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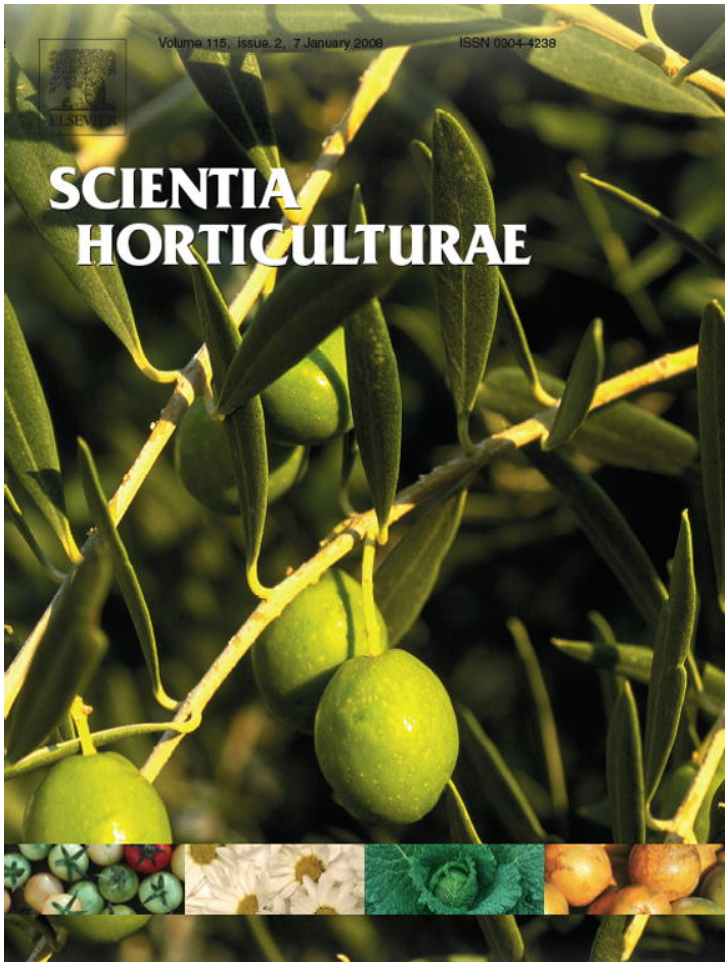

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Relationship of plant density to fruit yield of 'Sweet Charlie' strawberry grown in a pine bark soilless medium in a high-roof passively ventilated greenhouse

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Abstract

Eight plant densities (8.8, 9.5, 10.4, 11.4, 17.6, 19.1, 20.8, and 22.9 plants m^{-2}) in 2001–2002 and 12 plant densities (8.8, 9.5, 10.4, 11.4, 12.7, 14.3, 17.6, 19.1, 20.8, 22.9, 25.4, and 28.6 plants m^{-2}) in 2002–2003 were evaluated on growth and fruit yield of 'Sweet Charlie' strawberry (*Fragaria* × *ananassa* Duch.) grown in a passively ventilated greenhouse. Plant densities were derived by varying within-row plant spacings (PS) (17.5 and 35 cm) with between row spacings (RS) (40, 45, 50, 55, 60 and 65 cm). Plants were grown in Polygal® 'Hanging Bed-Pack' troughs filled with pine bark and fertigated with a complete nutrient solution. In 2001–2002, total marketable yield (g $plant^{-1}$) or (no. fruit $plant^{-1}$) were not influenced by RS. In 2002–2003, total marketable yield (g $plant^{-1}$) or (no. fruit $plant^{-1}$) were reduced at 40 cm RS, the narrowest RS used in the experiment. Early (November through January) and total marketable yields (g $plant^{-1}$), crown diameter, and leaf number of plants grown at 35 cm PS were significantly greater than those of plants grown at 17.5 cm RS in both experiments. Total and early marketable yield (kg m^{-2}) increased linearly as plant density (plants m^{-2}) increased in both experiments. Winter strawberry production in a greenhouse using high plant densities and soilless substrates may be a viable alternative to open-field with methyl bromide fumigation production system.

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Keywords: *Fragaria* × *ananassa* Duch.; Row spacing; Plant spacing; Plant population; Biological control

1. Introduction

In Florida, strawberries (*Fragaria* × *ananassa* Duch.) are grown in the field on 70 cm wide raised beds that are spaced 1.2–1.5 m apart. Beds are planted in double rows of plants that are spaced 30–35 cm apart and 30–40 cm between plants within a row. Plant populations range from 39,520 to 54,340 plants ha^{-1} (3.8–5.3 plants m^{-2}) (Legard et al., 2003) and are similar to those used by strawberry growers in North Carolina. In California, plant populations are slightly greater than those used in Florida and North Carolina, and range between 50,635 and 57,000 plants ha^{-1}. At a bed spacing of 1.4 m center-to-center, nearly 50% of the area per ha is alleyways.

In protected strawberry culture, plants can be grown in polyethylene bags, plastic or polystyrene pots, and polyvinyl chloride (PVC) troughs or pipes of various shapes and sizes. Polyethylene bags used in horizontal systems are approximately 100 cm long, 10 cm wide, 8 cm high, and typically accommodate 6–10 strawberry plants (Paranjpe et al., 2003). Polyethylene bags used in vertical systems may be up to 2 m long, and can accommodate up to 36 plants per bag (Özeker et al., 1999). Radajewska and Aumiller (1997) reported that 'Selva' strawberries grown in horizontally arranged peat bags at 12.5 plants m^{-2} (5 plants bag^{-1}) produced marketable yields of up to 2.07 kg m^{-2}. Dijkstra et al. (1993) reported that 'Elsanta' strawberries grown in horizontal peat bags linearly increased yield per m^2 (1.94–2.51 kg m^{-2}) as plant density

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increased from 4.3 to 8.5 plants m^{-2} (2, 3, or 4 plants bag^{-1}); however, yield per plant decreased as plant density increased. Özeker et al. (1999) reported that 'Tioga' and 'Cruz' strawberry plants grown at a density of 37.5 plants m^{-2} in 2 m long vertically arranged bags produced marketable yields of up to 2.7 kg m^{-2}. Dijkstra et al. (1993) also reported that strawberry plants grown in 6 L plastic pots at plant densities of 4.3, 6.4 and 8.5 plants m^{-2} (2, 3, or 4 plants pot^{-1}) did not increase yields per m^2 with increasing plant density due to compensatory reductions in yield per plant as plant density increased. Takeda (2000) reported that 'Chandler' and 'Camarosa' strawberry plants grown in 7.6 L round pots or 2.8 L square pots arranged on a bench at a plant density of 17.2 plants m^{-2} (4 or 5 plants pot^{-1}) produced marketable yields of 14.3 kg m^{-2} (500 g $plant^{-1}$) over a 7-month growing period.

PVC troughs are used in liquid based as well as aggregate based strawberry production systems. Generally, wider troughs (25–30 cm wide) are used in liquid based (NFT) systems, whereas the narrower (10–12 cm wide) troughs such as the Polygal® Hanging Bed-Pack troughs are commonly used in aggregate based strawberry culture. PVC pipes are commonly used in rockwool-based NFT culture; however, they can also be used in substrate-based culture (Durner, 1999). Sarooshi and Cresswell (1994) reported that marketable yield of 'Torrey' strawberry plants grown in a rockwool-based NFT system increased linearly from 1.66 to 2.34 kg m^{-2}, but yield per plant declined from 310 to 252 g $plant^{-1}$ as plant density increased from 5.3 to 9.3 plants m^{-2}. Van Looy and Aerts (1982) reported that strawberries grown in horizontal troughs arranged in multiple tiers on an A-frame were adversely affected by the uneven distribution of light. Plants at the lower A-frame had small and malformed fruit, increased fruit rot, and inconsistencies in fruit color. Durner (1999) reported that 'Sweet Charlie' strawberry plants grown in a vertical PVC column filled with perlite at 32 plants m^{-2} had total yields of 11.8 kg m^{-2} but yield per plant decreased by 40 g with every 30 cm decrease in the height of the vertical column, perhaps due to reduced light intensity in the lower sections of the growing system.

Information on planting arrangement and densities of strawberry grown in Polygal troughs under greenhouse conditions is minimal. The objective of this study was to evaluate the effect of plant densities on plant growth and fruit yield of strawberries grown in Polygal troughs hung horizontally in a high-roof passively ventilated greenhouse.

2. Materials and methods

Plant densities were evaluated in the 2001–2002 season (10 October 2001 to 22 March 2002) and the 2002–2003 season (1 October 2002 to 26 March 2003), respectively. The experiments were conducted in two bays (8 m wide × 32 m long × 9 m high) of a seven-bay gutter-connected passively ventilated greenhouse (Top Greenhouses Ltd., Rosh Ha'ayin, Israel) located at the Univ. FL. Horticulture Unit, Gainesville, FL.

Propagation procedures of 'Sweet Charlie' strawberry plants for use in these experiments were described by Paranjpe (2004). On 16 September 2001 and 2002, 105-day old plug transplants were transferred to a walk-in growth chamber and subjected to a 14-day conditioning treatment (25/15 °C day/night temperatures, 9 h photoperiod) (Bish et al., 1997). During conditioning, plugs were overhead irrigated as needed. Light (410 μmol m^{-2} s^{-1}) was provided with a combination of fluorescent and incandescent bulbs.

In 2001–2002, 8 densities (8.8, 9.5, 10.4, 11.4, 17.6, 19.1, 20.8, and 22.9 plants m^{-2}) and in 2002–2003, 12 densities (8.8, 9.5, 10.4, 11.4, 12.7, 14.3, 17.6, 19.1, 20.8, 22.9, 25.4, and 28.6 plants m^{-2}) were evaluated. Plant densities were derived by altering two plant spacings (PS) (17.5 and 35 cm plant-to-plant) with four (50, 55, 60, and 65 cm apart center-to-center; 2001–2002) or six (40, 45, 50, 55, 60, and 65 cm apart center-to-center; 2002–2003) row spacings (RS). Each row (trough) consisted of two lines of plants (Fig. 1). During both seasons, Polygal® 'Hanging Bed-Pack' troughs (10 cm bottom width × 12 cm wall height, 5 cm diameter planting holes spaced 17.5 cm apart, Polygal® Industries, Ramat Hashofet, Israel) were used as growing containers. Troughs were suspended 1.8 m above ground level. Steel wire (2 mm gauge) was used for suspending the troughs to the cross-members of the greenhouse structure.

A split-plot experimental design was used with RS as the main plot and PS as the split-plot with each RS × PS combination replicated four times. Each plot consisted of 1 m long sections of the Polygal® 'Hanging Bed-Pack' troughs. Plots were separated within the rows by a 1 m long guard section (Fig. 2). Treatments with 17.5 cm PS consisted of 11 plants per plot, and treatments with 35 cm PS consisted of six plants per plot. Arrangement of rows for RS treatments is illustrated in Fig. 3.

Polygal® 'Hanging Bed-Pack' troughs were filled with pine bark (6.5 cm^2 sieved, Elixon Wood Products Inc., Starke, FL) and irrigated manually until thoroughly wet. On 2 October 2001 and 2002, conditioned plug transplants of 'Sweet Charlie' were transplanted. Plants were fertigated 8–10 times daily with a drip

Fig. 1. 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs in six row spacings (RS) and two plant spacings (PS). Fall 2002–2003, UF Protected Ag Project, Gainesville, FL.

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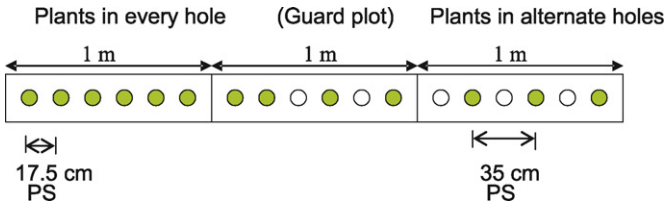

Fig. 2. Arrangement of plants grown at 17.5 cm or 35 cm plant spacing (PS).

tape (0.38 mm thickness, 5 cm emitter spacing, 0.9 L h^{-1} discharge, Chapin Watermatics Inc., Watertown, NY). Each fertigation event was 2 min, with 90-min intervals, and each plant received approximately 150 mL of nutrient solution per day. An electronic timer (Superior Controls Co., Valencia, CA) was used to control the irrigation events. Two days after transplanting, plants received a complete nutrient solution during each irrigation. The concentration of nitrogen (N) was maintained at 60 mg L^{-1} until the end of October, and thereafter at 70 mg L^{-1} until the end of the season. The concentrations of the remaining elements (P 50, K 85, Ca 100, Mg 40, S 56, Fe 2.8, B 0.6, Mn 0.4, Zn 0.2, Cu 0.1, Mo 0.03 mg L^{-1}) were the same throughout the season. All treatments were provided with the same concentration and volume of nutrient solution throughout the growing season. Concentrated fertilizer was injected from two stock tanks with two injectors (DI 16-11 GPM, Dosatron Inc., Clearwater, FL) assembled in series.

One class-A beehive (Koppert Biological Systems Inc., Romulus, MI) containing 75–100 bumblebees (*Bombus terrestris*) was introduced into the experiment 15 days after transplanting. The beehive was placed on a stand with a roof to protect it from direct sunlight. Bees were removed from the greenhouse before applying chemical pesticides, and were not returned until the recommended period for re-introduction of bees had elapsed (Koppert Biological Systems, 2004). Water was provided to the bees in a dish with a moist sponge that was placed adjacent to the beehive.

During each seasons, two-spotted spider mites (*Tetranichus urticae* Koch), cotton aphids (*Aphis gossypii* Glover), and western flower thrips (*Frankliniella* spp.) were the most common arthropod pests. Powdery mildew (*Sphaerotheca macularis*) appeared in mid-November and was present until the end of the experiment. The incidence of grey mold (*Botrytis cinerea*) was negligible and was noticed occasionally on overripe fruit.

During the 2001–2002 season, abamectin (Agri-Mek®), dicofol (Kelthane®), fenbutatin-oxide (Vendex®), and hexathiazox (Savey®) were used to control two-spotted spider mites, and *Beauvaria bassiana* (BotaniGard®) was used to control aphids. Myclobutanil (Nova®), azoxystrobin (Quadris®), and *Ampelomyces quisqualis* (AQ-10®) fungicides were used to control powdery mildew. Since the level of control achieved with chemical pesticides was not satisfactory, augmentative releases of beneficial arthropods, such as *Aphidius colemani* parasitic wasps (IPM Laboratories, Locke, NY; Koppert Biological Systems Inc., Romulus, MI) and *Neoseiulus californicus* predatory mites (Biotactics Inc., Perris, CA), were initiated towards the end of the season.

During the 2002–2003 season, no chemical pesticides were used. *N. californicus* predatory mites were released at the rate of approximately 40 mites m^{-2} per month, and *A. colemani* parasitic wasps were released bi-weekly at a rate of approximately 10 wasps m^{-2} to control aphids. Additionally, *Coleomegilla maculata* larvae (approximately 5 larvae m^{-2} per week) and *Geocoris punctipes* nymphs (approximately 5 nymphs m^{-2} per week) were released to control aphids, and *Orius insidiosus* nymphs (approximately 2 nymphs m^{-2} per week) were used to control thrips.

Mature fruit (i.e., 75–100% color) were harvested from each plot at 4–5 days intervals. For each plot, marketable fruit (>10 g, not deformed or diseased) were counted and weighted. Mean fruit weight (g $fruit^{-1}$) was calculated as: marketable fruit weight (g)/marketable fruit number. For data analysis, the harvests were grouped into early season (November through end of January) and total season (November through end of March).

Crown size (mean of two measurements: one at the widest section of the crown, and the other at the narrowest section of the crown), number of leaves, and fruit number and weight were recorded separately from three plants located in the center of each plot. Crown size and leaf number were measured on 2 February 2001 and 5 February 2002.

Marketable fruit yield, individual fruit weight, crown size, and leaf number were subjected to analysis of variance (ANOVA). Significant main effect of RS or RS within each PS (for variables that had a significant RS × PS interaction) were partitioned into linear (L), quadratic (Q), or cubic (C) orthogonal contrasts. Main effect means of PS were separated by an F-test. Pearson's correlations (r) were calculated between the crown size and leaf number with marketable fruit yield. Linear regression analyses were conducted using plant densities as the independent variable and either earlier or total marketable yield as the dependent variable. All statistical analyses were conducted using the Statistical Analysis System (SAS) software (SAS Institute Inc., 2001).

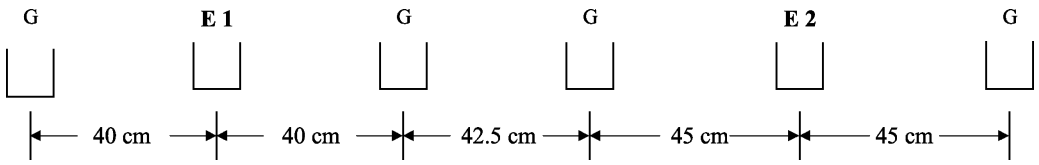

Fig. 3. Arrangement of treatments with different row spacings (RS). *Note*: Each experimental row (e.g., E1 and E2) is flanked by a guard row (G) on either side. Therefore, E1 corresponds to the treatment with 40 cm row spacing, and E2 corresponds to the treatment with 45 cm row spacing. The two guard rows that separate two different treatments are spaced at a distance (42.5 cm) that is equal to the average of the spacing of the two adjoining treatments. Treatments with 40 and 45 cm RS are illustrated. The remaining treatments (50, 55, 60, and 65 cm RS) were arranged in a similar pattern.

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Table 1
Row spacing (RS) and plant spacing (PS) effects on early marketable yield, 2001–2002 (28 November 2001 to 28 January 2002), of 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs

Treatments	Marketable yield[a]							
	PS (No. fruit plant^{-1})		PS (No. fruit m^{-2})		g plant^{-1}	PS (kg m^{-2})		g fruit^{-1}
	17.5	35	17.5	35		17.5	35	
Row spacing (RS) (cm)								
50	10.0	9.5	221	114	195	4.5	2.2	19.9
55	10.6	9.0	211	98	202	4.4	2.2	20.7
60	10.4	8.9	191	89	197	3.9	1.8	20.4
65	9.9	9.7	166	90	199	3.4	1.8	20.4
Significance	Q*	Q*	L**	L**	NS	L**	L**	Q*
Plant spacing (PS) (cm)								
17.5					201			19.7
35.0					196			21.0
Significance					NS			**
RS × PS	*		**		NS	**		NS

Significant F-test at $*P < 0.05$ and $**P < 0.01$, and non-significant (NS), respectively. L, Q: linear or quadratic response, respectively.
[a] Includes fruit that were >10 g, and are not deformed or diseased.

3. Results

3.1. Early marketable yields 2001–2002

Row spacing significantly interacted with PS for marketable fruit number per plant, fruit number per m^2, and fruit weight per m^2 (Table 1). At both PS, fruit number per plant responded quadratically to increasing RS, while fruit number and weight per m^2 decreased linearly to increasing RS. Row spacing did not influence marketable fruit yield (g) per plant, crown diameter, or leaf number (Table 2). However, as RS increased, mean fruit weight increased quadratically. Shading effects appeared to be negligible, even at a RS of 50 cm, therefore no threshold occurred for optimum RS. Therefore, in 2002–2003, two narrower row spacings (40 and 45 cm) treatments were added to the four RS treatments used during 2001–2002.

Plant spacing did not influence marketable yield (g) per plant. This is somewhat surprising considering that the volume of media available for root growth at 17.5 cm PS (1.1 L plant^{-1}) was nearly half of that available at 35 cm PS (2.0 L plant^{-1}). Plants grown at 17.5 cm PS had smaller crowns (37 mm versus 41 mm) and fewer leaves (19.6 versus 21.1) than plants grown at 35 cm PS (Table 2). Crown diameter and leaf number were significantly correlated with marketable yield ($r = 0.55$** and $r = 0.66$**, respectively). The wider PS resulted in heavier fruit (21 g versus 19.7 g) (Table 1). As plant density increased early marketable yield per unit area (m^2) increased linearly ($R^2 = 0.98$) (Fig. 4).

Table 2
Row spacing (RS) and plant spacing (PS) effect on crown diameter and number of leaves per plant of 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs[a]

Treatments	Crown diameter (mm)		Leaves (No. of plant^{-1})	
	2001–2002	2002–2003	2001–2002	2002–2003
Row spacing (RS) (cm)				
40		31.8		16.4
45		36.7		17.5
50	37.9	38.8	20.2	18.6
55	39.4	37.6	20.0	17.7
60	39.0	39.6	20.8	18.4
65	39.9	37.8	20.4	18.2
Significance	NS	L**	NS	NS
Plant spacing (PS) (cm)				
17.5	37.1	35.1	19.6	17.1
35.0	41.0	39.0	21.1	18.5
Significance	**	**	**	**
RS × PS	NS	NS	NS	NS

Significant F-test at $**P < 0.01$ and non-significant (NS), respectively. L: linear response.
[a] Means derived by averaging the data obtained from three sample plants located in the center of each plot.

3.2. Early marketable yields 2002–2003

Row spacing did not interact with PS for any measured variable (Table 3). Row spacing did not influence fruit number,

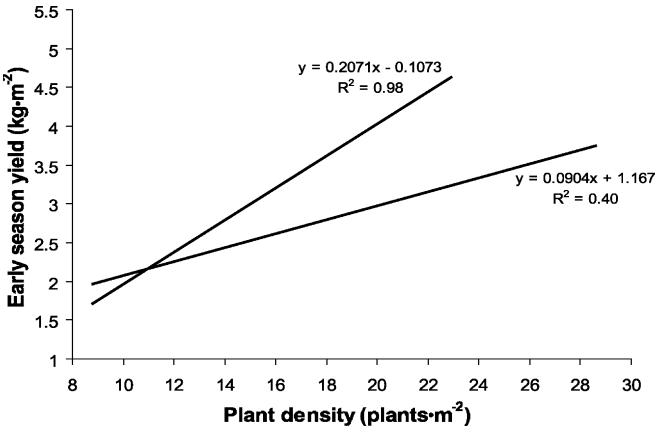

Fig. 4. Linear regression between plant density and early season marketable yield during 2001–2002 and 2002–2003 seasons for 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs with pine bark as soilless substrate.

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Table 3
Row spacing (RS) and plant spacing (PS) effect on early marketable yield, 2002–2003 (25 November 2002 to 31 January 2003), of 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs

Treatments	Marketable yield[a]				
	No. fruit plant^{-1}	No. fruit m^{-2}	g plant^{-1}	kg m^{-2}	g fruit^{-1}
Row spacing (RS)(cm)					
40	8.1	161	133	2.7	16.4
45	9.2	166	173	3.1	18.7
50	10.7	178	188	3.1	17.5
55	10.9	162	195	2.9	17.9
60	9.1	123	166	2.2	18.2
65	9.1	115	164	2.1	18.2
Significance	NS	L**	NS	NS	NS
Plant spacing (PS)(cm)					
17.5	8.3	177	145	3.1	17.5
35.0	10.7	125	194	2.3	18.1
Significance	**	**	**	**	NS
RS × PS	NS	NS	NS	NS	NS

Significant F-test at $^{**}P < 0.01$ and non-significant (NS), respectively.
[a] Includes fruit that were >10 g, and are not deformed or diseased.

fruit weight per plant, or fruit weight per m^2, despite the two additional RS (40 and 45 cm) that were included in the 2002–2003 trial. However, crown diameter decreased as RS decreased (Table 2). Competition for light among plants grown at 40 cm RS was evident through smaller plant size. However, plant canopies during the early part of the season were not sufficiently large enough to create a shading effect; consequently marketable fruit yields were not adversely affected.

Plants grown at 17.5 cm PS produced significantly less marketable fruit number per plant (8.3 versus 10.7) and lower fruit weight per plant (145 g versus 194 g) than plants grown at 35 cm PS, but the higher plant density at 17.5 cm PS more than compensated for this lower yield per plant (Table 3). Plants at the 17.5 cm PS produced 3.1 kg of marketable fruit per m^2, as compared to 2.3 kg of fruit per m^2 for plants at the 35 cm PS. Plants grown at 35 cm PS had larger crowns and more leaves than plants grown at 17.5 cm PS (Table 2), which may have attributed to the higher fruit weight per plant.

As plant density increased, marketable yield per unit area (kg m^2) increased linearly ($R^2 = 0.40$) (Fig. 4). The low R^2 may have been associated with the increased plant-to-plant variation attributed to differences in pest control between the 2001–2002 and 2002–2003 seasons. Since biological agents were used exclusively for pest control in 2002–2003, pest populations and subsequent plant injury in 2002–2003 may not have been as uniformly distributed among the plots as they were in 2001–2002.

3.3. Total marketable yields 2001–2002

Row spacing significantly interacted with PS for marketable number of fruit per m^2 and fruit weight per m^2 (Table 4). At 17.5 cm PS, fruit number per m^2 decreased linearly with

Table 4
Row spacing (RS) and plant spacing (PS) effects on total marketable yield, 2001–2002 (28 November 2001 to 22 March 2002), of 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs

Treatments	Marketable yield[a]						
	No. fruit plant^{-1}	PS (No. fruit m^{-2})		g plant^{-1}	PS (kg m^{-2})		g fruit^{-1}
		17.5	35		17.5	35	
Row spacing (RS) (cm)							
50	21.5	465	261	414	9.3	4.8	19.3
55	21.7	432	237	420	8.6	4.5	19.4
60	21.8	400	217	420	8.0	4.0	19.3
65	21.7	358	205	421	7.3	3.8	19.4
Significance	NS	L*	NS	NS	L**	L**	NS
Plant spacing (PS) (cm)							
17.5	21.4			412			19.2
35.0	21.9			426			19.5
Significance	*			**			NS
RS × PS	NS	*		NS	**		NS

Significant F-test at $^{*}P < 0.05$ and $^{**}P < 0.01$, and non-significant (NS), respectively. L: linear response.
[a] Includes fruit that were >10 g, and are not deformed or diseased.

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Table 5
Row spacing (RS) and plant spacing (PS) effect on total marketable yield, 2002–2003 (25 November 2002 to 23 March 2003), of 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs

Treatments	Marketable yield[a]				
	No. fruit plant^{-1}	No. fruit m^{-2}	g plant^{-1}	kg m^{-2}	g fruit^{-1}
Row spacing (RS) (cm)					
40	19.4	399	331	6.9	17.2
45	25.1	452	456	8.2	18.2
50	25.4	405	461	7.3	18.1
55	27.5	415	512	7.7	18.7
60	26.4	354	510	6.9	19.3
65	27.4	335	500	6.1	18.1
Significance	L**	L**	L**	C*	L**
Plant spacing (PS) (cm)					
17.5	21.3	452	388	8.2	18.2
35.0	29.1	335	535	6.1	18.3
Significance	**	**	**	**	NS
RS × PS	NS	NS	NS	NS	NS

Significant F-test at $*P < 0.05$ and $**P < 0.01$, and non-significant (NS), respectively. L, C: linear or cubic response.
[a] Includes fruit that were >10 g, and are not deformed or diseased.

increasing RS, while at the 35 cm PS, fruit number per m^2 were unaffected by RS (Table 4). At both plant spacings, fruit weight per m^2 decreased linearly with increasing RS, but the rate of increase in yield with every unit decrease in RS was greater at the 17.5 cm PS. However, plants grown at 35 cm PS had larger crown diameters and greater total per plant yields than those grown at 17.5 cm PS. As plant density increased, total marketable yields (kg m^2) increased linearly (Fig. 5), with yield increasing 0.4 kg m^{-2} for each additional plant per m^2.

3.4. Total marketable yields 2002–2003

As RS increased from 40 to 65 cm, fruit number and weight per plant increased linearly from 19.4 to 27.4 and from 331 to 500 g, respectively (Table 5). Plants at the 17.5 cm PS were less productive than plants at the 35 cm PS, but the greater number of plants per m^2 at the 17.5 cm PS more than compensated for the lower yield per plant (Table 5). As plant density increased, a linear increased in total marketable yields (kg m^{-2}) occurred (Fig. 5).

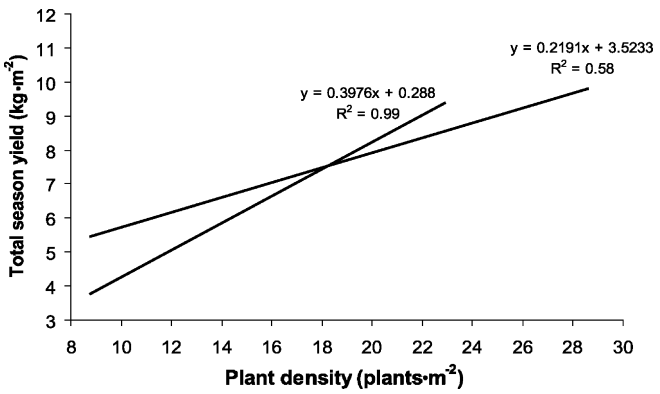

Fig. 5. Linear regression between plant density and total season marketable yield during 2001–2002 and 2002–2003 seasons for 'Sweet Charlie' strawberry grown in a passively ventilated greenhouse in Polygal® Hanging Bed-Pack troughs with pine bark as soilless substrate.

4. Discussion

In Florida, early yield is important economically since the average market prices of fresh strawberries during the early season (November to January) are about 30–40% higher than during the later part of the season (February to April). In both seasons, RS did not influence early marketable fruit yields (g) per plant. However, as RS increased, early marketable fruit number per m^2 linearly decreased in both seasons. Plants grown at 17.5 cm PS generally had smaller crowns, fewer leaves, and produce similar (2001–2002) or less (2002–2003) early marketable yield (g) per plant than plants grown at 35 cm PS. Total marketable fruit weight per m^2 decreased with increasing RS during both seasons. Generally, plants grown at 17.5 cm PS had smaller crowns and had lower total marketable yields per plant than those grown at 35 cm PS.

The combination of chemical control augmented with biological control did not effectively control insect and disease pests in 2001–2002. However, the exclusive use of biological control measures was effective in controlling pests during the 2002–2003 season. Regardless, in both seasons, early and total marketable yield per area (kg m^{-2}) increased linearly with increasing plant densities (plants m^{-2}). Similarly, Sarooshi and Cresswell (1994) reported that strawberry grown under protective culture had yield increases with increasing plant densities. Dijkstra et al. (1993) reported an increase in strawberry yields with increasing plant densities using horizontal peat bags but not with 6 L plastic pots.

5. Conclusions

Marketable fruit yield (kg m^2) of 'Sweet Charlie' strawberry grown in the Polygal® 'Hanging Bed-Pack' trough system in a high-roof passively ventilated greenhouse increased as plant density increased. Additionally, these yield increases were achieved without adversely affecting mean fruit size. For example, a density of 23 plants m^{-2} is well above the density of

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4.3 plants m^{-2} that is standard for the commercial open field production system in Florida, and, in fact, approaches densities used in vertical systems. The hanging trough system used in this study appears to provide high plant densities, while minimizing shading effects that often plague vertical systems.

The November through January marketable yields per plant measured in this study are comparable to the November through January yields per plant obtained from 'Sweet Charlie' grown in open-field production during the 2001–2002 and 2002–2003 seasons in west central Florida (C.K. Chandler, unpublished data). This suggests that 'Sweet Charlie' grown in the greenhouse using a hydroponic trough system may produce over five times more early fruit yield per unit area than 'Sweet Charlie' grown in the open-field, raised bed system.

References

Bish, E.B., Cantliffe, D.J., Hochmuth, G.J., Chandler, C.K., 1997. Development of containerized strawberry transplants for Florida's winter production system. Acta Hortic. 439, 461–467.

Dijkstra, J., De Bruijn, J., Scholtens, A., Wijsmuller, J.M., 1993. Effects of planting distance and peat volume on strawberry production in bag and bucket culture. Acta Hortic. 348, 180–184.

Durner, E.F., 1999. Winter greenhouse strawberry production using conditioned plug plants. HortScience 34, 615–616.

Koppert Biological Systems, 2004. Side Effects Database (http://www.koppert.nl/e0110.html).

Legard, D.E., Hochmuth, G.J., Stall, W.M., Duval, J.R., Price, J.F., Taylor, T.G., Smith, S.A., 2003. Strawberry production in Florida. In: Olson, S.M., Maynard, D.N. (Eds.), Vegetable Production Guide for Florida. Univ. FL-IFAS Coop. Ext. Serv., Gainesville, FL, USA, pp. 239–244.

Özeker, E., Eltez, R.Z., Tuzel, A., Gul, K., Onal, A., Tanrisever, A., 1999. Investigations on the effects of different growing media on the yield and quality of strawberries grown in vertical bags. Acta Hortic. 491, 409–412.

Paranjpe, A.V., 2004. Soilless media, growing containers, plant densities and cultivars for greenhouse strawberry production in Florida. Master's Thesis. Univ. FL, Gainesville, FL, USA.

Paranjpe, A.V., Cantliffe, D.J., Lamb, E.M., Stoffella, P.J., Powell, C.A., 2003. Increasing winter strawberry production in north-central Florida using passive ventilated greenhouses and high plant densities. Acta Hortic. 626, 269–276.

Radajewska, B., Aumiller, A., 1997. Influence of cultivation system on the yield of strawberries in an unheated glasshouse. Acta Hortic. 439, 481–482.

Sarooshi, R.A., Cresswell, G.C., 1994. Effects of hydroponic solution composition, electrical conductivity and plant spacing on yield and quality of strawberries. Aust. J. Exp. Agric. 43, 529–535.

SAS, 2001. SAS/STAT Guide for Personal Computer, V. 8.2. SAS Institute, Cary, NC.

Takeda, F., 2000. Out-of-season greenhouse strawberry production in soilless substrate. Adv. Strawberry Res. 18, 4–15.

Van Looy, J., Aerts, J., 1982. Annual Report on Strawberries. Proefbedrijf der Noorderkempen, Meerle, p. 146.