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Fertilizer type and irrigation frequency affect plant growth, yield, and gas exchange of containerized strawberry cultivars

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Abstract

Small-scale strawberry production in southeastern states requires cultivars adaptive to local climates and with season extension potentials. This study investigated plant growth, yield, gas exchange, and fruit quality of ten strawberry (*Fragaria* × *ananassa* Duch.) cultivars affected by fertilizer type and irrigation frequency in a containerized production system in 2018. Bare root liners of seven June-bearing and three day-neutral cultivars were grown in 2-gallon containers, fertilized with a conventional fertilizer or an organic fertilizer at comparable rates, and irrigated once or twice daily with the same total irrigation volume**.** Strawberry cultivars varied in vegetative growth (including plant growth index (PGI), leaf SPAD, number of crowns, visual score, and root dry weight) and fruiting characteristics (including first harvest date, yield, number of fruit, berry size, fruit soluble solids content, and firmness). Day-neutral cultivars 'Evie 2' and 'Seascape' produced the highest total yields and late-season yield in June. The conventional fertilizer resulted in higher PGI, leaf SPAD, plant visual score, fruit yield in May, daily water use, and net photosynthetic rate than the organic fertilizer. Two irrigations per day increased substrate moisture compared with one irrigation per day, and increased shoot dry weight with the conventional fertilizer application. Irrigation frequency did not affect PGI, leaf SPAD, gas exchange, fruit yield, or quality in tested strawberry cultivars.

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INTRODUCTION

The United States is the world's second largest producer of strawberries (*Fragaria* × *ananassa* Duch.)[1]. In 2017, the U.S. produced 1.6 billion pounds of strawberries, with an industry value of near $3.5 billion[2,3]. Strawberry is one of the most consumed fruits in the U.S., with per capita consumption of 7.12 lbs in 2018[4−6]. Strawberries are rich in basic nutritional components including sugars, mineral nutrients, and vitamins, and bioactive compounds that are known to have antioxidant capacity, scavenge free radicals, and introduce health benefits such as slowing down aging, preventing cardiovascular diseases, inflammation, and certain types of cancers[7, 8].

Cultivated strawberry plants are classified into three types of cultivars based on their flowering response to photoperiod and temperature: June-bearing, everbearing, or day-neutral[9]. June-bearing strawberries initiate flowering in response to a short photoperiod of 14 h or less, or low temperatures below 15 °C, and typically produce one flush of fruit in spring[9,10]. Everbearing cultivars initiate flower buds with days of greater than 12 h, resulting in a fall harvest or two crops in one year[11]. Day-neutral strawberry plants can produce crowns and flower buds whenever the temperature is within a favorable range of 4 to 29 °C regardless of the day length[12]. This ability allows for potential year-round fruit harvest in areas where summer or fall temperatures stay in this range or where high tunnels or other protected cultivation methods can produce the favorable conditions[12,13]. Commercial production of strawberries uses mostly June-bearing cultivars or a combination of June-bearing and day-neutral cultivars, with ever-bearing cultivars rarely grown outside of home gardens. There has been increasing interest in using day-neutral cultivars for extended harvest season[3].

The leading states for strawberry production in the U.S. are California and Florida, producing approximately 91% and 8% of the nation's strawberry crop[14]. Commercial strawberry production in the U.S. uses primarily an annual hill production system featuring plasticulture and raised beds. Strawberry production in all other states is mainly small-scale and aims for local market outlets[3]. Growers are seeking ways to improve competitiveness, including using protected culture with greenhouses, high and low tunnels, or soilless culture to achieve season extension, reduce pest pressure, and improve fruit yield and quality[3,15]. Besides using an annual hill system, strawberry plants can also be grown as hanging baskets and marketed to home gardeners for both the decorative and edible attributes. Best management practices including fertilization and irrigation of containerized strawberry plants using soilless substrate largely remain unknown and merits investigation.

There has been strong consumer demand for locally, sustainably, or organically grown fruits and vegetables with increasing consumer health consciousness[16−18]. Organically grown strawberry fruit were found to have lower pesticide residues, better fruit quality, and greater antioxidant activity[17]. By comparison, Hargreaves et al.[19] found no significant differences in yield, total soluble solids content or antioxidant capacity in organically versus conventionally grown strawberries. Similar flavanol and phenolic acid contents were found in berries grown organically and conventionally by Häkkinen & Törrönen[20]. Fertilization management is an important aspect of growing strawberry plants in an alternative production system. There lacks information regarding effects of certain organic growing practices like fertilizer type on plant growth, fruit yield and quality of strawberry plants.

An efficient irrigation program should be economically sound, and reduce excessive nutrient leaching to ground water. Deficit irrigation increased concentrations of taste- and health-related compounds including sugars and acids in strawberry fruit, but resulted in smaller fruit size[21]. Fare et al.[22] reported that splitting the irrigation volume into separate times reduced water runoff and nitrate leached from the substrate in container grown holly (*Ilex crenata* Thunb. 'Compacta'). Scagel et al.[23,24] reported that increased irrigation frequency decreased water stress, increased nitrogen use efficiency, and had varying effects on mineral nutrient uptake of three *Rhododendron* species. Irrigation applied in split intervals increased plant growth, carbon dioxide (CO_2) assimilation, stomatal conductance, and water use efficiency of *Cotoneaster dammeri* 'Skogholm' compared with plants receiving water once in the morning[25]. Plant species varied in their response to altered irrigation frequency. Li et al.[26] found that increasing irrigation frequency from once to twice per day decreased plant growth index, root dry weight, length, surface area, and flower number per plant in *Rhododendron sp*. 'Chiffon'. Two irrigations per day increased plant size, substrate moisture, and N concentration in *Hydrangea macrophylla* 'Merritt Supreme' compared to one irrigation[27]. The effect of altering irrigation frequency on plant growth and fruit production of strawberry cultivars remains unclear.

We hypothesized that fertilizer type and irrigation frequency may affect strawberry plant performance independently or interactively when grown in containers with soilless substrate. The objective of this study was to investigate plant vegetative growth, gas exchanges, fruit yield and quality of ten containerized strawberry cultivars, including seven June-bearing and three day-neutral, as affected by fertilizer type and irrigation frequency in USDA hardiness zone 8a.

MATERIALS AND METHODS

Plant culture and treatments

Seven June-bearing cultivars 'Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour', and three day-neutral cultivars 'Evie 2', 'San Andreas', and 'Seascape' were evaluated in this study. Bare root liners of the ten selected cultivars were purchased from a commercial nursery (Nourse Farms, Whately, MA, U.S.) and transplanted into 2-gallon plastic containers (C900, top diameter 24.1 cm, height 23.2 cm, volume 7.33 L; Nursery Supplies® Inc., Chambersburg, PA, U.S.) on 28 Feb. 2018. Pine bark : peat moss : perlite in a volume ratio of 4:3:1 was used as growing substrate. The substrate was incorporated with 0.89 kg·m^{-3} micronutrient (Micromax®; ICL Specialty Fertilizers, Summerville, SC, U.S.) and 2.97 kg·m^{-3} lime (Soil Doctor Pelletized Lawn Lime; Oldcastle, Atlanta, GA, U.S.). Each containerized plant was fertilized with 60 g granular organic fertilizer 5N-1.3P-3.3K (5-3-4; McGeary Organics, Lancaster, PA, U.S.) or 20 g conventional controlled-release fertilizer 15N-2P-10K (Osmocote® 15-9-12 5–6 months; Scotts Miracle-Grow Co., Marysville, OH, U.S.). All strawberry plants were maintained outdoors in full sun at the R. R. Foil Plant Science Research Center of Mississippi State University in Starkville, MS, U.S. (lat. 33.45° N, long. 88.79° W; USDA hardiness zone 8a). Strawberry plants were drip irrigated at a flow rate of half gallon per hour with the same total daily irrigation volume through two irrigation frequencies: once per day at 0800$_{HR}$ or twice per day at 0800$_{HR}$ (half volume) and 1430$_{HR}$ (half volume). Plants were irrigated to replace daily water loss plus 10% to 15% leaching fraction. Irrigation volume was determined by randomly selecting ten plants and measuring their daily water use approximately once per month.

Local outdoor air temperature in Starkville were obtained from the website of the USDA-Natural Resources Conservation Service[28]. Growing degree days (GDDs) were calculated daily by [(Daily maximum temperature + Daily minimum temperature)/2 − Base temperature]. Cumulative GDDs between certain time periods were estimated by summing daily GDDs. The base temperature used for strawberry was 3 °C[29].

Plant growth and visual quality

Plant height and widths (width 1, the widest point of canopy; width 2, perpendicular width of width 1) of each plant were measured on 22 June 2018. Plant growth index (PGI) was calculated as the average of the plant height and two widths to estimate plant size. On 20 June, relative leaf chlorophyll content was estimated by SPAD readings. Leaf SPAD readings were measured from the terminal leaflet of three fully expanded new leaves using a chlorophyll meter (SPAD 502 Plus; Konica Minolta, Inc., Osaka Japan). An average of the three readings were calculated to represent relative leaf chlorophyll content of an individual plant. Plant visual quality was evaluated by a five-point scale, where 1 = poor quality with severe leaf damage over 70%; 2 = leaf damage of 50% to 70%, 3 = moderate quality with 20% to 50% leaf damage; 4 = good quality with minor leaf damage of less than 20%; 5 = excellent quality without any leaf damage. A dead plant was rated 0 for the visual score.

One plant from each treatment combination was destructively harvested with three replications. For each individual plant, shoots were separated from roots, and roots were then cleaned free of substrate. Roots and shoots samples were oven dried at 60 °C to constant weight. The number of crowns from each harvested plant and the dry weight of each sample were recorded.

Water use and substrate moisture

Daily water use (DWU) was determined in plants irrigated once per day using a gravimetric method by subtracting pot weight (plant included) 24 h after irrigation from pot weight at container capacity (about half an hour after irrigation). Daily water use was measured twice on 19 June and 27 June, respectively. Substrate moisture at 6-cm depth was measured using a soil moisture sensor (ML2x; Delta-T Devices, Cambridge, England) with two readings collected from each container. The moisture sensor was connected to a soil sensor reader (HH2; Delta-T Devices) for instant moisture readings. Substrate moisture was measured on 27 June before scheduled daily irrigation in the morning.

Gas exchange measurements

To evaluate physiological activities of plants affected by fertilizer type and irrigation frequency, leaf net photosynthetic rate (Pn), stomatal conductance (g_s), and transpiration rate (E) of strawberry plants were measured between 1100_{HR} and 1500_{HR} on 27 June and 28 June using a portable photosynthesis system (LI-6400XT; LI-COR, Lincoln, NE, U.S.). Three plants were randomly selected from three different blocks for gas exchange measurements for each treatment combination. One recent fully expanded leaf, not shaded by other leaves, was selected for the measurement. The selected leaf was enclosed into a 2-cm^2 leaf chamber with a fluorometer (6400-40; LI-COR) as the light source. A reference CO_2 concentration of 400 $\mu mol \cdot mol^{-1}$ and photosynthetically active radiation (*PAR*) of 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were maintained inside the leaf chamber during gas exchange measurements. Block temperature was maintained according to outdoor air temperature on the measurement date.

Strawberry fruit harvest

Strawberry fruit was harvested once per week. The date of first fruit harvest was recorded for each plant. Strawberries were culled for misshaped, disease- or insect-damaged fruits. Fruit yield and the number of fruit at each harvest were recorded. Yield from each harvest was summed up for a season total. Soluble solids content of strawberry fruit from each plant were measured using a digital refractometer (PR-32α; Atago U.S.A., Inc., Bellevue, WA, U.S.). Fruit firmness was measured with a fruit hardness tester (FR-5120; Lutron Electronic Enterprise CO., LTD, Taipei, Taiwan, ROC). One marketable fruit was used to measure soluble solids content and fruit firmness from each plant, respectively.

Experimental design and data analyses

The experiment was designed in a factorial randomized complete block design with five replications. Three mains factors are strawberry cultivar (10), fertilizer type (2), and irrigation frequency (2), resulting in 40 treatment combinations. Each replication contained two single-plant subsamples. Due to the large number of treatment combinations, data of plant dry weights and gas exchange were measured with three replications, where the three plants were randomly selected from different blocks. Data were analyzed by analysis of variance (ANOVA) using the PROC GLIMMIX procedure in SAS (version 9.4; SAS Institute, Cary, NC, U.S.). Where indicated by ANOVA, means were separated using Tukey's Honest Significant Difference (HSD) test at $P \leq 0.05$.

RESULTS

Plant vegetative growth

Plant vegetative growth variables including plant growth index (PGI) ($P < 0.0001$), leaf relative chlorophyll content measured as leaf SPAD ($P < 0.0001$), number of crowns per plant ($P = 0.040$), visual score ($P < 0.0001$), and root dry weight ($P < 0.0001$) varied among cultivars (Table 1), with PGI ($P = 0.0003$), SPAD ($P < 0.0001$), and plant visual score ($P < 0.0001$) also affected by the main effect of fertilizer type without interactions (Table 2).

'Allstar', 'Jewel', and 'Honeoye' had comparable highest PGIs ranging from 40.9 to 41.6 cm, higher than 'Chandler', 'Evie 2', or 'San Andreas' with the lowest PGIs of 37.0 to 37.6 cm (Table 1). The other four cultivars 'Darselect', 'Earlyglow', 'L'Amour', and 'Seascape' had similar PGIs of 38.3 to 39.5 cm. The three day-neutral cultivars 'Evie 2', 'San Andreas', and 'Seascape' had the comparable highest leaf SPAD ranging from 35.7 to 37.5, with 'Allstar', 'Chandler', 'Darselect', and 'Jewel' having the lowest SPAD ranging from 30.4 to 31.9. Ten tested cultivars generally produced similar number of crowns per plant averaged 3.5 to 5.2 per plant. 'Honeoye' had the highest visual scores averaged 3.8 with minor leaf diseases. 'L'Amour' and 'Seascape' had intermediate visual scores of 3.2 and 3.3, respectively. 'Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Evie 2', 'Jewel', and 'San Andreas' had comparable visual scores ranging from 2.6 to 3.0 out of 5.

Shoot dry weight ranged from 58.8 to 81.5 g per plant, similar among all tested cultivars. 'Allstar', 'Darselect', 'Honeoye', 'Jewel' and 'L'Amour' had comparable root dry weights of 12.9 to 17.3 g per plant, with 'Chanlder', 'Earlyglow', 'Evie 2', 'San Andreas', and 'Seascape' having comparable root dry weights of 9.6 to 12.3 g per plant (Table 1).

When affected by the main effect of fertilizer type, the conventional fertilizer increased PGI, SPAD, and visual score by

Table 1. Vegetative growth of seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars grown in Starkville, Mississippi in 2018.

Cultivar	PGI[1,2] (cm)	SPAD	Number of crowns (per plant)	Visual score (1-5)[3]	Shoot dry wt. (g per plant)	Root dry wt. (g per plant)
Allstar	41.2 ab	31.9 def	4.1 ab	3.0 bcde	71.4	13.5 abcd
Chandler	37.4 c	30.1 f	4.3 ab	2.9 bcde	65.8	10.1 d
Darselect	39.5 abc	31.0 ef	3.8 ab	2.6 e	65.1	14.6 abc
Earlyglow	38.3 bc	32.9 de	4.0 ab	2.8 cde	63.7	11.9 cd
Evie 2	37.0 c	36.3 ab	3.8 ab	3.0 bcde	58.8	9.6 d
Honeoye	40.9 ab	35.3 bc	4.2 ab	3.8 a	81.5	16.5 ab
Jewel	41.6 a	30.4 f	3.5 b	2.7 de	67.5	12.9 abcd
L'Amour	38.5 abc	33.5 cd	4.4 ab	3.2 bc	75.9	17.3 a
San Andreas	37.6 c	37.5 a	4.2 ab	2.9 cde	64.4	12.3 bcd
Seascape	38.7 abc	35.7 abc	5.2 a	3.3 b	63.2	11.5 cd
P-value	<.0001	<.0001	0.040	<.0001	0.13	<.0001

[1] Plant growth index (PGI) = [plant height + widest width 1 + width 2 (width at the perpendicular direction to width 1]/3.
[2] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.
[3] Plant visual quality was evaluated by a five-point scale, where 1 = poor quality with severe leaf damage over 70%; 2 = leaf damage of 50% to 70%; 3 = moderate quality with 20% to 50% leaf damage; 4 = good quality with minor leaf damage of less than 20%; 5 = excellent quality without any leaf damage. A dead plant was rated 0 for the visual score.

Table 2. Effect of fertilizer type on plant growth index (PGI), leaf SPAD, visual score, yield in May, daily water use, substrate moisture, and net photosynthetic rate (Pn) of container-grown strawberries grown in Starkville, Mississippi.

Fertilizer[1]	PGI[2] (cm)	SPAD	Visual score (1−5)	Yield in May (g per plant)	Daily water use (L per day)		Substrate moisture (%)	Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)
					19 June	26 June		
Organic	38.3 b	32.3 b	2.8 b	57.9 b	0.54 b	0.62 b	27.2 a	10.7 b
Conventional	39.9 a	34.6 a	3.2 a	67.9 a	0.65 a	0.73 a	24.6 b	12.0 a
P-value	0.0003	<0.0001	<0.0001	0.044	<0.0001	0.0003	<0.0001	0.0059

[1] Strawberry plants were fertilized with a conventional controlled release fertilizer or an organic fertilizer at comparable rates.
[2] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

4.2%, 7.1%, and 14.3% compared to the organic fertilizer, respectively (Table 2). Fertilizer type did not affect other vegetative growth variables including number of crowns, shoot, and root dry weight.

Affected by the interaction between fertilizer type and irrigation frequency ($P = 0.049$), strawberry plants fertilized with the conventional fertilizer and irrigated twice per day produced higher shoot dry weight of 81.8 g per plant than plants fertilized with organic fertilizer and irrigated twice per day, or plants irrigated once per day fertilized with the conventional or the organic fertilizer (Table 3). Irrigation frequency did not affect plant vegetative growth variables including PGI, SPAD, number of crowns, visual score, and root dry weight.

Timing of fruit harvest

When transplanted on 28 Feb, 2018, fruit harvest of tested strawberry cultivars started 49.4 days after transplanting (DAT) in 'Honeoye' to 65.7 DAT in 'Chandler' in the 2018 growing season (Table 4), with correspondent cumulative GDDs of 536 and 783 (Fig. 1a), respectively. The day-neutral cultivar 'Evie 2' was the second latest-fruiting cultivar with the first harvest being 60.9 DAT. Local average daily air temperature was in between 12.8 to 23.6 °C during the first fruit harvest of tested cultivars (Fig. 1b). Fertilizer type or irrigation frequency did not affect the fruit production timing of any tested cultivar. The first fruit harvest was on 19 Apr and the last fruit harvest was on 13 June 2018 with a total of ten harvests.

Yield

In April, five cultivars 'Darselect', 'Earlyglow', 'Honeoye', 'San Andreas', and 'Seascape' produced similar yield ranging from 17.9 to 24.4 g fruit per plant, higher than 'Allstar', 'Chandler', or 'Jewel' (Table 5). In May, the two day-neutral cultivars 'Evie 2' and 'Seascape' produced the highest and second highest yield of 170.6 and 135.7 g fruit per plant, with 'Chandler', 'Darselect','Earlyglow', 'Honeoye', and 'L'Amour' producing the lowest yield of 16.6 and 50.2 g fruit per plant. The cultivars 'Allstar', 'Jewel', and 'San Andreas' produced similar intermediate yields of 52.0 to 61.1 g fruit per plant in May. The conventional fertilizer increased yield in May by 17.3% compared with the organic fertilizer (Table 2). In June, 'Evie 2' produced the highest yield of 56.8 g fruit per plant, with all other cultivars producing similar yield below 10 g fruit per plant. 'Darselect' and 'Jewel' did not produce any fruit in June. Except for the two early ripening cultivars 'Earlyglow' and 'Honeoye' producing peak harvest in April, the other eight cultivars produced peak harvest in May, which was 68% to 92% of total yield.

For total yield, the two day-neutral cultivars 'Evie 2' and 'Seascape' ranked first and second producing yield of 236.3 and 167.6 g per plant, respectively (Table 5). 'Evie 2' and 'Seascape' also produced the highest and the second highest fruit number of 16.5 and 12.3 per plant among all tested cultivars (Table 4). The seven June-bearing cultivars Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour' generally produced similar total yield and number of fruit per plant ranging from 35.2 to 65.8 g per plant and 3.1 to 6.9 fruits per plant, respectively.

Table 3. Shoot dry weight affected by the interaction between irrigation frequency and fertilizer type and substrate moisture affected by the main effect of irrigation frequency of container-grown strawberries.

Irrigation frequency[1]	Fertilizer	Shoot dry wt (g per plant)[2]	Substrate moisture (%)
Once	Organic	60.3 b	21.21 b
	Conventional	68.1 b	
Twice	Organic	60.7 b	30.55 a
	Conventional	81.8 a	
P-value		0.049	<0.0001

[1] Seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars were grown in 2-gal containers irrigated once or twice per day with the same total irrigation volume, and fertilized with a conventional controlled release fertilizer or an organic fertilizer at comparable rates.
[2] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

Table 4. Fruiting characteristics including first harvest date, number of fruit per plant, berry size, soluble solids content, and fruit firmness of seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars grown in Starkville, Mississippi in 2018.

Cultivar	First harvest date[1] (DAT)	Number of fruit (per plant)	Berry size (g per berry)	Soluble solids content (°Brix)	Fruit firmness (N)
Allstar	58.6 bc	6.9 c	8.8 e	10.5 a	1.89 abc
Chandler	65.7 a	4.6 cd	11.7 d	10.4 a	1.32 e
Darselect	54.0 def	4.7 cd	14.0 bc	11.5 a	1.48 de
Earlyglow	51.3 fg	3.9 cd	9.3 e	11.5 a	1.49 de
Evie 2	60.9 b	16.5 a	14.8 b	8.4 c	1.53 de
Honeoye	49.4 g	4.4 cd	10.1 de	10.4 ab	1.60 cde
Jewel	58.4 bcd	6.0 cd	10.2 de	10.3 ab	1.73 bcd
L'Amour	57.3 bcde	3.1 d	12.2 cd	11.1 a	2.00 ab
San Andreas	53.7 efg	5.0 cd	17.8 a	8.7 bc	2.17 a
Seascape	54.4 cdef	12.3 b	14.2 bc	10.9 a	1.65 cd
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

Fruit quality

The day-neutral cultivar 'San Andreas' produced the largest berry size averaged 17.8 g per berry, higher than 'Darselect',

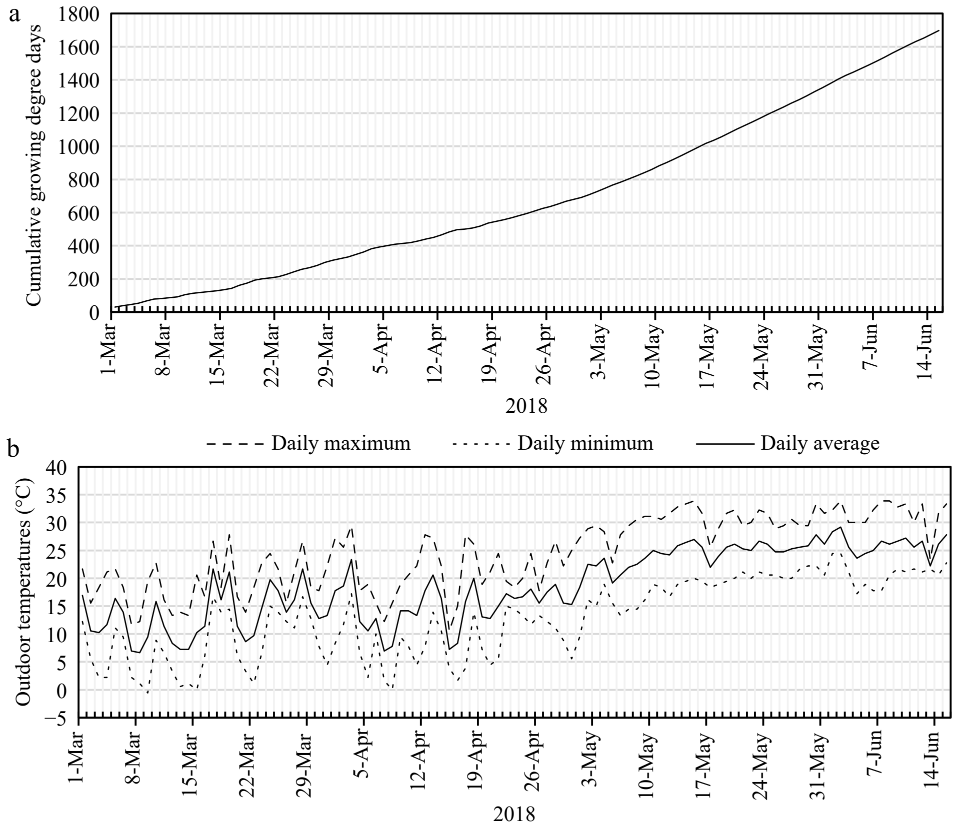

Fig. 1 (a) Cumulative growing degree days (GDDs) and (b) outdoor daily air temperatures from 1 Mar to 15 June 2018 in Starkville, Mississippi, U.S. GDDs = $(T_{daily\ max} + T_{daily\ min})/2 - T_{base}$. T_{base} = 3 °C for strawberries. GDDs was calculated on a daily basis, and cumulative GDDs during certain time periods were estimated by summing up daily GDDs; Local outdoor air temperature data was obtained from the USDA Natural Resources Conservation Service website.

Table 5. Monthly and total yield of seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars grown in Starkville, Mississippi in 2018.

Cultivar	Strawberry yield in 2018 (g per plant)[1]			
	April	May	June	Total
Allstar	5.0 c	52.0 cd	1.5 b	58.4 cd
Chandler	3.5 c	50.2 cde	1.9 b	55.7 cd
Darselect	18.6 ab	47.3 cde	0 b	65.8 cd
Earlyglow	17.9 ab	16.7 e	0.6 b	35.2 d
Evie 2	8.9 bc	170.6 a	56.8 a	236.3 a
Honeoye	24.4 a	16.6 e	0.5 b	41.5 d
Jewel	4.6 c	53.8 cd	0 b	58.5 cd
L'Amour	10.0 bc	25.3 de	0.5 b	35.8 d
San Andreas	23.4 a	61.1 c	5.3 b	89.8 c
Seascape	22.5 a	135.7 b	9.4 b	167.6 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001

[1] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

'Evie 2', or 'Seascape' producing berry size of 14.0 to 14.8 g per berry. 'Allstar', 'Earlyglow', 'Honeoye', and 'Jewel' produced comparable lowest berry sizes of 8.8 to 10.1 g per berry (Table 4).

'Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', 'L'Amour', and 'Seascape' had comparable soluble solids content ranging from 10.3 to 11.1 °Brix, with 'Evie 2' and 'San Andreas' producing fruit with the lowest soluble solids content of 8.4 and 8.7 °Brix, respectively. 'San Andreas', 'L'Amour', and 'Allstar' produced the firmest strawberry fruit of 1.89 to 2.17 N, higher than 'Chandler', 'Darselect', 'Earlyglow', or 'Evie 2' producing the least firm fruit of 1.32 to 1.53 N (Table 4).

Fruiting characteristics including time of fruit harvest, strawberry yield, berry size, number of fruit per plant, fruit soluble solids content and firmness were not affected by fertilizer type or irrigation frequency.

Water use and substrate moisture

Daily water use was significantly different among cultivars on June 19 but similar among cultivars on June 26 ranging from 0.57 to 0.78 L per day (Table 6). On June 19, eight cultivars had similar daily water use ranging from 0.54 L ('San Andreas') to 0.67 L ('Allstar'), with 'L'Amour' and 'Seascape' having the highest and lowest daily water use of 0.71 and 0.53 L per day, respectively. Substrate moisture at 6-cm depth was generally similar among cultivars ranging from 23.1% in 'Darselect' to 28.0% in 'Allstar'. Organic fertilizer resulted in increased substrate moisture by 10.6% compared to the conventional fertilizer (Table 2). Two irrigations per day also increased substrate moisture by 44.0% compared to one irrigation per day (Table 3).

Gas exchange

Net photosynthetic rate (Pn) was the highest in 'L'Amour' of 14.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$, similar to 'San Andreas' or 'Seascape', but higher than the other seven cultivars ranging from 9.7 to 11.2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Table 7). Stomatal conductance (g_s) was

Table 6. Daily water use measured on two dates and substrate moisture measured on 27 June 2018 of seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars grown in containers in Starkville, Mississippi.

Cultivar	Daily water use (L per day)[1]		Substrate moisture (%)
	19 June	26 June	27 June
Allstar	0.67 ab	0.78	28.0 a
Chandler	0.58 abc	0.73	25.0 ab
Darselect	0.60 abc	0.66	23.1 b
Earlyglow	0.58 abc	0.67	26.8 ab
Evie 2	0.53 bc	0.65	26.9 ab
Honeoye	0.65 abc	0.72	27.5 a
Jewel	0.57 abc	0.62	27.3 ab
L'Amour	0.71 a	0.72	23.8 ab
San Andreas	0.54 bc	0.61	25.5 ab
Seascape	0.53 c	0.57	25.0 ab
P-value	0.0004	0.074	0.0037

[1] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

Table 7. Gas exchange measurements including net photosynthetic rate (Pn), stomatal conductance (g_s), and transpiration rate (E) of seven June-bearing ('Allstar', 'Chandler', 'Darselect', 'Earlyglow', 'Honeoye', 'Jewel', and 'L'Amour') and three day-neutral ('Evie 2', 'San Andreas', and 'Seascape') strawberry cultivars grown in containers in Starkville, Mississippi.

Cultivar	Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)[1]	g_s ($mol \cdot m^{-2} \cdot s^{-1}$)	E ($mmol \cdot m^{-2} \cdot s^{-1}$)
Allstar	9.8 d	0.10 a	4.37 ab
Chandler	11.2 bcd	0.12 a	4.73 ab
Darselect	10.3 bcd	0.072 a	3.16 b
Earlyglow	10.7 bcd	0.11 a	5.57 ab
Evie 2	11.2 bcd	0.11 a	4.61 ab
Honeoye	9.7 d	0.089 a	3.74 b
Jewel	9.9 cd	0.083 a	3.98 b
L'Amour	14.4 a	0.14 a	5.53 ab
San Andreas	13.4 ab	0.14 a	6.65 a
Seascape	13.0 abc	0.12 a	5.09 ab
P-value	<0.0001	0.026	0.0006

[1] Different lower-case letters within a column suggest significant difference indicated by Tukey's HSD test at $P \leq 0.05$.

similar among all cultivars ranging from 0.072 $mol \cdot m^{-2} \cdot s^{-1}$ in 'Darselect' to 0.14 $mol \cdot m^{-2} \cdot s^{-1}$ in 'L'Amour' or 'San Andreas'. The conventional fertilizer increased Pn by 12.1% compared with the organic fertilizer (Table 2). 'San Andreas' had the highest transpiration rate (E) of 6.65 $mmol \cdot m^{-2} \cdot s^{-1}$, similar to 'Allstar', 'Chandler', 'Earlyglow', 'Evie 2', 'L'Amour', and 'Seascape', but higher than 'Darselect', 'Honeoye', or 'Jewel' with E ranging from 3.16 $mmol \cdot m^{-2} \cdot s^{-1}$ to 3.98 $mmol \cdot m^{-2} \cdot s^{-1}$. Gas exchange measurements including Pn, g_s, and E were not affected by irrigation frequency.

DISCUSSION

The ten cultivars tested in this study generally showed satisfactory vegetative growth in terms of PGI, leaf SPAD, shoot and root dry weights, with five cultivars 'Allstar', 'Evie 2', 'Honeoye', 'L'Amour', and 'Seascape' having visual scores of 3 or above. The earliest ripening cultivars in this study were June-bearing 'Honeoye' and 'Earlyglow', producing ripe fruit 49.4 and 51.3 DAT, with cumulative GDDs of 536 and 556, respectively. The June-bearing 'Chandler' were the latest ripening cultivar, producing ripe fruit 65.7 DAT, with 783 GDDs.

Strawberry harvest season in midsouthern states including Arkansas, Louisiana, Mississippi, Oklahoma, and Texas occurs from February to late May or early June, with peak production typically in April to May[3]. The first fruit harvest was in late April in this study, consistent with local strawberry harvest timing in an open field production system[30]. In this current study, the two earliest ripening June-bearing cultivars 'Earlyglow' and 'Honeoye' produced peak yield in April, all other tested cultivars produced peak yield in May. They may potentially be used in fall planting or in protected culture like high tunnels for off-season strawberry production.

The ten cultivars generally produced lower yield and smaller fruit than reported ranges[13,31,32]. A possible reason might be the time of transplanting in spring using bare root liners. Local open field or high tunnel strawberry production systems in Mississippi typically use fall planting with plugs, which allows plants to establish vegetatively before flower and fruit production in spring[10]. Fall planted strawberry cultivars required 1,249.1 to 1,374.3 GDDs from transplanting to first ripe fruit in a high tunnel production system in the same location (unpublished data), and resulted in higher yield than spring planting. However, containerized strawberry plants can be marketed as hanging baskets and serve as ornamental plants, where overall visual quality can be valued as much as yield. The two day-neutral cultivars 'Evie 2' and 'Seascape' produced the highest and second highest total yield of all tested cultivars, higher than all June-bearing cultivars. 'Evie 2' also produced yield of 56.8 g per plant in June when all June-bearing cultivars produce less than 2 g berry per plant, showing potential for season extension into months with warmer temperatures. Local daily average air temperatures during the first two weeks of June were between 22.2 and 29.2 °C, with daily maximum air temperature ranging from 30 to 33.9 °C. High temperatures are the major limiting factor of using day-neutral cultivars to extend harvest season in Mississippi, requiring heat tolerant cultivars.

Compared with the organic fertilizer, the conventional fertilizer increased plant growth index, leaf SPAD, visual score, yield in May, daily water use, and net photosynthetic rate regardless of strawberry cultivars in this current study. This agreed with our previous study using the same two fertilizer types but in container grown southern highbush blueberry (*Vaccinium corymbosum* L.) cultivars, where the conventional fertilizer increased blueberry yield in 2016[33]. The conventional fertilizer also tended to advance blueberry ripening for approximately one week compared to the organic fertilizer[33], whereas the same two fertilizer types resulted in similar strawberry harvest date in this study. Nutrients in organic fertilizers are in organic forms and must go through mineralization for nutrients to be available to plant uptake[34,35], resulting in a slow release of nutrient. Gaskell et al.[36] reported it to be unpredictable to synchronize nitrogen (N) demand for establishing strawberry plants with release of N from various organic nutrient sources compared to conventional N sources. Large quantity and continuous application of organic fertilizers are required to achieve certain fertility and soil organic matter level for optimal yield in organic farming[37,38]. The two fertilizer types are applied in proportion to provide the same total amount of nutrients. Their effects on plant growth and fruit production are subject to the rate of nutrient release and the total amount of fertilizer available to plants. Their different effects on plant growth and crop yield may become more significant over time. Therefore, organic fertilization in container grown strawberry plant may require supplement of liquid fertilizer for its fast-acting effects.

The effect of irrigation frequency varied among plant species with different water requirements or soilless growing substrates with varying physical and chemical properties[26,27,39]. Increasing irrigation frequency can improve growth and plant nutrient uptake by continually resupplying nutrient solution to the depletion zone around the roots. Silber et al.[40] found that higher irrigation frequency led to more vegetative growth and higher concentrations of less mobile nutrients in iceberg lettuce (*Lactuca sativa* L.). *Rhododendron* species with low water requirement benefited from one irrigation per day over two irrigations: Encore azalea 'Chiffon' produced greater PGI, root biomass, and improved mineral nutrient uptake in roots under one irrigation per day[26]. Biomass production of *Hydrangea macrophylla* 'Merritt's Supreme' was not affected by irrigation frequency[27]. In this current study, two irrigations per day increased substrate moisture, which may affect nutrient availability in the substrate and merits further investigation. Two irrigations per day also increased plant shoot dry weight when fertilized with the conventional fertilizer, but did not affect plant size, visual quality, gas exchange, strawberry yield, or fruit quality of the ten tested strawberry cultivars. This was in agreement with Silber et al.[40] that higher irrigation frequency leads to increased vegetative growth, which can potentially be used in strawberry plant propagation to increase the number of runners per plant.

Soilless culture of strawberries is used in limited areas due to high production cost and high demands for management expertise. It is mostly used in greenhouses or high tunnels, where off-season strawberry production and high market demand can justify the production cost[15]. Planting strawberry plants in containers alleviates extensive soil management and the need for soil fumigation, and may potentially increase production sustainability[41]. This study provides reference in fertilization and irrigation management in containers with soilless substrate. There might be potential of using container-grown strawberry plants in nursery production for propagation purposes or to be used in small-scale production for certain niche markets, which warrants further investigation.

CONCLUSIONS

Of the ten tested cultivars, the two day-neutral cultivars 'Evie 2' and 'Seascape' produced higher total and late-season yields than any other June-bearing cultivar, with 'Earlyglow' and 'Honeoye' being the most early ripening cultivar. The conventional fertilizer increased plant vegetative growth, yield in May, and net photosynthesis of strawberry plants compared to the organic fertilizer at comparable rates, but did not affect time of fruit production or fruit quality. Organically fertilized strawberry plants grown in soilless substrate would likely require a combination of granular and liquid fertilizer sources to satisfy plant nutrient requirements effectively. More frequent irrigation in combination with the conventional fertilizer was beneficial for plant vegetative growth with improved shoot dry weight

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Conflict of interest

Guihong Bi and Tonyin Li are the Editorial Board members of journal *Technology in Horticulture*. They were blinded from reviewing or making decisions on the manuscript. The article was subject to the journal's standard procedures, with peer-review handled independently of these Editorial Board members and their research groups.

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REFERENCES

1. Food and Agriculture Organization of the United Nations (FAO). 2018. *Crops and Livestock Product*. www.fao.org/faostat/en/#data/QCL (Accessed on 12 December 2022)
2. Agricultural Marketing Resource Center (AgMRC). 2021. *Strawberries*. www.agmrc.org/commodities-products/fruits/strawberries (Accessed on 12 December 2022)
3. Samtani JB, Rom CR, Friedrich H, Fennimore SA, Finn CE, et al. 2019. The status and future of the strawberry industry in the United States. *HortTechnology* 29:11−14
4. Giampieri F, Tulipani S, Alvarez-Suarez JM, Quiles JL, Mezzetti B, et al. 2012. The strawberry: Composition, nutritional quality, and impact on human health. *Nutrition* 28:9−19
5. Shahbandeh M. 2019. Statistica: *U. S. per capita consumption of fresh strawberries 2000−2018*. www.statista.com/statistics/823192/us-per-capita-consumption-of-fresh-strawberries/ (Accessed on 11 December 2022)
6. U. S. Department of Agriculture (USDA). 2014. *Strawberry consumption continues to grow*. www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=77884 (Accessed on 12 December 2022)
7. Giampieri F, Alvarez-Suarez JM, Battino M. 2014. Strawberry and human health: Effects beyond antioxidant activity. *Journal of Agricultural and Food Chemistry* 62:3867−76
8. Miao L, Zhang Y, Yang X, Xiao J, Zhang H, et al. 2017. Fruit quality, antioxidant capacity, related genes, and enzyme activities in strawberry (*Fragaria* × *ananassa*) grown under colored plastic films. *HortScience* 52:1241−50
9. Hancock JF. 2020. Structural and Developmental Physiology. In *Crop Production Science in Horticulture*: *Strawberries*. 2nd edition. Boston: CABI. pp. 116−17.
10. Husaini AM, Neri D. 2016. *Strawberry: Growth, Development and Diseases*. Boston: CABI. pp. 99−118. https://doi.org/10.1079/9781780646633.0099
11. Gu S, Guan W, Beck JE. 2017. Strawberry cultivar evaluation under high-tunnel and organic management in North Carolina. *HortTechnology* 27:84−92

12. Rowley D, Black BL, Drost D, Feuz D. 2011. Late-season strawberry production using day-neutral cultivars in high-elevation high tunnels. *HortScience* 46:1480−85
13. Ballington JR, Poling B, Olive K. 2008. Day-neutral strawberry production for season extension in the Midsouth. *HortScience* 43:1098−86
14. U. S. Department of Agriculture (USDA). 2019. *Noncitrus fruits and nuts 2018 summary*. https://downloads.usda.library.cornell.edu/usda-esmis/files/zs25x846c/0z7096330/7s75dp373/ncit0619.pdf (Accessed on 11 December 2022)
15. Lieten P. 2013. Advances in strawberry substrate culture during the last twenty years in the Netherlands and Belgium. *International Journal of Fruit Science* 13:84−90
16. Olsson ME, Andersson CS, Oredsson S, Berglund RH, Gustavsson KE. 2006. Antioxidant levels and inhibition of cancer cell proliferation in vitro by extracts from organically and conventionally cultivated strawberries. *Journal of Agricultural and Food Chemistry* 54:1248−55
17. Reganold JP, Andrews PK, Reeve JR, Carpenter-Boggs L, Schadt CW, et al. 2010. Fruit and soil quality of organic and conventional strawberry agroecosystems. *PLoS One* 5:e12346
18. Strik BC, Vance A, Bryla DR. 2016. Organic production systems research in blueberry and blackberry- a review of industry-driven studies. *Acta Horticulturae* 1117:139−48
19. Hargreaves JC, Adl MS, Warman PR, Rupasinghe HVP. 2008. he effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. *Journal of the Science of Food and Agriculture* 88:2669−75
20. Häkkinen SH, Törrönen AR. 2000. Content of flavonols and selected phenolic acids in strawberries and *Vaccinium* species: influence of cultivar, cultivation site and technique. *Food Research International* 33:517−24
21. Giné Bordonaba J, Terry LA. 2010. Manipulating the taste-related composition of strawberry fruits (*Fragaria* × *ananassa*) from different cultivars using deficit irrigation. *Food Chemistry* 122:1020−26
22. Fare DC, Gilliam CH, Keever GJ, Olive JW. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. *HortScience* 29:1514−17
23. Scagel CF, Bi G, Fuchigami LH, Regan RP. 2011. Effects of irrigation frequency and nitrogen fertilizer rate on water stress, nitrogen uptake, and plant growth of container-grown rhododendron. *HortScience* 46:1569−603
24. Scagel CF, Bi G, Fuchigami LH, Regan RP. 2012. Irrigation frequency alters nutrient uptake in container-grown Rhododendron plants grown with different rates of nitrogen. *HortScience* 47:189−197
25. Warren SL, Bilderback TE. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. *Journal of Environmental Horticulture* 20:184−88
26. Li T, Bi G, Harkess RL, Denny GC, Blythe EK, et al. 2018. Nitrogen rate, irrigation frequency, and container type affect plant growth and nutrient uptake of Encore azalea 'Chiffon'. *HortScience* 53:560−66
27. Li T, Bi G, Harkess RL, Denny GC, Scagel C. 2019. Nitrogen fertilization and irrigation frequency affect hydrangea growth and nutrient uptake in two container types. *HortScience* 54:167−74
28. U. S. Department of Agriculture, National Resources Conservation Service (USDA-NRCS). 2020. *Report Generator 2.0*. https://wcc.sc.egov.usda.gov/reportGenerator/ (Accessed on 11 December 2022)
29. Krüger E, Josuttis M, Nestby R, Toldam-Andersen TB, Carlen C, et al. 2012. Influence of growing conditions at different latitudes of Europe on strawberry growth performance, yield and quality. *Journal of Berry Research* 2:143−57
30. Lewis KC. 2014. Local strawberries are finally in season. *Crop Report*. Mississippi State University Extension, U.S. http://extension.msstate.edu/news/crop-report/2014/local-strawberries-are-finally-season (Accessed on 11 December 2022)
31. Anderson HC, Rogers MA, Hoover EE. 2019. Low tunnel covering and microclimate, fruit yield, and quality in an organic strawberry production system. *HortTechnology* 29:590−598
32. Yao S, Guldan S, Flynn R, Ochoa C. 2015. Challenges of strawberry production in high-pH soil at high elevation in the southwestern United States. *HortScience* 50:254−258
33. Li T, Bi G. 2019. Container production of Southern highbush blueberries using high tunnels. *HortScience* 54:267−274
34. Lee J. 2010. Effect of application methods of organic fertilizer on growth, soil chemical properties and microbial densities in organic bulb onion production. *Scientia Horticulturae* 124:299−305
35. Roussos PA, Gasparatos D, Kechrologou K, Katsenos P, Bouchagier P. 2017. Impact of organic fertilization on soil properties, plant physiology and yield in two newly planted olive (*Olea europaea* L.) cultivars under mediterranean conditions. *Scientia Horticulturae* 220:11−19
36. Gaskell M, Bolda MP, Muramoto J, Daugovish O. 2009. Strawberry nitrogen fertilization from organic nutrient sources. *Strawberry nitrogen fertilization from organic nutrient sources* 842:385−88
37. Chang EH, Chung RS, Tsai YH. 2007. Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. *Soil Science and Plant Nutrition* 53:132−40
38. Li ZP, Zhang TL, Han FX, Felix-Henningsen P. 2005. Changes in soil C and N contents and mineralization across a cultivation chronosequence of paddy fields in subtropical China. *Pedosphere* 15:554−62
39. Li T, Bi G, Harkess RL, Blythe EK. 2019. Mineral nutrient uptake of Encore azalea 'Chiffon' affected by nitrogen, container, and irrigation frequency. *HortScience* 54:2240−48
40. Silber A, Xu G, Levkovitch I, Soriano S, Bilu A, et al. 2003. High fertigation frequency: the effects on uptake of nutrients, water and plant growth. *Plant and Soil* 253:467−77
41. Hochmuth G, Cantliffe D, Chandler C, Stanley C, Bish E, et al. 2006. Fruiting responses and economics of containerized and bare-root strawberry transplants established with different irrigation methods. *HortTechnology* 16:205−10