of irrigation water supply on the plant, which in turn may give an economic crop despite the decrease in irrigation rates.

For water supply levels, the obtained results reveal that leaf photosynthetic pigments were affected significantly by water supply levels; this was in harmony with results found by XiaoLi et al. (2013), Malik et al. (2014), Mahmoud and Youssef (2017a, b), Mahmoud et al. (2018).

Regarding salicylic acid, our results are in agreement with those obtained by other researchers Purcarea and Cachita-Cosma (2011), El-Shazly et al. (2015), Khoshbakht and Asgharei (2015), Metwaly and El-Shatoury (2017).

Moreover, according to Noreen and Ashraf (2008), Metwaly and El-Shatoury (2017) the influence of salicylic acid is due to activating changes in photosynthesis, antioxidant capacity, and ion homeostasis processes.

Data presented in Table 5 demonstrate a significant difference between the two seasons in the effects of ETc treatments on some fruit parameters, while salicylic acid had little effect on most parameters other than TSS/acid ratio and ascorbic acid. The highest significant value for fruit weight was gained by 100% of ETc, while the lowest significant value was gained by 50% of ETc. For salicylic acid (SA), there is no effect of the salicylic acid application on all physical and chemical fruit parameters except TSS/acid ratio and ascorbic acid. For the interaction between water rates and salicylic acid, the most significant treatments were 100% of ETc combined with SA 500 or 750 ppm, respectively. Generally, most of all physical and chemical fruit parameters take the same trend to fruit weight except for TSS/acid ratio and ascorbic acid. The TSS/acid ratio and ascorbic acid parameters effect by ETc or salicylic acid concentration, while the ascorbic acid parameter did not affect by the interaction between water rates and salicylic acid at all, but the TSS/acid ratio parameter was affected. This came true in the two seasons. For water supply levels, the results of the present investigation confirmed those obtained by Treeby et al. (2007), Mahmoud (2012), XiaoLi et al. (2013), Malik et al. (2014), ShenXi et al. (2016), Mahmoud and Youssef (2017a, b), Mahmoud et al. (2018).

Data in Table 6 and Figs. 2, 3, 4 summarize the benefits of this study. The use of 100% ETc resulted in the greatest significant increase in hypothetical yield per feddan, whereas the use of salicylic acid at 750 ppm resulted in the greatest significant increase in hypothetical yield per feddan. Also, water rates and salicylic acid interaction revealed that 100% of ETc combined with SA 500 or 750 ppm recorded the highest significant increment. This trend held true in both seasons.

The results have generally demonstrated the superiority of salicylic acid treatment in WUE and WUR, and the interaction clarified that the salicylic acid treatment (750 ppm) combined with 75% of ETc was better than the control combined with 100% of ETc, and it was better in water use efficiency and the economic return from using the water unit. Finally, it could be possible to say that salicylic acid treatment achieved what is targeted for citrus in SADS (Sustainable Agricultural Development Strategy toward 2030) by reducing the amount of water used to irrigate citrus orchards by a rate ranging from 25%, in the same time increased the water unit return (WUR).

Results of the present investigation revealed that yield characteristics were affected significantly by water supply levels. This work agrees with Mahmoud (2012), Melgar et al. (2012), Dorji et al. (2016), Falivene et al. (2016) on citrus trees.

This result may be due to using a high water irrigation supply, which may have increased soil moisture availability (Koshita and Takahara 2004; Falivene et al. 2016; Mahmoud and Youssef 2017a, b). This increase in yield might be due to the effect of water on some metabolic processes in the plant cell. Besides, the increase in soil moisture might have increased soil available *N*, *K*, and *P* as well as their uptake in the zone of roots, as well as enhanced photosynthetic processes, carbohydrates production, and yield (Ghosh et al. 2000; Ahmed and Abd El-Kader 2016).

Regarding water salicylic acid treatment, our results are in harmony with those observed by Mohamed et al. (2017), García-Pastor et al. (2020), Chakma et al. (2021).

Conclusions

In summary, from the results of the present study, it can be concluded that using salicylic acid treatment had a high economic return through increasing total yield, water use efficiency, and water unit return (WUR) which reached 9.06 and 12.38 EGP per every cubic meter of irrigation water in the first and the second seasons, respectively, for 75% of ETc combined with salicylic acid 750 ppm and using less water irrigation amount by 25% at the same time. Thus, we recommend applying the treatment of 75% of ETc combined with salicylic acid 750 ppm to Washington navel orange trees budded on sour orange rootstock to gain a high economic return.

Abbreviations

EGP	Egyptian pound
ETc	Estimated crop water requirement
ETo	Reference crop evapotranspiration rate
FAO	Food and Agriculture Organization
Kc	Crop coefficient
Kg	Kilogram
Ppm	Parts per million
SA	Salicylic acid
WUE	Water use efficiency
WUR	Water unit returns

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EA, TA, and MA performed the investigations. EA, TA, and MA contributed in writing the original data including analysis and interpretation. EA, TA, and MA performed the editing of the manuscript. All authors have read and approved the manuscript.

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