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Foliar Application of Biostimulants to Improve Growth, Yield and Fruit Quality of 'Valencia' Orange Trees under Deficit Irrigation Conditions

Ennab, Hassan[1], and Alam-Eldein, Shamel[2*]

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Abstract

Water is one of the most important components that affect plant growth and productivity. Foliar application of some biostimulants may reduce the amount of used water. New agricultural practices intended to enhance water use efficiency, require careful study to determine their effects on optimal irrigation levels. To examine the effect of irrigation and biostimulants spray on tree growth, yield and fruit quality, this research was carried out on seventy-two 'Valencia' orange (*Citrus sinensis*, Osbeck) trees grown at 5×5 m spacing in a private orchard at Badr district, Behaira Governorate, Egypt during 2017/2018 and 2018/2019 seasons. Trees were budded on 'Volkamer' lemon rootstock and grown in sandy soil under drip irrigation system. Three drip irrigation regimes were applied at 25,866; 19,240; and 12,933 L/tree/year, which represent about 100, 75, and 50% of tree water requirement using 16, 12, and 8 drippers/tree, respectively. Each irrigation regime was combined with the foliar application of tap water (control), seaweed extract (2.5g/L), fishmeal extract (10g/L) or compost tea extract (65ml/L). Foliar treatments were applied three times; three weeks before flowering, at full bloom and two months after full bloom. Results indicated that as irrigation volume increased, there was significant improvement in the vegetative growth, fruit set percentage, but the percentage of June fruit drop and preharvest fruit drop was negatively related to water volume. The greatest incremental effect between treatments generally occurred with the intermediate level of irrigation, which actually had significantly higher yield and fruit quality than the full irrigation treatment in both years. Foliar application of seaweed, fishmeal, or compost tea extracts enhanced tree growth, fruit set, total yield, and fruit physical and chemical characteristics. Compost tea had the most pronounced effect in this regard. Overall, the best results were obtained with the combination of 19,240 tree/year plus compost tea (65ml/L) for tree vegetative growth, fruit set, less fruit drop, total yield and most of fruit quality aspects. Furthermore, this combination saved about 25% of the total used water, and increased total yield per tree by 40.7% over the control.

The Mediterranean climate of Egypt is suited for citrus production. Oranges account for over half of the total fruit production in Egypt. Total cultivated area of oranges in 2018 was about 131,271 ha with a total annual production of 3,246,483 and average yield of 27.3 t/ha (FAO, 2017). Recently, water is becoming scarce in Egypt (Agricultural Statistics of Egypt, 2014) and may become a limiting factor for the citrus industry in the future. Scarcity is also considered the single biggest water problem worldwide (Jury and Vaux, 2005). Nonetheless, more than 70% of fresh water is used mainly for agricultural purposes (Du et al., 2015). In Egypt, water resources and rainfall are limited, and the Nile River is the most important water resource. Under such conditions, there is a need to reduce agricultural water demand and increase the economic productivity of water. Improving on-farm management of water by utilizing advanced irrigation technology and improved irrigation scheduling may offer the prospect of significant increase

[1] Citrus Research Department, Horticulture Research Institute, Agricultural Research Center (ARC), Giza, 12619, Egypt. hassan.ennab@yahoo.com

[2] Department of Horticulture, Faculty of Agriculture, Tanta University, Tanta, 31527, Egypt. shamel.alameldein@agr.tanta.edu.eg

[*] Corresponding author. phone +2-040-345-5584, fax +2-040-345-5570

in water productivity (Jury and Vaux, 2005; Cosgrove and Loucks, 2015).

Deficit irrigation effectively reduced water requirements for grapes (Costa et al., 2007), corn (El-Hendawy et al., 2008), citrus (Panigrahi and Srivastava, 2016), apple (Soliman et al., 2018) and tomato (Francaviglia and Bene, 2019). Deficit irrigation is a strategy where the amount of water applied is less than the full water requirement of a crop, and the resulting stress has minimal effects on total yield (English, 1990; Garcia-Tejero et al., 2011). Moderate water stress during certain crop growth stages enhances the yield and fruit quality of citrus (Boman et al., 1999; Gonzalez-Altozano and Castel, 1999). The most sensitive phenological stages of citrus to water stress are flowering, fruit set and fruit development (i.e., fruit enlargement) in which shortages of root-zone soil moisture reduces yield drastically (Ginestar and Castel, 1996) due to severe reduction in photosynthetic rate and stomatal conductance (Yakushiji et al., 1998). Reducing irrigation water to a certain level during non-critical growth stages, such as initial fruit growth stage, is one of the options to sustain citrus production with higher water productivity in water scarce areas with no effect on yield or fruit quality. Reducing water during the final growth stage (i.e., fruit ripening) negatively affected fruit size, and reduced yield by 25% (Gonzalez-Altozano and Castel, 2003; Panigrahi and Srivastava, 2016).

Foliar application of some biostimulants can also induce water stress resistance in plant (Van Oosten et al., 2017). Biostimulants are known to improve plant growth, yield and fruit quality. They include diverse substances like humic substances, compost tea, seaweed extracts, free amino acids and plant extracts, as well as microorganisms like free-living bacteria, fungi, and arbuscular mycorrhizal fungi (Calvo et al., 2014). Several reports have documented the value of foliarly applied biostimulants for alleviating the adverse effect of deficit irrigation and improve yield and fruit quality. Spann and Little (2010, 2011) showed that 'Hamlin' sweet orange trees sprayed with seaweed extract had greater total growth rate than non-treated trees grown under drought conditions. Foliarly applied biostimulants enhanced natural hormones and nutrient uptake, and improved yield and fruit quality under different irrigation levels (Zhang and Ervin, 2004; Mostafa et al., 2009). Khattab et al. (2012) reported that spraying pomegranate trees with amino acids (8 g/tree/year) and humic acid (32 g/tree/year) with moderate irrigation (7,000-9,000 L/tree/year) enhanced fruit set, reduced fruit drop, and improved yield and fruit quality. Zaghloul and Moursi (2017) reported that a foliarly applied mixture of seaweed extract (20.5%), free amino acids (6.5%), N (5.8%), P (3%), B (0.17%), and K (4.6 %) significantly improved fruit set, total yield, fruit weight and volume, fruit firmness, soluble solids concentration (SSC), SSC/acid ratio, and vitamin C of 'Washington' navel orange growing under different conditions of water deficit.

The aim of this research was to determine if foliarly applied biostimulants could improve growth, yield and fruit quality of 'Valencia' orange trees growing under different reduced-irrigation regimes.

Materials and Methods

This study was carried out during 2017/2018 and 2018/2019 seasons on 15 year-old 'Valencia' orange trees (*Citrus sinensis*, Osbeck) budded on 'Volkamer' lemon (*Citrus volkameriana* Ten. and Pasq.) rootstock, and planted at 5×5 m spacing in a private orchard located at Badr district (30°58′26" N, 30°70′63" E), Behaira Governorate, North East of the Western Desert and West to the Nile Delta in Egypt. All trees received the same cultural practices and the following soil fertilization program; 23.8 m^3 farmyard manure, 119 kg superphosphate (15.5% P_2O_5), 238.1 kg agricultural sulfur, and 119 kg potassium sulphate (48-52% K_2O) per ha during January. From mid-February to mid-October, trees received 714.3 kg am-

Table 1. Total amount of irrigation water applied for 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Months	Number of irrigation times per month	Duration per each irrigation (Hour)	Water amount (L/tree)		
			I_1 = 16 drippers/tree (Control = 100% water)	I_2 = 12 drippers/tree (25% less = 75% water)	I_3 = 8 drippers/tree (50% less = 50% water)
January	6	3 ¼	1248	936	624
February	10	1 ⅔	1066	800	533
March	15	2	1920	1440	960
April	15	2 ½	2400	1800	1200
May	20	2	2560	1920	1280
June	20	2	2560	1920	1280
July	24	2	3072	2304	1536
August	24	2	3072	2304	1536
September	20	2	2560	1920	1280
October	15	2 ½	2400	1800	1200
November	10	2 ¾	1760	1320	880
December	6	3 ¼	1248	936	624
Total irrigation water/tree/year (L)			25,866	19,400	12,933
Total irrigation water/hectare/year (L)			10,346,400	7,760,000	5,173,200

monium nitrate (33.5% N), 357.1 kg calcium nitrate (15.5% N), 76.2 kg phosphoric acid (50% P_2O_5), 476.2 kg potassium sulphate (48-52% K_2O), and 47.6 kg magnesium sulphate (33.3% MgO) per ha through drip irrigation. Soil texture was sandy (3.43% clay, 8.34% silt, and 88.23% sand) with 3.21% total carbonate content, 1.16 dS m^{-1} electrical conductivity, and pH = 7.8.

Seventy-two trees uniform in growth, vigor and productivity were selected in a randomized complete block design as a split-plot experiment. Trees appeared healthy and no symptoms of nutrient deficiency were observed. Split-plot design was chosen to minimize any variation among the trees. The field was divided into three replicates. Each replicate was divided into three whole-plots and one of three irrigation treatments was randomly assigned to one whole-plot per replicate. Each whole-plot was divided into four split-plots and received one of four foliar treatments, so there were 12 treatment combinations. Experimental units consisted of two adjacent trees and data were averaged for the two trees. Treatments were separated by two rows of buffer trees. Three levels of irrigation were produced by varying the number of drippers per tree and each dripper delivered 4.0 L/h. I_1, the control trees, had 16 drippers per tree (100% crop water requirement, based on regular irrigation program used in the area); I_2 had 12 drippers per tree to deliver 75% of crop water requirements; and I_3 had eight drippers per tree to deliver 50% of crop water requirements. Total amount of water per treatment is presented in Table 1. Biostimulant treatments of tap water (control, T_1), 2.5g seaweed extract/L (T_2), 10g fishmeal extract/L (T_3), or 65 ml compost tea/L (T_4) were applied three times in both seasons: 1) three weeks before flowering (11 Feb. 2017 and 14 Feb. 2018) to induce flowering (5 March 2017 and 8 March 2018); 2) full bloom (20 March 2017 and 23 March 2018); and 3) two months after full bloom (20 May 2017 and 23 May 2018). Physical and chemical characteristics of seaweed extract, fishmeal extract, and compost tea, as well as farmyard manure are shown in Table 2.

Table 2. Characteristics of seaweed extract, fishmeal extract, compost tea extract, and farmyard manure.

Parameter	Seaweed extract	Fishmeal extract	Compost tea extract	Farmyard manure
pH	4.90	5.89	8.14	8.70
EC (dSm^{-1})	3.85	4.80	4.33	1.70
Total protein (%)	6	59.2	2.10	--
Alginic Acid (%)	10	--	--	--
Mannitol (%)	4	--	--	--
C/N ratio	--	--	--	15.40
Organic carbon (%)	--	--	--	13.72
Organic matter (%)	--	--	--	23.60
Moisture (%)	--	--	--	35
Cubic meter weight (kg)	--	--	--	650
Macronutrients (%)				
N	3.40	8.22	2.10	0.89
P	2.61	2.61	0.90	0.32
K	4.71	0.52	1.60	0.92
Ca	0.25	3.97	0.11	1.82
Mg	0.58	0.27	0.10	0.96
S	3.56	0.39	1.10	--
Micronutrients (ppm)				
Fe	150	229	1400	750
Mn	13	3.7	160	420
Zn	70	74	90	53
Cu	6	6.2	130	--
Phytohormones (%)				
Cytokinins	0.02	--	0.0080	--
Gibberellins	0.01	--	0.0025	--
Auxins	0.03	--	0.0125	--
Microbial population (cfu/ml)				
Total bacteria	--	--	7.55×10^6	--
Total fungi	--	--	6.88×10^4	--
Total actinomycetes	--	--	1.28×10^5	--

Preparation of Biostimulants. All materials were prepared in a microbiology laboratory at the Soil, Water, and Environment Research Institute, Agricultural Research Station, Sakha, Kafr-Elsheikh, Egypt.

Seaweed extract. Acadian seaweed extract (Acadian Seaplants Limited Company, Dartmouth, Nova Scotia, Canada), imported by Techno Green company group, Cairo, Egypt, has been used. This product composed of a mixture of brown algae that mainly includes *Ascophyllum nodosum,* and some others like *Laminaria sp., Sargassum sp. and Fucus sp.* Twenty-liter stock solution was prepared by dissolving 2.5 g seaweed extract/L of dechlorinated water with continuous aeration for two days using a regular aquarium air pump (EHEIM GmbH & Co KG, Germany) with PVC pipe dipped in the solution.

Fishmeal extract. Fish powder was prepared by drying fresh Tilapia fish in an oven at 70°C for 24 hours, and then the dried fish was ground in a hammer mill (Jesma-Matador AS, Vejle, Denmark) to a particle size <1.00 mm, and any solid particles were removed. Twenty liters of the extract was prepared by dissolving 10 g fish powder/L of dechlorinated water with continuous aeration using the same air pump for two days.

Compost tea extract. The stock solution was prepared by soaking 5 kg of dry matured compost (made of Agricultural residues including rice straw, leaves, twigs, pruning residuals, and cattle dung manure) and 0.5 L molasses in 50 L of dechlorinated water in a polyethylene compost tea machine (100 L capacity) with continuous aeration using the air pump for three days, and then solution was filtered using a plastic net. Mature compost was prepared using a fermentation process of plant and animal waste materials for three months.

Data for the following response variables were recorded.

Vegetative growth. One current-season shoot on four sides of each tree (N, E, S, W) was tagged to measure shoot length (cm) and number of leaves per branch. Five mature mid-branch leaves were sampled from each branch to determine leaf area (cm^2) using a leaf area meter Model Li 3100 (LI-COR Inc., Lincoln, NE, USA). Canopy volume (m^3) of each tree was calculated at the end of the growing season according to the following equation; 0.5238 × tree height × $(\text{canopy diameter})^2$ (Turrell, 1946).

*Initial fruit set percentage. R*ecorded by counting the flowers at 5-day intervals starting from the second week of March until complete fruit set (2 April 2017 and 5 April 2018), then the number of fruitlets was counted and initial fruit set was calculated as (number of fruitlets ÷ total number of flowers) × 100.

Final fruit set percentage. Calculated as (number of fruit before harvest ÷ total number of flowers) × 100**.**

June drop percentage. Calculated as (number of dropped fruit in June ÷ number of fruitlets) × 100.

Pre-harvest drop percentage. Calculated as the number of dropped fruit from mid-December to mid-February (harvest period) divided by the number of dropped fruit at mid-December × 100.

Yield. Fruit were harvested on 11 February 2018 and 18 February 2019. Yield of each replicate was determined as kg/tree, and t/ha.

Fruit quality. At harvest, physiological disorders, such as splitted and creased fruit were counted and their percentages were calculated as

$$\text{Splitting or creasing \%} = \frac{\text{No. of splitted or creased fruits}}{\text{Total No. of fruits}} \times 100$$

Ten fruit were collected randomly from each tree to determine average fruit weight (g) using a bench-top digital scale Model PC-500 (Doran scales, Inc., Batavia, IL, USA). Average fruit volume (cm^3) was also determined using the water displacement method in a one-liter gradual cylinder. Average fruit firmness (N/mm^2) was measured on two sides of the fruit using a hand-held Shimpo digital force gauge, Model FGV-50XY fitted with 10 mm diameter plunger tip (Shimpo company, Wilmington, NC, USA). Juice volume per fruit was calculated as a percentage juice per 10 fruit. Total soluble solids (TSS) concentration (%) was measured with a hand-held refractometer Model RA-130 (KEM Kyoto Electronics Manufacturing Co. Ltd., Tokyo, Japan). Total acidity (%) was estimated as citric acid (g/100 ml) juice, using phenolphthalein as indicator, according to A.O.A.C. (1990). scorbic acid was estimated as mg per 100 ml juice, using 2, 6 dichlorophenol indophenol, according to Rangana (1977). Data of TSS and total acidity was used to calculate TSS/acid ratio.

Statistical analysis. Data were statistically analyzed using analysis of variance (ANOVA), and least significant difference (LSD) was used to compare means at $P \leq 5\%$ (Snedecor and Cochran, 1990).

Results and Discussion

Vegetative growth. Irrigation level significantly affected vegetative growth characteristics of 'Valencia' orange trees (Table 3). Shoot length, number of leaves per shoot, leaf area and canopy volume were positively related to the amount of water applied per tree in both seasons. Similar results were reported on 'Tahiti' lime (Junior et al., 2011) and 'Balady' mandarin (Ennab and El-Sayed, 2014). Irrigation at about 17,500 – 18,750 L/

Table 3. Effect of three irrigation regimes and foliarly applied biostimulants on vegetative growth characteristics of 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Treatments	Shoot length (cm)		Number of Leaves per shoot		Leaf area (cm^2)		Canopy volume (m^3)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Irrigation								
I_1: 100% water (control)	60.12	60.68	30.76	32.78	29.88	32.26	39.99	41.39
I_2: 75% water	53.40	52.88	25.20	26.41	22.27	23.46	37.99	39.88
I_3: 50% water	41.43	41.60	19.62	20.23	17.94	17.90	36.04	37.86
LSD ($P \leq 0.05$)	0.35	0.88	0.20	0.03	0.30	0.17	0.38	0.44
Biostimulants								
T_1: tap water (control)	43.43	45.84	22.02	22.54	19.49	21.67	33.47	36.12
T_2: seaweed extract	54.52	53.55	26.42	28.45	22.68	25.41	39.24	40.10
T_3: fishmeal extract	51.38	51.20	24.42	25.18	25.39	23.94	38.39	39.32
T_4: compost tea extract	57.27	56.28	27.92	29.73	25.89	27.14	40.92	43.30
LSD ($P \leq 0.05$)	0.32	0.39	0.16	0.08	0.17	0.18	0.22	0.34
Interaction								
$I_1 \times T_1$: control	47.60	52.09	28.17	29.19	25.70	28.29	36.74	38.40
$I_1 \times T_2$: 100% × seaweed	65.49	63.90	31.83	34.88	29.62	34.23	40.87	41.83
$I_1 \times T_3$: 100% × fishmeal	59.98	60.54	29.72	31.88	31.85	31.00	39.80	40.90
$I_1 \times T_4$: 100% × compost tea	67.41	66.19	33.33	35.20	32.35	35.55	42.55	44.45
$I_2 \times T_1$: 75% water	45.59	46.52	20.83	21.55	17.11	20.64	33.48	35.80
$I_2 \times T_2$: 75% × seaweed	56.18	55.21	27.39	29.33	21.65	24.78	39.38	40.40
$I_2 \times T_3$: 75% × fishmeal	52.60	52.50	23.72	23.66	24.92	21.78	38.53	39.76
$I_2 \times T_4$: 75% × compost tea	59.24	57.29	28.89	31.12	25.42	26.64	40.58	43.56
$I_3 \times T_1$: 50% water	37.11	38.91	17.06	16.88	15.68	16.08	30.20	34.17
$I_3 \times T_2$: 50% × seaweed	41.89	41.56	20.06	21.16	16.78	17.23	37.48	38.08
$I_3 \times T_3$: 50% × fishmeal	41.56	40.58	19.83	20.00	19.41	19.05	36.84	37.32
$I_3 \times T_4$: 50% × compost tea	45.18	45.36	21.56	22.88	19.91	19.25	39.65	41.90
LSD ($P \leq 0.05$)	0.64	0.79	0.33	0.17	0.34	0.36	0.45	0.68

tree/year (70-75% of tree water requirement) improved most vegetative growth parameters of 'Washington' navel orange trees grown in sandy soil, particularly trunk cross-sectional area, canopy volume, number of shoots, shoot length and diameter, number of leaves/shoot, and leaf area (Zayan et al., 2016). Enhanced growth with the highest irrigation level was likely attributed to the availability of sufficient moisture for increased development of leaf area, which improved whole-tree photosynthesis and positively affected plant growth. Limited water negatively affected photosynthesis, and hence cell elongation and plant growth (Muller et al., 2011; Fahad et al., 2017).

Application of seaweed, fishmeal, or compost tea extracts significantly improved vegetative growth characteristics of 'Valencia' orange trees compared to the control in both seasons (Table 3). Compost tea had the most pronounced effect on all growth parameters, followed by seaweed extract. Fishmeal extract promoted more growth than the control, but was least effective. Previous findings of Hegab et al. (2005) and Mostafa et al. (2009) indicated that foliar application of algae extract and compost tea significantly increased shoot length, number of leaves/shoot and leaf surface area of 'Balady' and 'Washington' navel oranges. Abdel Aal et al. (2012) reported that foliar application of seaweed extract significantly improved vegetative growth of 'Balady' mandarin compared to yeast and farmyard manure extracts. These results could be attributed to the richness of compost tea, seaweed, and fishmeal extracts in micro nutrients such as Fe, Cu, Zn, Co, Mo, Mn, and Ni, in addition to vitamins, amino acids, phytohormones like auxins, cytokinins and gibberellins (Calvo et al., 2014).

The magnitude of the growth response to biostimulants depended on the level of irrigation and also varied for different growth parameters. In most cases, trees receiving 75% of the water requirement plus one of the biostimulants had similar or greater growth as trees receiving 100% of the water requirement with no biostimulants. When trees received 50% of the water requirement, growth was increased by all biostimulants, but growth was still usually less than that of trees receiving 100% of the water requirement with no biostimulants.

Previous reports stated that under deficit irrigation conditions, spraying with compost tea or seaweed extracts enhanced growth and productivity of peach (Abd El Hamied and Ghieth, 2017) and strawberry (Kapur et al., 2017), respectively. Under drought conditions, foliar spray of seaweed extract on 'Hamlin' sweet orange trees budded on Carrizo citrange or Swingle citrumelo rootstocks significantly improved total tree growth compared to untreated stressed trees. Trees also had intermediate water use efficiency and increased drought tolerance (Spann and Little, 2010). Seaweed extract could improve citrus drought resistance possibly by improving stem water potential in citrus rootstocks under full irrigation and drought, as well as affecting photosynthesis, stomatal conductance and water use efficiency in leaves (Spann and Little, 2011). The beneficial effect of compost tea extract on vegetative growth characteristics could be attributed to its content of macro- and micronutrients (Mostafa et al., 2009), as well as its hormonal-like effect due to its content of auxins, gibberellins, and cytokinins. Compared to seaweed extract, the effectiveness of compost tea extract could be related to the higher content of micronutrients, especially Fe, Mn, Zn and Cu (Table 2), which play an important role in protein and chlorophyll synthesis, membrane function and cell elongation (Pokhrel and Dubey, 2013; Ojeda-Barrios et al., 2014). For instance, Zn plays a fundamental role in regulating osmotic activities, as well as protecting and maintaining cell water balance and the structural stability of cell membranes under stressful conditions (Haripriya et al 2018). Auxin initiates cell wall loosening process and cell enlargement (Hager, 2003), which lead to the emergence of lateral roots improving water absorbance and nutrients uptake under stress conditions (Trevisan et al., 2010). Increasing cytokinin levels on the account of auxin enhanced vegetative growth, photosynthetic pigments, yield and fruit quality of olive trees (Dabbaghi et al., 2018) and potato plants (Ekin, 2019).

Fruit set and fruit drop. Like vegetative growth characteristics, the percentage of initial and final fruit set increased, while June drop and preharvest drop decreased with increased irrigation level during both seasons (Table 4). Similar results were reported on fruit set of 'Valencia' orange trees (El Wazzan et al., 2001; Stover et al., 2002; El Sayed and Ennab, 2013). Moderate water stress could increase flower drop, and consequently leads to reduction in fruit set and total yield of mandarin trees (Conesa et al., 2018). Biostimulant treatments also effectively increased fruit set and reduced fruit drop compared to the control throughout the season (Table 4). The most pronounced effect was noticed with the application of compost tea extract, followed by seaweed extract, but fishmeal extract had the least effect on fruiting. These results confirm the previous findings of Koo and Mayo (1994), Masoud and Abd El Aal (2012), and Omar et al. (2012) on citrus.

Combining biostimulant treatments with full amount of water produced the highest fruit set and lowest fruit drop in both seasons (Table 4). However, reducing water requirement of 'Valencia' orange trees to 75% in combination with compost tea showed the best results of initial and final fruit set, as well as June fruit drop when compared to the control and all other treatments except the combination of 100% water × compost tea. Moreover, the combination of 75% water and compost tea significantly reduced preharvest fruit drop when compared with the control and all other water deficit treatments during both seasons. These results are consistent with previous reports on pomegranate (Khattab et al., 2012) and 'Washington' navel orange (Zaghloul and Moursi, 2017). The beneficial effect of compost tea may be due to its content of macro- and micronutrients, phytohormones, vitamins and antioxidants (Zaghloul et al., 2015). Macronutrients like P plays an important role in flower intensity

Table 4. Effect of three irrigation regimes and foliarly applied biostimulants on fruit set and fruit drop of 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Treatments	Initial fruit set (%)		Final fruit set (%)		June drop (%)		Preharvest drop (%)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Irrigation								
I_1: 100% water (control)	13.71	13.85	2.63	2.60	7.63	7.82	0.60	0.47
I_2: 75% water	12.86	12.41	2.41	2.17	8.58	8.36	0.92	0.84
I_3: 50% water	11.23	11.72	1.58	1.65	12.61	10.99	1.30	1.05
LSD ($P \leq 0.05$)	0.02	0.04	0.02	0.01	0.05	0.04	0.02	0.04
Biostimulants								
T_1: tap water (control)	10.56	10.43	1.60	1.67	12.61	12.02	1.36	1.04
T_2: seaweed extract	12.66	12.72	2.14	2.07	8.57	8.42	0.81	0.73
T_3: fishmeal extract	12.41	11.97	1.92	1.98	9.39	8.77	0.90	0.75
T_4: compost tea extract	14.78	15.52	3.15	2.84	7.46	7.02	0.68	0.62
LSD ($P \leq 0.05$)	0.04	0.07	0.08	0.02	0.04	0.04	0.03	0.02
Interaction								
$I_1 \times T_1$: control	10.34	11.50	1.90	2.00	10.44	10.68	0.86	0.63
$I_1 \times T_2$: 100% × seaweed	14.33	14.03	2.58	2.51	6.72	7.20	0.51	0.44
$I_1 \times T_3$: 100% × fishmeal	13.97	13.57	2.25	2.43	7.27	7.48	0.60	0.46
$I_1 \times T_4$: 100% × compost tea	16.23	16.32	3.80	3.46	6.12	5.95	0.43	0.38
$I_2 \times T_1$: 75% water	11.42	10.56	1.79	1.72	12.49	11.41	1.34	1.11
$I_2 \times T_2$: 75% × seaweed	12.75	12.88	2.30	2.10	7.35	7.63	0.80	0.78
$I_2 \times T_3$: 75% × fishmeal	12.47	11.46	2.10	2.00	8.11	8.00	0.88	0.81
$I_2 \times T_4$: 75% × compost tea	14.82	14.74	3.45	2.88	6.38	6.40	0.68	0.66
$I_3 \times T_1$: 50% water	9.94	9.23	1.13	1.30	14.90	13.97	1.90	1.40
$I_3 \times T_2$: 50% × seaweed	10.90	11.26	1.56	1.60	11.64	10.45	1.12	0.98
$I_3 \times T_3$: 50% × fishmeal	10.81	10.89	1.43	1.52	12.80	10.85	1.24	1.00
$I_3 \times T_4$: 50% × compost tea	13.29	15.50	2.21	2.18	9.90	8.71	0.95	0.82
LSD ($P \leq 0.05$)	0.08	0.15	0.17	0.05	0.09	0.09	0.06	0.04

and fruit set of olive (Erel et al., 2016). Micronutrients such as B and Zn enhance pollen germination and style tube formation; therefore has a vital role in fruit set (Acar et al., 2010). Boron affects fruit set and development due to its positive role on carbohydrate transport (Marschner, 2012). The hormonal effect of IAA along with micronutrients (e.g. B, Zn, Fe, Mn, and Cu) increased fruit retention percentage and tree productivity, and improved fruit physiochemical characteristics in mango (El-Kosary et al., 2011; Khan et al., 2012).

Yield. Results in Table 5 indicated that moderate water deficit at 75% of water requirement significantly increased total fruit yield compared to the control and severe water deficit at 50% during both seasons. This is in agreement with previous findings of Conesa et al. (2018). In addition, the application of biostimulants also improved total fruit yield. Compost tea had the greatest positive effect on yield. These results confirm previous results with 'Washington' navel orange (Omar and Abo El Enien, 2018).

Of all 12 treatment combinations, trees receiving 75% water plus compost tea extract had the highest yield (Table 5), and this may be due to the reduced fruit set under water deficit conditions (Table 4) that led to increased weight and size of the remaining fruit due to the role of compost tea (Table 5). The combination of 50% water deficit plus compost tea extract also had higher yield than 100% water with no biostimulants. This supports the role of compost tea affecting total yield due to the hormonal-like effect and micronutrient contents that alleviate the drastic effects of water stress, and improve C/N ratio, fruit set, number of fruit/tree and total yield (Negi et al., 2009). Similar results were obtained by irrigating to 60 to 70% of field capacity, which improved plant water use efficiency and fruit yield of 'Valencia' orange (El Sayed and Ennab, 2013), 'Washington' navel orange (Zaghloul and Moursi, 2017; Omar and Abo El Enien, 2018) and peach (Abd El Hamied and Ghieth, 2017). Compost tea was the most effective biostimulant treatment increasing the yield of 'Washington'

Table 5. Effect of three irrigation regimes and foliarly applied biostimulants on total fruit yield and percentage of fruit splitting and creasing of 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Treatments	Total fruit yield				Splitting (%)		Creasing (%)	
	Kg/tree		Ton/hectare					
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Irrigation								
I_1: 100% water (control)	91.24	98.03	36.50	39.21	4.27	3.67	3.77	4.59
I_2: 75% water	96.91	104.49	38.75	41.80	4.63	3.28	1.99	1.90
I_3: 50% water	79.48	84.18	31.79	33.67	5.20	4.90	5.87	5.61
LSD ($P \leq 0.05$)	0.04	0.03	0.45	0.36	0.05	0.03	0.02	0.03
Biostimulants								
T_1: tap water (control)	79.69	82.92	31.88	33.17	5.63	4.67	4.52	4.69
T_2: seaweed extract	87.71	94.91	35.08	37.96	4.50	3.49	3.78	3.94
T_3: fishmeal extract	86.10	90.43	34.44	36.17	4.70	4.20	3.97	4.12
T_4: compost tea extract	103.33	114.01	41.33	45.60	3.98	3.44	3.24	3.39
LSD ($P \leq 0.05$)	0.02	0.02	0.86	0.62	0.04	0.03	0.03	0.03
Interaction								
$I_1 \times T_1$: control	81.29	84.47	32.52	33.79	5.16	4.25	4.41	5.34
$I_1 \times T_2$: 100% × seaweed	89.42	96.23	35.77	38.49	4.24	3.46	3.71	4.48
$I_1 \times T_3$: 100% × fishmeal	87.79	92.61	35.12	37.04	4.13	3.84	3.88	4.70
$I_1 \times T_4$: 100% × compost tea	106.48	118.84	42.59	47.54	3.58	3.15	3.10	3.85
$I_2 \times T_1$: 75% water	86.32	91.41	34.53	36.56	5.58	4.12	2.32	2.21
$I_2 \times T_2$: 75% × seaweed	95.00	106.10	38.00	42.44	4.38	2.38	1.94	1.86
$I_2 \times T_3$: 75% × fishmeal	93.22	100.28	37.29	40.11	4.70	3.65	2.03	1.94
$I_2 \times T_4$: 75% × compost tea	113.10	120.20	45.24	48.08	3.88	2.98	1.68	1.60
$I_3 \times T_1$: 50% water	71.48	72.90	28.59	29.16	6.17	5.64	6.84	6.52
$I_3 \times T_2$: 50% × seaweed	78.73	82.41	31.49	32.96	4.90	4.63	5.70	5.48
$I_3 \times T_3$: 50% × fishmeal	77.30	78.42	30.92	31.37	5.27	5.13	6.00	5.72
$I_3 \times T_4$: 50% × compost tea	90.42	103.00	36.17	41.20	4.48	4.21	4.96	4.73
LSD ($P \leq 0.05$)	0.04	0.04	1.74	1.24	0.09	0.06	0.07	0.06

navel orange per tree by 39% (Mostafa et al., 2009; Omar et al., 2012). In this respect, seaweed extract increased the yield of 'Clementine' mandarin and 'Navelina' orange by 11% and 8%, respectively (Fornes et al., 2002). Therefore, reducing irrigation to 75% of water requirement with the application of compost tea extract was the most effective treatment on 'Valencia' orange tree production. This treatment actually saved about 25% of water used in irrigation, and increased total fruit yield per tree by 40.7% over the control (Table 5).

Fruit physiological disorders. The current study has focused on splitting and creasing disorders. Splitting; praimarily occurs during cell enlargement period, fruit maturity period, or throughout the entire fruit growth and development period (Juan and Jiezhong, 2017). There are three types, including flavedo splitting (i.e., begins with cuticle splitting followed by flavedo cells until cracking reaches the albedo cells) (Wang and Qin, 1987), inner cracking (i.e., starts at fruit central axis, then fruit top) (Wu et al., 1987) and albedo splitting, which is also defined as creasing. Creasing; also know as albedo breakdown in citrus rind (Davies and Albrigo, 1994), is characterized by separation of albed cells resulting in channels in the rind (Treeby et al., 1995). Results in Table 5 indicate that water deficit at 75% significantly reduced the percentage of fruit creasing, but the effect on fruit splitting was only noticeable during the second season. In addition, the application of biostimulants also effectively reduced splitting and creasing percentage, and compost tea was the most effective biostimulant during both seasons. Physiological disorders like splitting and creasing are usually associated with tree water status and soil moisture content (Mesejo et al., 2016). Zaghloul and Moursi (2017) reported that foliar spray of biostimulants reduced fruit splitting and creasing of 'Washington' navel orange. This may be due to their richness in phytohormones (i.e., auxins, cytokinins and gibberellins), amino acids and micronutrients (Zaghloul et al., 2015). Abd El Rahman et al. (2012) found that foliar application of

GA_3 and potassium nitrate had reduced fruit splitting percentage of 'Washington' navel orange.

The combined application of 75% of total water requirement and compost tea extract, followed by 75% water and seaweed extract were the most effective treatments reducing creasing percentage. Full water amount with compost tea extract, and 75% of water amount with seaweed extract during the first and the second seasons, respectively reduced splitting (Table 5). Compost tea was previously the most effective biostimulant treatment minimizing fruit splitting and creasing (Zaghloul and Moursi, 2017). Compared to the control, the reduction in fruit creasing was about 66% with 75% of water requirement plus compost tea, whereas it was 61% for 75% water plus seaweed extract (Table 5). The higher nutrient contents, especially Ca, K, Zn and B could be important to reduce fruit physiological disorders due to their role in stabilizing pectin fractions in cell wall improving fruit firmness (Ali et al, 2000; Treeby et al., 2000; O'Neill et al., 2004; Goldbach and Wimmer, 2007). Reduced fruit creasing and splitting may be due to the earlier application of biostimulants; before flowering, at full bloom, and two months after full bloom. It is suggested that mineral elements are needed before the pectin structure of cell wall has been completed, before the end of cell division in albedo, which is approximately six weeks after petal fall (Bower, 2004).

Fruit quality. In regards to the main effect of water deficit treatments, results indicated that the best values of fruit physical characteristics (Table 6) and vitamin C (Table 7) were related to the application of 75% of water requirement during both seasons. However, when compared to the control, juice content was not significantly affect by 75% water (Table 6). These results support the findings of Gonzalez-Altozano and Castel (2003), Perez-pastor et al. (2007), Moursi and Abo El Enien (2015) and Shirgure et al. (2016). The best value of TSS was obtained by reducing water requirement to 50%, whereas control showed the best values of acidity and TSS/acid ratio, in both seasons (Table 7).

Table 6. Effect of three irrigation regimes and foliarly applied biostimulants on fruit physical characteristics of 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Treatments	Fruit weight (g)		Fruit size (cm^3)		Juice (%)		Fruit firmness (N/mm^2)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Irrigation								
I_1: 100% water (control)	286.74	288.73	302.98	307.17	65.47	65.16	0.791	0.717
I_2: 75% water	290.16	290.20	306.79	308.73	66.25	65.50	0.863	0.793
I_3: 50% water	274.30	274.28	289.84	291.80	62.62	61.49	0.588	0.502
LSD ($P \leq 0.05$)	0.27	0.54	0.26	0.43	1.00	0.50	0.006	0.008
Biostimulants								
T_1: tap water (control)	212.15	222.19	224.16	236.39	48.44	50.15	0.703	0.623
T_2: seaweed extract	313.97	308.85	331.77	328.58	71.68	69.71	0.748	0.676
T_3: fishmeal extract	271.54	277.72	286.92	295.45	61.99	61.94	0.804	0.712
T_4: compost tea extract	337.27	328.85	356.65	349.85	77.01	74.42	0.734	0.672
LSD ($P \leq 0.05$)	0.41	0.33	0.37	0.49	0.95	0.48	0.007	0.005
Interaction								
$I_1 \times T_1$: control	214.39	225.57	226.53	239.98	48.97	50.91	0.743	0.682
$I_1 \times T_2$: 100% × seaweed	317.29	313.54	335.26	333.57	72.44	70.77	0.812	0.713
$I_1 \times T_3$: 100% × fishmeal	274.41	281.96	289.95	299.97	62.65	63.64	0.817	0.735
$I_1 \times T_4$: 100% × compost tea	340.88	333.85	360.21	355.17	77.83	75.35	0.791	0.741
$I_2 \times T_1$: 75% water	216.97	226.72	229.26	241.20	49.53	51.17	0.810	0.715
$I_2 \times T_2$: 75% × seaweed	321.11	315.15	339.29	335.28	73.31	71.13	0.838	0.806
$I_2 \times T_3$: 75% × fishmeal	277.72	283.40	293.45	301.50	63.40	63.97	0.976	0.868
$I_2 \times T_4$: 75% × compost tea	344.84	335.54	365.19	356.97	78.76	75.73	0.827	0.783
$I_3 \times T_1$: 50% water	205.09	214.30	216.70	227.99	46.82	48.37	0.557	0.472
$I_3 \times T_2$: 50% × seaweed	303.53	297.87	320.76	316.89	69.30	67.23	0.595	0.511
$I_3 \times T_3$: 50% × fishmeal	262.51	267.80	277.37	284.90	59.93	58.21	0.618	0.535
$I_3 \times T_4$: 50% × compost tea	326.09	317.16	344.56	337.42	74.45	72.18	0.583	0.492
LSD ($P \leq 0.05$)	0.83	0.95	0.75	0.99	1.92	0.98	0.014	0.010

TSS and acidity increased as the amount of applied water decreased (El Sayed and Ennab, 2013; Conesa et al., 2018). Moderate irrigation produced the highest TSS, TSS/acid ratio and vitamin C in 'Nagpur' mandarin (Shirgure et al., 2016) and 'Washington' navel orange (Omar and Abo El Enien, 2018). Averaged over the irrigation treatments, all biostimulant treatments improved fruit physical (Table 6) and chemical characteristics, except acidity and TSS/acid ratio (Table 7), compared to the control during both seasons. Compost tea extract had the greatest effect on fruit weight and size, juice content (Table 6), TSS, and vitamin C. Although this treatment showed high acidity content, but the difference in TSS/acid ratio was insignificant compared to the control (Table 7). These results confirm the previous reports of Omar et al. (2012), Zaghloul et al. (2015) and Al Musawi (2018).

The combined application of 75% water and compost tea extract, followed by 100% water and compost tea extract produced the best values of fruit weight and size, and juice content in comparison to all treatments and the control during both seasons, however, the difference between both treatments was not significant in regards to juice content (Table 6). Spraying compost tea and seaweed extracts increased fruit weight, size, length and diameter diameter, and juice content of 'Balady' lime (Masoud and Abd El Aal, 2012) and sour orange fruit (Al Musawi, 2018). The effect of compost tea may be due to the high content of nutrients and vitamins, in addition to its content of useful bacteria, fungi and actinomycetes, which are acting to enhance vegetative growth and nutritional status of the tree, and eventually affect fruit quality (Calvo et al., 2014). Fruit firmness was greatest with 75% water plus fishmeal extract, followed by 75% water plus seaweed extract, then 75% water plus compost tea extract (Table 6). Biostimulants improved fruit firmness due to their content of IAA, GA_3 and Ca (Kinay et al., 2005). The auxin and gibberellin constituents of biostimulantscomponents are responsible of retarding the activity of falvedo α-mannosidase and albedo β-galactosidases

Table 7. Effect of three irrigation regimes and foliarly applied biostimulants on fruit chemical characteristics of 'Valencia' orange trees during 2017/2018 and 2018/2019 seasons.

Treatments	TSS (%)		Acidity (%)		TSS/acid ratio		Vitamin C (mg/100 ml juice)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Irrigation								
I_1: 100% water (control)	12.36	12.36	1.11	1.05	11.16	11.77	46.69	43.79
I_2: 75% water	12.59	12.76	1.16	1.11	10.85	11.50	47.59	46.38
I_3: 50% water	13.09	13.03	1.26	1.19	10.40	10.94	46.78	44.88
LSD ($P \leq 0.05$)	0.12	0.02	0.01	0.01	0.14	0.26	0.38	0.32
Biostimulants								
T_1: tap water (control)	11.54	11.62	1.08	1.03	10.68	11.28	43.23	41.40
T_2: seaweed extract	12.99	13.12	1.18	1.15	11.01	11.41	47.56	46.36
T_3: fishmeal extract	12.61	12.50	1.17	1.11	10.77	11.30	46.70	44.29
T_4: compost tea extract	13.58	13.64	1.26	1.19	10.77	11.46	50.59	48.02
LSD ($P \leq 0.05$)	0.09	0.03	0.02	0.02	0.13	0.18	0.21	0.34
Interaction								
$I_1 \times T_1$: control	11.11	11.29	1.02	0.97	10.89	11.64	42.94	40.27
$I_1 \times T_2$: 100% × seaweed	12.92	12.76	1.10	1.08	11.74	11.81	47.23	45.10
$I_1 \times T_3$: 100% × fishmeal	12.29	12.15	1.12	1.03	10.97	11.80	46.37	43.08
$I_1 \times T_4$: 100% × compost tea	13.14	13.26	1.19	1.12	11.04	11.84	50.23	46.71
$I_2 \times T_1$: 75% water	11.55	11.66	1.07	1.02	10.79	11.43	43.77	42.66
$I_2 \times T_2$: 75% × seaweed	12.80	13.17	1.17	1.14	10.94	11.55	48.14	47.77
$I_2 \times T_3$: 75% × fishmeal	12.55	12.54	1.15	1.09	10.91	11.50	47.27	45.64
$I_2 \times T_4$: 75% × compost tea	13.46	13.68	1.25	1.18	10.77	11.59	51.21	49.48
$I_3 \times T_1$: 50% water	11.96	11.91	1.16	1.10	10.31	10.83	43.00	41.28
$I_3 \times T_2$: 50% × seaweed	13.25	13.45	1.27	1.23	10.43	10.93	47.33	46.23
$I_3 \times T_3$: 50% × fishmeal	12.99	12.81	1.25	1.17	10.39	10.95	46.47	44.16
$I_3 \times T_4$: 50% × compost tea	14.16	13.98	1.35	1.27	10.49	11.00	50.34	47.88
LSD ($P \leq 0.05$)	0.18	0.07	0.04	0.05	0.26	0.38	0.62	0.68

(Alam-Eldein, 2011) and reduce the degradation of pectin polymers of cell wall, which are associated with fruit softening (Mitcham and McDonald, 1993). These three later treatments in the same order also reduced fruit creasing in both seasons, and splitting in the first season (Table 5) showing a positive relationship between fruit firmness and susceptibility to peel cracking. These findings contradict reports of Bower (2004), and Juan and Jiezhong (2017) where increasing peel thickness and hardness reduced creasing percentage in citrus. The positive relationship in this current study might be due to the effect of reduced water conditions (Table 5 and 6), which cause changes in the ultrastructure of the cell wall and lead to cell loosening in albedo tissue, thus resulting in fruit ceasing or splitting (Li et al., 2008). In addition, Treeby et al. (2000) reported that creasing fruit rate of trees on lemon rootstocks is higher than that of trees on orange rootstocks.

Vitamin C was highest with the application of 75% water plus compost tea, followed by 50% water plus compost tea (Table 7). TSS was highest with 50% water plus compost tea extract, followed by 75% water plus compost tea extract. Acidity increased more in dryer conditions. The highest and the lowest values were recorded with the application of 50% water plus compost tea extract, and the control, respectively in both seasons. TSS: acid ratio tends to be higher in more wet conditions, and the highest values were associated with 100% water plus seaweed extract and 100% water plus compost tea extract during the first and the second seasons, respectively with insignificant difference compared to the control in the second season (Table 7). These results agree with those of Zaghloul and Moursi (2017) on 'Washington' navel orange. Results in Table 7 also revealed that acidity increased more than TSS under dry conditions, consequently TSS: acid ratio decreased, and this confirms the previous reports of Wittwer (1995). The reduction in TSS: acid ratio is mainly related to the reduction in photosynthesis rate under water stress conditions (Vu and Yelenosky, 1989). Biostimulant applications improved TSS of stressed 'Valencia' trees (Table 7), and this could be related to the hormone-like effect, which increases the sink capacity of the fruit improving the mobilization activity of water, carbohydrates, and nutrients (Agusti et al., 1992). Yakushiji et al. (1996) found that glucose and fructose were largely responsible for active osmoregulation in Satsuma mandarin fruit under moderate drought conditions. Furthermore, the total sugar concentration of fruit from water-stressed trees was higher than that of well-watered trees (Alam-Eldein, 2011), suggesting that sugar accumulation in fruit was not caused by dehydration under water stress, but rather sugar accumulated from carbon assimilates and tree reserve by active osmoregulation to maintain cell turgor and minimize the detrimental effects of water stress (Yakushiji et al., 1998). Cohen and Goell (1988) found that these accumulated sugars were not completely utilized for fruit growth even after irrigation was resumed. Increase in fruit sugar concentration is usually associated with increases in TSS, because sugars constitute about 75-80% of TSS (Grierson, 2006). This supports the role of biostimulants improving fruit quality under water deficit conditions.

In summary, it is worth mentioning that Gonzalez-Altozano and Castel (2003) showed that moderate water deficit during initial fruit growth stages did not affect citrus fruit yield compared to the control, whereas yield decreased by 25% when water deficit has applied during fruit ripening stage. Also, Garcia-Tejero et al. (2012) showed that reduced citrus yield was related to the phenological stage, and the most sensitive stages were flowering, fruit growth and ripening in relation to water deficit to 50% of crop evapotranspiration. Yield reduction in these three stages was 20, 10, and 6%, respectively. In a more recent study, reduced yield was more related to late stages of fruit growth, while moderate water deficit (i.e., 20 or 40% reduction in crop evapotranspiration) during flowering and early stages of fruit growth resulted in higher fruit number per tree, but total yield and fruit quality were not affected (Conesa et al., 2018). However, in this current study water deficit treatments were extended throughout the season (Table 1), rather than a specific period during fruit growth and development, suggesting that improved total yield with reducing water to 75% was mainly related to the beneficial effect of biostimulant sprays (Table 5), which mitigate the drastic effects of water stress (Van Oosten et al., 2017). Even with reducing water to 50% with no biostimulant, the reduced total yield compared to the control was 12.1 and 13.7% in 2017 and 2018 season, respectively, which is a smaller reduction compared to previous reports. Goldhamer and Salinas (2000) reported that the response of citrus cultivars to deficit irrigation depends on the level of water stress endured by the plant at different phenological stages. Rootstocks may play an important role in this regard (Rodriguez-Gamir et al., 2010). 'Volkamer' rootstock effectively improved the scion's photosynthetic capacity linked to carbohydrate distribution, which impacts plant vegetative and reproductive development under water deficit conditions (Martinez-Cuenca et al., 2016) in sandy soils (Roose, 2014). 'Volkamer' is important for the desert citrus industry, because it is vigorous and produces high-yielding trees with excellent fruit size (Wright and Poe, 2018), but lower juice quality due to its lemon × sour orange origin (Roose, 2014). The behavior of 'Valencia' orange trees under moderate deficit irrigation (75%) in this current study may have been just a prevention mechanism rather than tolerance, according to Verslues et al. (2006) and Lawlor (2013). Prevention occurs with high water absorbance due to deeper and denser root systems (Blum, 2005), which are characteristics of 'Volkamer' roots (Roose, 2014). Therefore, the trees continue growing and fruiting, albeit at a reduced rate (Zhao et al., 2015), and never commence the tolerance mechanism until the prevention mechanism becomes insufficient to protect the plant (Claeys and Inze, 2013). This could also support the preventative and stimulative role of biostimulants, compost tea in particular, for improving growth, productivity and fruit quality under deficit irrigation conditions (Calvo et al., 2014).

Conclusion

'Volkamer'-budded 'Valencia' orange trees grown in sandy soil under drip irrigation conditions showed better vegetative growth, fruit development, yield and fruit quality with moderate deficit irrigation of 19,400 L/tree/year (75% of crop water requirement) plus foliar application of compost tea (65ml/L). This combination treatment saved about 25% of used water with no negative effect on tree growth, productivity, or fruit quality. The increase in yield was about 40.7% over the control. Previous studies applied water deficit treatments at specific phenological stages of plant growth and development during the season, but in the current study trees were water-stressed throughout the entire season. This may have caused a specific type of tree adaptation to water stress, because trees became water-stressed gradually, rather than suddenly. In addition, the application of biostimulants partially negated the negative effects of water stress.

In comparison to previous reports of 25% (Gonzalez-Altozano and Castel, 2003) and 20% (Garcia-Tejero et al., 2012) yield reduction with limited fruit quality, we found a smaller reduction in yield (12.9%) (Table 5) with improved fruit TSS and vitamin C content (Table 7) in response to 50% water deficit. Similar treatments may be a focal point for future research (i.e., at the molecular level) to improve tree productivity and fruit quality under such conditions.

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Correction:

In the web version of the paper "*Standardized Phenotyping in Black Raspberry*" three of the authors names were misspelled and should be: Christine M. Bradish, Jill M. Bushakra, Lisa R. Robbins, Eda Karaadaç, Sabrina Teo, Jamie L. Willard, Penelope Perkins-Veazie, Jungmin Lee, Joseph C. Scheerens, Courtney A. Weber, Michael Dossett, Nahla V. Bassil, Chad E. Finn, and Gina E. Fernandez

About The Cover:

Mechanical harvest of English Walnuts in California.