Proc. Fla. State Hort. Soc. 120:142–150. 2007.

Influence of Soilless Media, Growing Containers, and Plug Transplants on Vegetative Growth and Fruit Yield of 'Sweet Charlie' Strawberry Grown under Protected Culture

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Additional index words. pine bark, perlite, peat mix, greenhouse, polyethylene bags, trough

'Sweet Charlie' strawberries (*Fragaria ×ananassa* Duch.) were grown in a passively ventilated greenhouse to evaluate the effects of soilless media (pine bark, peat-mix, and perlite), growing systems ("bag on gutter," "Polygal Hanging Bed-pack® trough," and "bag on ground"), and sources of plug (greenhouse-grown and field-grown) on yield and plant growth during two production seasons. Plants grown in perlite generally produced higher early marketable yields than those grown in peat-mix or pine bark. Plants grown in "bag on gutter" or "bag on ground" had larger crowns and more leaves than plants grown in "Polygal trough," during both seasons. Total marketable yields responded differentially to growing system and media during both seasons with higher yields generally from plants grown in "bags on gutter" with peat-mix (first season) and with peat-mix or perlite (second season) than other growing system × media combinations. Field-grown plugs generally produced plants with larger crown diameters, more leaves, and higher total marketable yields than plants from greenhouse-grown plugs. Mean fruit weight was not influenced by media, growing system, or source of plug. Using pine bark as a soilless substrate in protected strawberry culture reduced media costs by 50% than for peat-mix and 42% than for perlite. "Polygal troughs" were easy to install, and the cost per season ($0.43 per meter) was comparable to that of polyethylene bags within a PVC (polyvinylchloride) gutter ($0.39 per meter). Fruits from plants grown in elevated containers were easier to harvest than from plants grown in containers on the ground. Therefore, protected strawberry culture using specialized growing containers such as "Polygal troughs," cost-effective soilless media such as pine bark, and field-grown plugs can enhance winter strawberry production in north-central Florida. Protected culture provides a practical commercial alternative to methyl-bromide dependent field production of strawberry.

Performance of soilless media such as peat-mix and perlite in protected strawberry culture has been studied extensively. However, the suitability of tree bark in protected strawberry culture has not been investigated. Protected culture of strawberries in soilless media can provide an alternative to methyl bromide-dependent field production systems (Hochmuth et al., 1998b; Özeker et al., 1999; Takeda, 2000; US Environmental Protection Agency, 1997). Studies conducted in several countries have reported differences in yield from soilless media used in protected strawberry culture. In Greece, Anagnostou and Vasilakakis (1995) reported that 'Selva' and 'Fern' strawberry plants grown in vertical bags produced similar early yields (172 and 198 g/plant, respectively) in perlite, peat mix, or reused perlite. However, total yield of 'Fern' (321 g/plant) was highest in perlite, whereas 'Selva' was most productive (268 g/plant) when grown in peat mix. Plants of both cultivars grown in reused perlite produced significantly lower total yields and had a greater percentage of chlorotic symptoms. In Turkey, Özeker et al. (1999) reported that early and total yields obtained from 'Tioga' or 'Cruz' strawberry plants grown in vertical bags filled with pumice, perlite, pumice+perlite, and peat+perlite were similar. Hochmuth et al. (1998a) reported that strawberry yields from an outdoor bag production system were similar regardless if plants were grown in peat-mix or perlite.

Strawberry plant growth and fruit yield are dependent on the type of growing container used and the configuration or arrangement of the containers. The volume and dimensions of containers not only affect the physical characteristics (such as aeration and water holding capacity) of soilless media and hence plant growth, but also affect the cost of the soilless medium, which may impact production costs (Cantliffe et al., 2001; Dufault and Waters, 1985). Takeda (2000) reported that yields obtained from 'Chandler' and 'Camarosa' strawberry plants grown in a greenhouse over a 7-month period using 7.6-L plastic pots (5 plants/pot and 1.5 L/plant) or 2.8-L interlocking polystyrene pots (4 plants/pot and 0.7 L/pot) filled with peat-mix were similar, suggesting that the

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volume of the container did not influence fruit yield. However, Dijkstra et al. (1993) reported that a minimum peat volume of 2.5 to 3 L per plant was necessary to obtain optimum yields from 'Elsanta' strawberry grown in 6-L plastic pots or 8-L plastic bags in an unheated tunnel.

Vertically arranged containers generally accommodate higher plant densities than those arranged horizontally. However, the non-uniform light distribution in vertically arranged systems often has a negative impact on plant growth and ultimately fruit yield. Durner (1999) reported that 'Sweet Charlie' strawberry grown in vertical polyvinyl chloride (PVC) columns filled with perlite at a plant density of 32 plants/m^2 produced a marketable yield of 11.8 $kg \cdot m^{-2}$; however, yield per plant was reduced by 40 g with every 30-cm decrease in the height of the vertical column, presumably due to suboptimal light conditions in the lower sections of the vertical column. Takeda (2000) reported that the intensity of sunlight [100 $\mu M \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (*PAR*)] reaching the plant canopy at the bottom end of a vertical tower of seven Styrofoam pots was only 10% of that reaching the top, and the suboptimal light conditions in the middle and bottom section of the tower adversely affected strawberry plant growth and fruit yield. Van Looy and Aerts (1982) reported that strawberry plants growing in lower sections of an A-frame trough system experienced partial shading and produced a high number of small and malformed fruit, increased fruit rot, and problems in fruit coloration. Besides affecting fruit yield and quality, harvest efficiency in vertical and multiple tier horizontal systems may also be adversely affected since fruit requires harvesting at different heights.

A single tier of growing containers arranged in a horizontal plane facilitates more uniform distribution of sunlight, subsequently resulting in more consistent fruit yield and quality. Furthermore, harvest efficiency is improved since all fruit can be harvested at the same elevation. Radajewska and Aumiller (1997) evaluated cold-stored plantlets of 'Elsanta' strawberry in a glasshouse by planting in peat-filled bags placed on hanging gutters suspended 1.5 m aboveground and peat-filled bags placed on 30-cm-high cement platforms. Although total yield obtained from plants grown in both growing systems was similar, higher economic yields were obtained from plants grown at 1.5-m elevation. This presumably occurred from an accelerated fruit ripening at the 1.5-m elevation, which resulted in increased early yields that subsequently achieved a higher economic yield.

Hochmuth et al. (2006) reported that containerized plug strawberry transplants reduced the establishment period, water use, and enhanced early plant growth and flowering than bare-root transplants grown in the field. These same principles hold true for the use of plug transplants for greenhouse-grown strawberries (Paranjpe et al., 2003c). Various factors affect flowering and yield of plug grown transplants (Bish et al., 1997). Bish et al. (2001) reported and patented a system for producing large quantities of greenhouse-grown plantlets for strawberry plug production. Factors such as container size, plant size, and temperature conditioning can affect early flowering and ultimately yield (Bish and Cantliffe, 2000; Bish et al., 2002, 2003). Currently, many of the commercial strawberry plugs are field-grown to reduce production costs. Concerns of field-grown plugs have occurred due to insufficient conditioning and potentially higher incidence of insect and disease pests.

Considerable restrictions have been imposed on peat-mining due to the adverse effects of large-scale peat-mining on the environment. The use of rockwool, which presents a massive solid-waste disposal problem (Riviere and Caron, 2001), may be restricted in the future. The global consumption of perlite is increasing at a rate of 2% per year, and horticulture is the fastest growing consumer of perlite with an average annual increase of 9.5% from 1992 to 1998 (Roskill Information Services, 2003). Presently, the rapid increase in the use of perlite has not created any environmental concerns, but it may face similar restrictions (as that of rockwool or peat) in the future if excessive mining is demonstrated to have adverse impacts on the environment. An analysis by Riviere and Caron (2001) has underscored the need for investigating the suitability of by-products such as barks and coconut coir in horticultural crop production. The objectives of this study were to determine the effects of several growing containers, soilless media, and source of plugs on fruit yield and vegetative growth of 'Sweet Charlie' strawberries grown during winter in a passively ventilated greenhouse.

Materials and Methods

The effects of soilless media, growing systems, and plug transplants on plant growth and fruit yield of 'Sweet Charlie' strawberry were evaluated during Fall–Winter 2000 (1 Oct. 2000–10 Mar. 2001) and Fall–Winter 2001 (10 Oct. 2001–22 Mar. 2002). Experiments were conducted in a single bay (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). Three soilless media were evaluated: 1) 2:1 (v/v) mixture of Canadian peat moss (Black Bale®, Lamberts Co., Rivière-Ouelle, QC, Canada) and coarse perlite (particle size 1.3 to 5.1 mm, Verlite Co., Vero Beach, FL); 2) coarse perlite; and 3) pine bark (2.5-cm^2 sieved, Elixon Wood Products Inc., Starke, FL).

The three growing systems evaluated were: 1) "bag on ground"; 18-L capacity white polyethylene bags (15 cm wide × 12 cm deep × 100 cm long) placed at ground level on the middle (10 cm wide) raised portion of a drainage channel made from Styrofoam strips and black-on-white polyethylene sheet (Fig. 1a); 2) "bag on gutter"; 18-L capacity white polyethylene bags (15 cm wide × 12 cm deep × 100 cm long) placed on PVC gutter sections (10 cm wide × 10 cm deep × 300 cm long) suspended at a height of 1.2 m aboveground (Fig. 1b). The PVC gutter sections were suspended from cross members of the greenhouse structure with 2 mm gauge steel wire, and supported from underneath by wooden stands; 3) "Polygal troughs"; 12-L capacity PVC "Hanging Bed-pack®" troughs (10-cm bottom width × 12-cm wall height, 5-cm-diameter planting holes, Polygal Industries, Ramat Hashofet, Israel) suspended 1.2 m aboveground (Fig. 1c). Troughs were suspended from cross-members of the greenhouse structure with 2-mm gauge steel wire.

Plug transplants were: 1) "GH plugs"; 120-d-old, greenhouse-grown, artificially-conditioned plug transplants produced in Gainesville, FL. "GH-plugs" were produced in a fan-pad cooled greenhouse and received a 2-week conditioning treatment in a walk-in growth chamber (25 °C day/15 °C night temperatures, 9-h photoperiod) prior to planting in the greenhouse; 2) "FG plugs"; 75-d-old, field-grown, commercially available plug transplants, grown at a high-elevation nursery in Cashiers, NC, under natural short photoperiods and low temperatures.

A total of 18 treatment (3 soilless media × 3 growing systems × 2 plug types) combinations were replicated three times in a split-block experimental design. Growing systems were considered the main plots and soilless media and plant type were

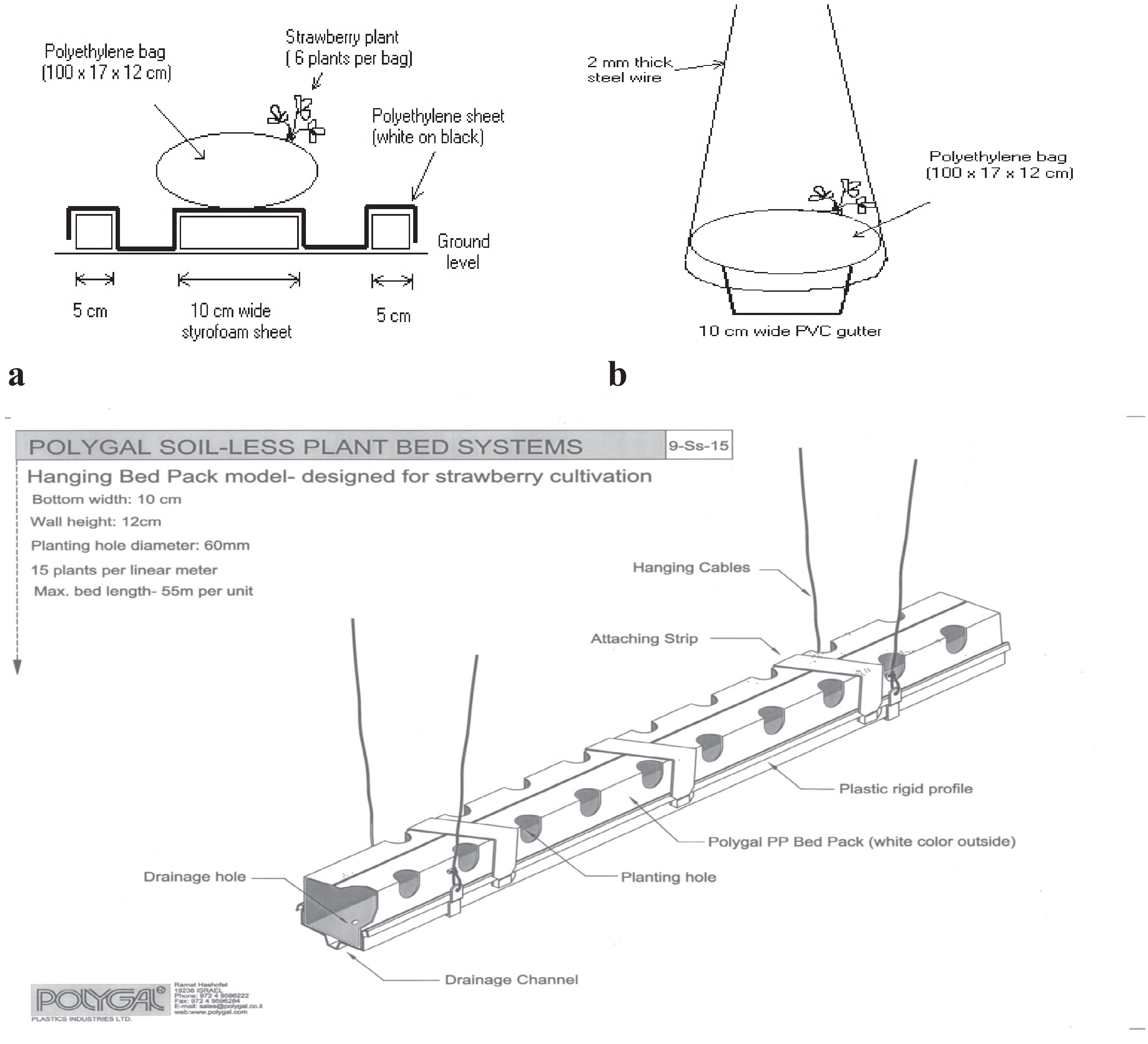

Fig. 1. (**a**) "Bag on ground" culture; (**b**) "Bag on gutter" culture; (**c**) Polygal® "Hanging Bed-Pack" trough. Printed with permission from Gilad Roter, Polygal, Israel.

considered the split-plot. During Fall 2000, each plot was 3 m long, consisting of three 1-m-long bags with six plants per bag, or 3-m-long sections of the "Polygal troughs" with 6 plants/m of the trough section. There were a total of 18 plants per plot. Rows were spaced 80 cm apart and plants were spaced 32 cm apart which was equivalent to a plant density of 7.5 plants/m^2. During Fall 2001, each plot was 2 m long, consisting of two 1-m-long bags with 10 plants per bag, or 2-m-long sections of the Polygal "Hanging Bed-pack®" troughs with 10 plants/m of the trough section. Each plot consisted of 20 plants. Rows were spaced 80 cm apart and plants were spaced 20 cm apart, which was equivalent to a plant density of 12.5 plants/m^2.

One day prior to transplanting, the growing systems were filled with soilless media and irrigated for 2–3 h to thoroughly moisten the soilless media. Both sources of plugs were transplanted into the various growing system and media treatments on 3 Oct. 2000 and 10 Oct. 2001.

Plants received a complete nutrient solution with every irrigation cycle and all treatments received the same concentration and volume of nutrient solution throughout the growing season (Paranjpe et al., 2003b). Concentrated fertilizer was injected from two stock tanks with two injectors (DI 16-11 GPM, Dosatron Inc., Clearwater, FL) assembled in series. Plants were fertigated 8 to 10 times daily with drip tape (15-mil thickness, 5-cm emitter spacing, 0.9 $L \cdot h^{-1}$ discharge, Chapin Watermatics Inc., Watertown, NY). Each fertigation event was 2 min long with 90-min intervals. Each plant received approximately 150 mL of nutrient solution per day. An electronic timer (Superior Controls Co., Valencia, CA) was used to control irrigation events. Final nutrient concentration of the irrigation solution: N, 65 ppm; P, 50 ppm; K, 85 ppm; Ca, 95–100 ppm; Mg, 40 ppm; S, 56 ppm; Fe, 2.8 ppm; B, 0.6 ppm; Mn, 0.4 ppm; Cu, 0.1 ppm; Zn, 0.2 ppm; and Mo, 0.03 ppm (Paranjpe et al., 2003c).

One class-A beehive (Koppert Biological Systems Inc., Romulus, MI) containing approximately 75–100 bumblebees (*Bombus* sp.) was introduced into the experiment, 15 d after transplanting (onset of anthesis).

During both seasons, two-spotted spider mites (*Tetranichus urticae* Koch), cotton aphids (*Aphis gossypii* Glover), and western flower thrips (*Frankliniella occidentalis* Pergande) were the most prominent arthropod pests. Powdery mildew (*Sphaerotheca macularis* f. sp. Fragariae) spores appeared in mid-November and were present at varying levels until the end of the experiment. The incidence of gray mold (*Botrytis cinerea*) was negligible and was noticed occasionally on overripe fruit.

During Fall 2000, an IPM strategy that relied mostly on chemical control and to a lesser extent on biological control was adopted. To control two-spotted spider mites, chemical acaricides such as Savey (Gowan Co., Yuma, AZ), fenbutatin-oxide (Vendex, DuPont, Wilmington, DE), dificol (Kelthane, Dow AgroSciences LLC, Indianapolis, IN), and abamectin (Avid, Syngenta Crop Protection, Inc., Greensboro, NC) were applied via a PulsFOG® fogger (Dramm USA, Manitowoc, WI) at the rates recommended for strawberry. Biological control agents such as *Neoseiulus californicus* McGregor predatory mites (Biotactics Inc., Perris, CA) were released at the rate of approximately 20 mites/m^2 each month. Nymphs of *Geocoris punctipes* Say (Entomos LLC., Gainesville, FL) were also released at the rate of approximately 5 nymphs/m^2 per month for controlling two-spotted spider mites. To control cotton aphids, mycoinsecticide (BotaniGard, BioWorks, Inc., Faiport, NY) was applied at the rate recommended for strawberry, and soap (0.1%, Lemon Joy; Proctor & Gamble Co.) was applied with a hose-end sprayer. Additionally, parasitic wasps *Aphidius colemani* L. (IPM Laboratories, Locke, NY; Koppert Biological Systems Inc., Romulus, MI) were released at bi-weekly intervals at a mean rate of approximately 2.5 wasps/m^2 to control aphids. Ladybug beetles (*Coleomegilla maculata* De Geer) (IPM Laboratories, Locke, NY; Entomos LLC., Gainesville, FL) were also released at the rate of approximately 100 beetles/m^2 per month for controlling aphids. For controlling powdery mildew, fungicides such as myclobutanil (Nova, Dow AgroSciences LLC), azoxystrobin (Quadris, Syngenta Crop Protection, Inc.), Captan (Micro Flo Co. LLC, Memphis, TN), and *Ampelomyces quisqualis* biofungicide (AQ-10, Ecogen Inc., Langhorne, PA) were applied at the rates recommended for strawberry.

In Fall 2001, a similar pest management strategy was implemented during the first half of the season; then the use of chemical pesticides was discontinued, and pest management was via biological control. The application rates and frequency of release for biological control agents were modified, wherein *N. californicus* were released at the rate of 40 mites/m^2 each month, and *A. colemani* were released at the rate of approximately 10 wasps/m^2 per month. The application rates of *C. maculata* and *G. punctipes* were not changed.

Fruits with 80% red color were harvested at 4- to 5-d intervals. Fruits that weighed more than 10 g and not deformed or diseased were considered marketable. For each plot, fruit number and fruit weight were recorded for marketable and non-marketable fruit yield. Marketable yield per plant was calculated by summarizing the yield of all harvests from each plot and dividing it by the number of plants (18 plants per plot in Fall 2000, and 20 plants per plot in Fall 2001). For data analysis, harvests were grouped into early yield (November–January), and total yield (November–March).

Crown diameter and number of leaves were recorded from three plants located in the center of each plot on 25 Jan. 2001 and 27 Jan. 2002. Since the crown of a strawberry plant branches and re-branches as the plant grows, its shape is irregular. In this study, the term "crown size" or "crown diameter" is used for the irregularly shaped mass of multiple crowns measured as a whole at the widest section and at the narrowest section with a caliper (Manostat, Switzerland). The mean of the two measurements per replication were used for statistical analysis. The number of leaves per plant was counted.

Air temperatures (°C) inside and outside the greenhouse were recorded by using a thermocouple. Solar radiation (W·m^{-2}) was also recorded using a LI 200X pyranometer sensor (LI-COR Inc., Lincoln, NE). Both air temperature and solar radiation data were stored in a CR 10X data-logger (Campbell Scientific, Logan, UT).

For each experiment, data were subjected to analyses of variance (ANOVA) with the Statistical Analysis System program (SAS Institute, Inc., 1987). Main effects (plug transplants, soilless media, and growing system) means were presented only if interactions were nonsignificant. Significant main effect and interaction means were separated by a least significant difference (LSD) test, 5% level. Correlation coefficients (r) were calculated between crown diameter and leaf number for each experiment (data not shown).

Results and Discussion

Early marketable fruit yield. During Fall 2000, early fruit number and fruit weight per plant were significantly higher when plants were grown in perlite than peat-mix or pinebark (Table 1). Percentages of marketable fruit number and fruit weight obtained from plants grown in peat-mix and pine bark were greater than that from plants grown in perlite, but mean fruit weight was unaffected by media (Table 1). During Fall 2001, media did not affect the number of fruit produced per plant, the marketable fruit weight obtained from plants grown in perlite (175 g/plant) was significantly greater than that obtained from plants grown in peat-mix (167 g/plant) or pine bark (166 g/plant) (Table 2).

In Fall 2000, growing system by plug transplant interactions were significant for all early marketable yield variables except for the mean fruit weight (Table 1). Higher early fruit number and fruit weight were obtained from plants grown in "Polygal troughs" than plants grown in "bag on gutter" or "bag on ground" with "FG plugs" but were similar with "GH plugs" (Table 1). A higher percentage of marketable fruit number and fruit weight was obtained from plants grown in "bag on gutter" and "Polygal troughs" than plants grown in "bag on ground." When grown in "Polygal troughs" the "FG plugs" produced higher fruit number and fruit weight than "GH plugs." However, the yield from both plug types was similar when grown in "bag on gutter" or "bag on ground." In Fall 2001, there was no interaction between growing system and plug transplant for any early marketable yield variables (Table 2). Strawberry yields were similar between plug types. Plants grown in "bag on gutter" or "Polygal troughs" produced higher marketable yields but similar mean fruit weight than plants grown in "bag on ground."

Total marketable fruit yield. During Fall 2000, a significant media by growing system interaction occurred for marketable fruit number and fruit weight (Table 3). Media did not influence yields from plants grown in "bag on gutter." Plants grown in "Polygal troughs" produced higher yields in peat-mix and pine bark than perlite. However, plants grown in "bag on ground" produced higher yields in perlite than pine bark.

Table 1. Effects of growing systems, soilless media, and plug transplants on the early marketable fruit yield and quality of *Fragaria ×ananassa* cv. Sweet Charlie grown in a passively ventilated greenhouse (Fall 2000, 13 harvests: 17 Nov. 2000 to 20 Jan. 2001).

	Marketable yield					Marketable yield[z] (%)			
	Plug transplants[y]					Plug transplants[y]			
	GH	FG	GH	FG		GH	FG	GH	FG
Treatments	--- (fruit/plant) ----		--- (g/plant) ---		(g/fruit)	-- (fruit/plant) --		---- (g/plant) ---	
Plug transplants (P)[y]									
GH plugs					19.8				
FG plugs					19.9				
Significance					NS				
Media (M)									
Peat mix	7.6		151		19.9	81.7		91.1	
Pine bark	7.6		153		20.0	81.2		91.1	
Perlite	8.5		166		19.6	77.1		88.9	
$LSD_{(0.05)}$	0.6		12			1.8		1.3	
Growing system (GS)									
Bag on gutter	8.5	7.4	168	148	19.9	76.7	85.2	88.9	93.4
Polygal troughs	7.2	9.3	143	181	19.7	75.7	88.0	87.9	94.8
Bag on ground	8.2	6.8	162	137	20.0	67.6	86.8	83.2	93.9
GS × P $LSD_{(0.05)}$	1.7		31.1			6.0		3.6	

[z]Includes fruit that weighed more than 10 g and were not deformed or diseased.
[y]"GH Plugs" were 4 months old, conditioned, greenhouse-grown in Gainesville, FL. "FG Plugs' were 2.5 months old, naturally conditioned, field-grown in Cashiers, NC.
[NS]Nonsignificant.

Table 2. Effects of growing systems, soilless media, and plug transplants on the early marketable fruit yield and quality of *Fragaria ×ananassa* cv. Sweet Charlie grown in a passively ventilated greenhouse (Fall 2001, 13 harvests: 20 Nov. 2001 to 22 Jan. 2002).

	Marketable yield			Marketable yield[z] (%)	
Treatments	(fruit/plant)	(g/plant)	(g/fruit)	(fruit/plant)	(g/plant)
Plug transplants (P)[y]					
GH plugs	8.3	170	20.3	73.7	88.1
FG plugs	8.3	169	20.4	75.5	89.1
Significance	NS	NS	NS	NS	**
Media (M)					
Peat mix	8.2	167	20.4	73.8	88.4
Pine bark	8.2	166	20.3	74.5	88.4
Perlite	8.6	175	20.4	75.6	89.1
$LSD_{(0.05)}$		5.2			
Growing system (GS)					
Bag on gutter	8.4	173	20.6	75.6	89.6
Polygal troughs	8.4	171	20.3	73.9	88.1
Bag on ground	8.1	164	20.1	74.4	88.2
$LSD_{(0.05)}$	0.2	3.6			

[z]Includes fruit that weighed more than 10 g and were not deformed or diseased.
[y]"GH Plugs" were 4 months old, conditioned, greenhouse-grown in Gainesville, FL. "FG Plugs" were 2.5 months old, naturally conditioned, field-grown in Cashiers, NC.
[**, NS]Nonsignificant or significant at 1% level, respectively.

During Fall 2001, a significant soilless media × growing system interaction occurred for marketable fruit number and fruit weight (Table 4). Plants grown in "bag on gutter" produced higher yields in peat-mix and perlite as compared with pine bark. Plants grown in "bag on ground" produced higher yields in peat-mix than pine bark, but yields were similar to plants grown in perlite. The soilless media did not influence yields from plants grown in "Polygal troughs." The combination of "bag on gutter" with either peat-mix or perlite produced significantly higher yields than any other growing system by soilless media combination.

During Fall 2000, significant growing system by plug transplant interaction occurred for percentage of marketable fruit number and fruit weight (Table 3). The percentage of marketable fruit number and fruit weight of "FG plugs" was not influenced by growing system. For "GH plugs," plants grown in a "bag on gutter" system had a higher percent of marketable fruit number and weight than plants grown in "bag on ground" system. During Fall 2001, there was no interaction between growing system and plug transplant. During both seasons, "FG plugs" produced greater fruit number and fruit weight than "GH plugs" (Tables 3–4). However, plug

Table 3. Growing systems, soilless media, and plug transplants effects on the total marketable fruit yield and quality of *Fragaria* ×*ananassa* cv. Sweet Charlie grown in a passively ventilated greenhouse (Fall 2000, 20 harvests: 17 Nov. 2000 to 10 Mar. 2001).

	Marketable yield[z]							Marketable yield (%)			
	Media							Plug transplant			
	Peat mix	Pine bark	Perlite	Peat mix	Pine bark	Perlite		GH plugs	FG plugs	GH plugs	FG plugs
Treatments	(fruit/plant)			(g/plant)			(g/fruit)	(fruit/plant)		(g/fruit)	
Plug transplants (P)[y]											
GH plugs		20.5			373		18.2				
FG plugs		22.6			412		18.2				
Significance		*			*		NS				
Media (M)											
Peat mix							18.3	75.9		87.0	
Pine bark							18.2	75.2		86.5	
Perlite							18.1	72.2		84.9	
LSD$_{(0.05)}$								0.9		0.7	
Growing system (GS)											
Bag on gutter	24.4	23.3	22.5	445	428	410	18.3	73.0	77.7	85.2	88.0
Polygal troughs	21.9	21.8	19.3	396	395	345	18.0	72.7	75.5	84.8	87.1
Bag on ground	21.3	18.5	20.8	348	335	383	18.4	68.6	78.8	82.6	88.9
GS × M LSD$_{(0.05)}$		2.5			40.6						
GS × P LSD$_{(0.05)}$								3.6		2.2	

[z]Includes fruit that weighed more than 10 g and were not deformed or diseased.

[y]"GH Plugs" were 4 months old, conditioned, greenhouse-grown in Gainesville, FL. "FG Plugs" were 2.5 months old, naturally conditioned, field-grown in Cashiers, NC.

[*, NS]Nonsignificant or significant at 5% level, respectively.

Table 4. Growing systems, soilless media, and plug transplants effects on total marketable fruit yield and quality of *Fragaria* ×*ananassa* cv. Sweet Charlie grown in a passively ventilated greenhouse (Fall 2001, 25 harvests: 20 Nov. 2001 to 22 Mar. 2002).

	Marketable yield[z]							Marketable yield (%)	
	Media								
	Peat mix	Pine bark	Perlite	Peat mix	Pine bark	Perlite			
Treatments	(fruit/plant)			(g/plant)			(g/fruit)	(fruit/plant)	(g/fruit)
Plug transplants (P)[y]									
GH plugs		22.0			416		18.9	69.5	85.2
FG plugs		22.9			429		18.7	70.0	85.4
Significance		**			**		NS	NS	NS
Media (M)									
Peat mix							19.2	70.6	86.2
Pine bark							18.7	69.6	85.1
Perlite							18.6	69.1	84.6
LSD$_{(0.05)}$									0.5
Growing system (GS)									
Bag on gutter	24.0	22.3	25.1	462	416	467		71.3	86.0
Polygal troughs	21.6	21.9	22.2	415	410	406		68.8	84.9
Bag on ground	22.3	21.2	21.6	424	394	409		69.2	85.0
GS × M LSD$_{(0.05)}$		1.4			15.8			NS	NS

[z]Includes fruit that weighed more than 10 g and are not deformed or diseased.

[y]"GH Plugs' were 4 months old, conditioned, greenhouse-grown in Gainesville, FL. "FG Plugs' were 2.5 months old, naturally conditioned, field-grown in Cashiers, NC.

[**, NS]Nonsignificant or significant at 1% level, respectively.

types produced a similar percentage of marketable fruit number and fruit weight during Fall 2001 (Table 4) but varied among growing systems during Fall 2000 (Table 3).

Crown size and leaf number. In Fall 2000, crown diameter of plants grown in "bag on gutter" (51.8 mm) and "bag on ground" (50.0 mm) was significantly larger than that of plants grown in "Polygal troughs" (41.4 mm) (Table 5). In Fall 2001, crown diameters of plants were significantly larger for "bag on gutter" than "bag on ground" or "Polygal trough" systems (Table 5).

In Fall 2000, plants grown in peat-mix had a larger crown diameter than plants grown in perlite (Table 5). Also, "FG plugs" produced plants with larger crown diameter than those produced from "GH plugs." Plants grown in "bag on gutter" and "bag on ground" produced more leaves per plant than plants grown in "Polygal troughs" (Table 5). More leaves per plant occurred from plants grown in peat-mix than the perlite medium.

Table 5. Growing systems, soilless media, and plug transplants effects on the crown diameter and number of leaves for each plot) of *Fragaria ×ananassa* cv. Sweet Charlie plants grown in a passively ventilated greenhouse.

	Crown diam (mm)		Leaves (no/plant)	
Treatments	Fall 2000	Fall 2001	Fall 2000	Fall 2001
Plug transplants (P)[z]				
GH plugs	46.2	44.3	24.8	23.5
FG plugs	49.3	47.3	25.0	24.7
Significance	**	**	NS	*
Media (M)				
Peat mix	50.6	47.8	26.6	25.2
Pine bark	47.2	44.6	24.8	24.3
Perlite	45.4	44.9	23.4	22.7
$LSD_{(0.05)}$	3.9		2.4	1.7
Growing system (GS)				
Bag on gutter	51.8	48.9	26.4	25.2
Polygal trough	41.4	42.6	21.5	22.3
Bag on ground	50.0	45.9	26.9	24.7
$LSD_{(0.05)}$	4.2	3.5	2.4	1.8

[z]"GH Plugs' were 4 months old, conditioned, greenhouse-grown in Gainesville, FL. "FG Plugs' were 2.5 months old, naturally conditioned, field-grown in Cashiers, NC.

**, *, NSNonsignificant or significant at 1% or 5% levels, respectively.

In Fall 2000, the number of leaves per plant produced by "FG plugs" were similar to "GH plugs" (Table 5). In Fall 2001, the "FG plugs" produced more leaves per plant than the "GH plugs." Crown diameter and leaf number were significantly correlated in Fall 2000 ($r = 0.84^{**}$) and in Fall 2001 ($r = 0.81^{**}$) seasons.

Media influenced the early yields of 'Sweet Charlie' strawberry plants regardless of growing system or plug type. Except for fruit number during Fall 2001, plants grown in perlite produced more early marketable yields than those grown in peat-mix or pine bark. Early marketable yields were similar from plants grown in peat-mix or pine bark in both seasons. Peat-mix is the most widely used soilless substrate for protected strawberry culture in Europe, and is generally regarded as an optimum substrate for horticultural and ornamental crop production. However, peat-mix is an expensive soilless substrate. In this study, plants grown in pine bark (costs \$8.50/m^3) produced early marketable yields that were similar to or less than those obtained in peat-mix (costs \$55/m^3). On a per hectare basis, the cost of pine bark used for strawberry production would be \$2040, vs. \$13,200 for peat-mix. In addition to being six times less expensive than peat-mix, pine bark is readily available in Florida, and is easy to handle and dispose of. Despite differences in early marketable yield among soilless media, plants grown in all three soilless medium produced early yields (151–175 g/plant) that were comparable to previously reported yields (141 g/plant; Durner, 1999) for 'Sweet Charlie' strawberry grown in soilless culture. Plant populations in this study were limited to 7.5 plants/m^2 in the Fall 2000 study and 12.5 plants/m^2 in the Fall 2001 study. This limit was imposed by the container layout so that populations could be similar among treatments each year. Paranjpe et al. (2003b), using the "Polygal trough" system, determined that 25.4 plants/m^2 resulted in yields five times more than traditional field production for west central Florida.

Significant media by growing system interactions occurred for total marketable yield per plant in both seasons. In general, plants grown in "bag on gutter" and peat-mix produced higher total yields than those produced from most other growing system by media combinations. When "Polygal troughs" were used, total yields were similar among soilless media. Plants grown in "bag on ground" generally produced consistently lower yields regardless of media used. These lower yields may have been attributed to infestations of two-spotted spider mites which appeared to be more severe on plants grown in "bag on ground" than to those observed on plants grown in "bag on gutter" or "Polygal troughs." The spider mite populations may have spread more easily between rows when the bags were in contact with the ground than systems suspended in air. Despite the total marketable yield differences obtained from various combinations of growing systems and soilless media, yields obtained from almost all growing system by media combinations in this study (up to 462 g/plant) were greater than previously reported yields for 'Sweet Charlie' strawberry grown in soilless culture (368 g/plant by Durner, 1999; 157–247 g/plant by Takeda, 2000).

The decision to choose a growing system or soilless media depends on their cost, ease of use, and ability to enhance fruit quality and yields. Polyethylene bags can be used only for one season since they degrade faster from exposure to UV radiation, whereas "Polygal troughs" can be used for up to seven seasons since they do not degrade as fast as the polyethylene bags (N. Gnayem, 2003, personal communication). The volume in "Polygal troughs" (12 L·m^{-1}) is 33% less than the volume of polyethylene bags (18 L·m^{-1}) and therefore, the quantity and cost of the soilless media required to fill the "Polygal troughs" is 33% lower than that required for polyethylene bags. Polyethylene bags (filled with soilless substrate and irrigated to field capacity) and placed on PVC gutters weight approximately two times more than the "Polygal troughs," and therefore are bulky and difficult to handle, especially if they are suspended aboveground.

The weight of the growing system is also an important consideration while designing the greenhouse structure. A heavier growing system will require a stronger structure which may substantially increase the structural costs. Although the initial cost of "Polygal troughs" (\$3/m) is higher than "bag on gutter" (\$1.25/m), the depreciated cost of "Polygal troughs" (over seven seasons; \$0.43/m per season) is comparable to that of "bag on gutter" (\$0.39/m per season). Additionally, the lower volume (and cost) of soilless media required to fill the troughs, made "Polygal troughs" more economical on a per season basis (Paranjpe et al., 2003a, 2003c). Despite lower yields obtained from "Polygal troughs" due to their small container volume (12 L·m^{-1} for "Polygal troughs" vs. 18 L·m^{-1} for polyethylene bags), "Polygal troughs" are easy to establish and can typically accommodate 25% more plants per unit area than "bag on gutter." Therefore, from a management standpoint, their cost effectiveness, ease of handling, and ability to accommodate higher plant populations make "Polygal troughs" more suited for protected strawberry culture.

Early strawberry fruit production may depend in part on root carbohydrate reserves for up to one month after transplanting (Nishizawa and Shishido, 1998; Nishizawa et al., 1997). Kirshbaum et al. (1998) reported that propagation site latitude affects the early yield of 'Sweet Charlie' strawberry, wherein plants propagated in northern latitudes (Lavaltrie, Canada) produced a larger crown diameter, greater leaf crown dry weights, greater soluble carbohydrate concentration in the crown and roots, and produced more early (November–December) and total (November–February) marketable yields than plants propagated in southern latitudes (Hillsborough County, FL).

The early yields (November–January) obtained from artificially-conditioned "GH plugs' propagated in Gainesville, FL, and "FG plugs' propagated in Cashiers, NC, under natural short daylength and low temperatures were generally similar. These results were similar to those reported by Durner and Poling (1998), wherein 'Sweet Charlie' plugs conditioned at 10 or 16 °C and 8-h photoperiod for 3 weeks produced early (December–January) yields that were similar to the control (non-artificially conditioned) plugs grown in the mountains of North Carolina. The natural conditioning treatment received by "FG plugs" may explain why they generally produced early (November–January) yields that were similar to those obtained from artificially conditioned "GH plugs" (Bish et al., 2001). The naturally conditioned "FG plugs" generally developed plants with larger crowns and more leaves than artificially conditioned "GH plugs."

This may have attributed to the higher total yields of "FG plugs" than for "GH plugs." The yield from "GH plugs" may have also been adversely affected by their inferior root system that developed over an excessively long period (120 d) in small cells, including 45 d in a sub-irrigation system under partially submerged conditions (Bish et al., 2002).

Reports by Bish et al. (2001), Hamann and Poling (1997), and Takeda and Hokanson (2002) and this study suggest that strawberry plug transplants that are not more than 75 d old at the time of transplanting, and are propagated at high-elevation nurseries under natural short photoperiods and low air temperatures would be suitable for winter strawberry production.

Naturally conditioned "FG plugs" generally produced plants with larger crowns and more leaves, resulting in higher total yields than conditioned "GH plugs." These results were similar to those reported in previous studies (Kirschbaum et al., 1998; Strik and Proctor, 1988) whereas larger crowns and higher leaf numbers were correlated with increased fruit yields in strawberry.

Plants grown in peat-mix produced larger crowns during Fall 2000 and more leaves during both seasons than plants grown in perlite. The larger crown size and greater leaf number of plants grown in peat-mix may be related to its higher water holding capacity (42.9%) and total porosity (71.6%) as compared to pine bark (16.9% and 63.3%, respectively) or perlite (17.2% and 57.8%, respectively) (Paranjpe et al., 2003b; Shaw et al., 2004). Plants grown in polyethylene bags ("bag on gutter" or "bag on ground') generally produced larger crowns and more leaves than plants grown in "Polygal troughs." The larger container volume of the polyethylene bags (18-L) as compared to "Polygal troughs" (12-L) may have enhanced the vegetative growth of plants grown in polyethylene bags and subsequently increased crown size and number of leaves.

The cost of using a combination of "Polygal troughs" and pine bark ($\$1.06/m^2$) is 51% less expensive than using a combination of "Polygal troughs" and peat-mix ($\$2.18/m^2$), and 42% less expensive than using a combination of "Polygal troughs" and perlite ($\$1.84/m^2$) (Paranjpe et al., 2003a, 2003c). Pine bark can be recommended as a soilless medium for "Polygal troughs" not only for its cost advantage, but also since the yields obtained from plants grown in pine bark were similar, or higher, than yields obtained from plants grown in either peat-mix or perlite.

In conclusion, it was demonstrated that strawberries could be grown in a high-roof passively ventilated greenhouse using inexpensive pine bark as a medium in easy-to-harvest hanging troughs.

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