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WINTER STRAWBERRY PRODUCTION IN GREENHOUSES USING SOILLESS SUBSTRATES: AN ALTERNATIVE TO METHYL BROMIDE SOIL FUMIGATION

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Abstract. In an effort to develop an alternative to methyl bromide-dependant strawberry (*Fragaria* × *ananassa* Duch.) field production in north-central Florida, we evaluated various soilless substrates, growing containers, plug transplants, plant densities, cultivars, and biological control strategies in a passively ventilated high-roof greenhouse near Gainesville, Florida. The type of soilless media used influenced total yield of field-grown and greenhouse-grown plugs when plants were grown in Polygal® troughs or poly-bags placed at ground level, but did not influence total yield when plants were grown in poly-bags placed on elevated gutter sections. Type of growing container did not affect the yield of greenhouse-grown plugs, however, early yield of field-grown plugs was higher when grown in poly-bags placed on elevated gutter sections than when grown in the other types of containers. Twelve plant densities ranging from 0.86 to 2.55 per ft^2 (37,462 to 111,078 per acre) were evaluated. Plant densities were derived by combinations of six between-row spacings (16, 18, 20, 22, 24, and 26 inches center-center) and two within-row spacings (7 and 12 inches plant-to-plant). In Fall 2001, the yield per ft^2 increased linearly with plant density. However, in Fall 2002, the yield per ft^2 did not increase linearly due to a reduction in yield per plant at the between-row spacing of 16 inches. Strawberry yields of 1.96 lb/ft^2 (7,115 12-lb flats per acre) were obtained from greenhouse production compared to a 10-year average yield of 2,392 12-lb flats per acre (FDACS, 2002) for field production. New cultivars such as FL97-39 and Carmine produced high early yields, but FL97-39 was highly susceptible to powdery mildew (*Sphaerotheca macularis*), and 'Carmine' and 'Sweet Charlie' were more affected by aphids than other cultivars. *Aphidius colemani* and *Lysiphlebus testaceipes* parasitic wasps, and *Neoseiulus californicus* predatory mites were effective in controlling aphids (*Aphis gossypii*) and two-spotted spider mites (*Tetranichus urticae*) respectively. Thus, protected strawberry culture can enhance early and total yields, improve harvest efficiency, improve fruit quality by reducing pesticide usage, and eliminate dependency on methyl bromide.

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Since the early 1900s, the Florida strawberry industry has undergone many changes from growing strawberries on straw-covered beds with furrow irrigation to the present day annual plasticulture system that uses methyl bromide, polyethylene mulch, and drip irrigation. Most of the 6,900 acres under strawberry production are concentrated in Hillsborough County in west-central Florida. Nearly three-quarters of the total production occurs in February, March, and April when market prices are relatively low ($10.10-$6.20 per 12-lb flat) while only 26% of the total production occurs in November, December, and January when the market prices are high ($16.20-$12.90 per 12-lb flat) (FDACS, 2002).

Until now, Florida's strawberry industry has managed to remain competitive largely due to the small window of opportunity that exists from mid-November to the end of January, a period when the volume of strawberries produced in California is low, and the market prices are high. In recent years, however, the Florida strawberry industry has been battling a number of problems that could make conventional strawberry production in Florida more difficult and less profitable in the future. Commercial strawberry production in Florida is heavily dependant on methyl bromide, which will be phased out in the U.S. by 2005 (U.S. EPA, 2002). For Florida strawberry producers, a mixture of 1,3-dichloropropene (Telone) and chloropicrin has emerged as the most promising alternative to methyl bromide. However, this alternative may reduce strawberry yields by 10-20 percent (VanSickle, 2000).

The Florida strawberry industry is also faced with other challenges such as occasional freezes, acute draw-downs in wells during freeze protection, high labor costs, and concerns associated with farming in an increasingly urban environment. Due to the unusually cold winter of 2002-03, the Florida strawberry industry lost more than 15% of its early production. The harvesting cost, which accounts for more than 50% of the total cost of strawberry production, continues to increase, and the migrant labor could become more difficult to find in the future if job opportunities that are less physically demanding and pay higher wages are available (Chandler et al., 1993). Also, field-grown strawberries are vulnerable to damage by migratory birds and sporadic pests such as sap beetles (*Stelidota geminata*) (Price, 2001).

In the context of this challenging scenario faced by the strawberry industry, there is a need to consider new alternatives such as protected culture. Since protective structures can provide protection against low temperatures and rainfall, winter strawberry production can be enhanced, increasing the growers' ability to obtain better and more consistent market prices. The use of soilless growing media in protected culture will eliminate the need for methyl bromide (Takeda, 1999). The use of plug transplants will reduce water consumption while ensuring 100% transplant survival (Durner et al., 2002). Specialized growing containers such as polyvinyl chloride (PVC) troughs that can be raised or lowered to a desirable height can not only accommodate higher plant densities and increase yields per unit area (Paranjpe et al., 2003), but also facilitate ease of harvest and reduce the labor costs. The effective use of biological pest management practices can reduce the use of pesticides and potentially enable the grower to market strawberries as 'pesticide free'.

This paper summarizes the results of three different studies conducted in a passively ventilated greenhouse located at the UF Protected Agriculture Project site in Gainesville, Florida (http://www.hos.ufl.edu/protectedag). These studies were aimed at identifying suitable growing containers, soilless media, plug transplants, plant densities, cultivars, and biological control methods for winter strawberry production under protected culture in north-central Florida.

Protective Structures

Protective structures, such as high or low tunnels, greenhouses, or glasshouses, can protect the crop from rain, strong winds, and extreme temperatures. Protective structures that are equipped with insect screens can reduce entry of insect pests and retain pollinators. Also, UV-resistant plastic, which is used for covering the roof and walls of protective structures, can interfere with whitefly reproduction and reduce the incidence of viral diseases. In central Europe, there are approximately 17,280 acres of strawberries under protected culture, with Italy, Spain, U.K., Belgium, and France accounting for more 90% of this area (Lieten, 2001). Protected cultivation of strawberries is done on approximately 19,760 acres in Japan (Takeda, 1999), and 18,525 acres in South Korea (Kang and Oh, 1996). Strawberries are also grown under protective structures in many other countries including Morocco (2,200 acres), Israel (110 acres), Australia (120 acres), and Canada (48 acres).

Although United States is the largest strawberry producer in the world, protected cultivation of strawberries in the U.S. is almost nonexistent. At present, there are only about 2 acres of strawberries grown under protected culture in Florida. The acreage of vegetables under protective structures has been increasing in Florida, and is presently estimated at about 100 acres (Hochmuth, 2003). Given the technology and infrastructure available in the U.S., there is a tremendous potential for protected cultivation of strawberry, especially in states such as Florida that have a mild winter climate where light quality is excellent and energy consumption is low due to minimal heating requirements. Passively ventilated high-roof greenhouses (Fig. 1; Top Greenhouses Ltd., Rosh Ha'ayin, Israel) that can retain heat during winter months and maintain ambient temperatures during warmer months are well-suited for winter strawberry production in Florida. These greenhouses have a total height of approximately 30 ft (22 ft to the gutter), 12 ft high retractable side-walls, 3.3 ft high roof-vents, insect screens covering the side-walls and roof-vents, and a double layer of UV resistant polyethylene on the roof.

Temperature Management in Passively Ventilated Greenhouses

Strawberry cultivars adapted to Florida grow well within a temperature range of 60 °F to 80 °F, but plant growth slows down considerably below 50 °F. At high temperatures (>80 °F), fruit quality characteristics such as firmness and soluble solids content may be adversely affected. During severe cold weather, higher temperatures can be maintained in passively ventilated high-roof greenhouses by closing the side curtains and roof vents to trap the heat generated by solar radiation. If necessary, supplemental heat can be provided when night temperature is expected to fall below 32 °F. Diesel heaters with polyethylene convection tubes for uniform heat distribution work well under Florida conditions, and have fuel requirements of approximately 350 gal/d for heating a 1-acre greenhouse. During warmer months of the season, ambient temperature can be maintained by lowering the side-curtains and opening the roof-vents.

Fertigation

Strawberries grown in soilless culture need to be provided with all major and minor elements, since most soilless media are devoid of any nutrients. We developed a fertilizer formula for soilless strawberry culture by making modifications to the hydroponic tomato formula described by Hochmuth and Hochmuth (2001). The nutrient solution consisted of the following macro and micro nutrients (ppm in final solution): N: 65 ppm (NO_3-N = 55 ppm, NH_4-N = 10 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, Mo: 0.03 ppm. Plants receive approximately 150 ml of the nutrient solution per day. The concentrated nutrient solution is injected with two injectors (Dosatron, Inc., Clearwater, Fla.) assembled in series, and delivered to the plants in splits of 8-10 irrigation events via drip tape (2-inch emitter, 0.24 GPH discharge) (Chapin Watermatics, Inc., Watertown, N.Y.). The nutrient solution is adjusted to a pH of 5.5, and an electrical conductivity of 1.6 $mS{\cdot}cm^{-1}$.

Pollination

Pollination of strawberry flowers is aided by wind, bees, and other insects. However, in a greenhouse, the activity of these natural agents is restricted, and the use of commercially available bumblebees is essential to ensure good pollination. One beehive (Koppert Biological Systems Inc., Romulus, Mich.) containing approximately 75 bumblebees is generally introduced into the crop 15 d after transplanting.

Biological Control of Arthropod Pests and Fungal Diseases

Two-spotted spider mites (*Tetranichus urticae*), cotton aphids (*Aphis gossypii*), and western flower thrips (*Frankliniella occidentalis*) are the main arthropod pests of greenhouse strawberries. Under climatic conditions of north-central Florida, monthly preventive releases of *N. californicus* at the rate of four predatory mites per ft^2 of greenhouse space provided satisfactory control of two-spotted spider mites. For aphids, weekly preventive releases of *Aphidius colemani* parasitic wasps at the rate of 0.025 wasps per ft^2 (about 1000 wasps per acre) would be the best preventive strategy, but for control of established aphid populations, higher release rates of up to one wasp per ft^2 per week for at least three consecutive weeks may be necessary. *Lysiphlebus testaceipes*, a wasp species native to Florida, is also effective against aphids, however, they are not available commercially at present. For controlling thrips, *Amblyseius cucumeris* predatory mites work well under greenhouse conditions and preventive releases can be made as soon as flowers emerge. *A. cucumeris* primarily feed on larvae of thrips, and sometimes on eggs and adults of two-spotted spider mites. Typical release rates for *A. cucumeris* range between 10-100 predators per ft^2 per week over a 6-week period, depending on how well they establish in the crop.

Fig. 1. Passively ventilated, high-roof greenhouse with double layer polyethylene roof and insect screens (Protected Agriculture Project, Gainesville, Fla.).

Powdery mildew (*Sphaerotheca macularis*) infects the leaves, petioles, flowers, peduncles, and fruits of strawberry plants and is probably the most important and widespread fungal pathogen of strawberries grown under protected culture worldwide. Powdery mildew proliferates rapidly when humidity is moderate to high and air temperatures are between 59 °F and 81 °F (Hancock, 1999). AQ-10 biofungicide (*Ampelomyces quisqualis*, Ecogen, Inc., Langhorne, PA) can provide limited control of powdery mildew, but other fungicides like sulfur and potassium or sodium bicarbonate, which are mildly toxic to beneficial insects, may be more effective. Botrytis fruit rot or gray mold caused by *Botrytis cineria* is not as severe a problem in protected strawberries as it is in field-grown strawberries. However, it can be a serious problem in protected strawberries (Robert Hochmuth 2003, personal communication) that are grown under conditions of high humidity and moderate daytime temperatures (60 °F to 75 °F) (Legard, 2003).

Soilless Media, Growing Containers (Systems), and Plug Transplants

During Fall 2000 and 2001, a study was conducted to evaluate the effect of three growing systems, three soilless substrates, and two kinds of plug transplants on 'Sweet Charlie' strawberry yield and quality in protected culture. The growing systems were: (a) polyethylene bags (40 × 7 × 5 inches) suspended 4 ft above the ground on PVC gutter sections, (b) polyethylene bags (40 × 7 × 5 inches) placed at ground level, and (c) Polygal® 'Hanging Bed-pack troughs (4-inch bottom width × 5-inch wall height, with 2-inch diameter planting holes) (Polygal Industries, Ramat Hashofet, Israel) (Fig. 2) suspended 4 ft above the ground. The soilless media were: (a) peat-mix [2:1 peat:perlite (v:v)], (b) pine bark, and (c) perlite. The two kinds of plugs were: (a) GH plugs: 4 months old greenhouse-grown, conditioned (77 °F day/59 °F night, 9-h photoperiod for 2 weeks) (Bish et al., 1997) plug transplants grown in an evaporative-pad cooled greenhouse, and (b) FG plugs: 2.5 months old, field-grown, non-conditioned plug transplants grown in Cashiers, North Carolina (Norton Creek Farms, Cashiers, N.C.). Although these plugs were not conditioned artificially, they may have received some natural chilling since they were produced at a high elevation nursery.

Treatments were randomized in a split block design with three replications. Fruit with 80 percent color development were harvested at 4-5 d intervals. Fruit that weighed more than 10 g and were not deformed or diseased were considered marketable. Fruit that weighed less than 10 g or were deformed or diseased were considered non-marketable. For each plot, the number of fruit and fruit weight was recorded for marketable and non-marketable fruit yield and quality. Data were analyzed with SAS software (SAS Institute, Inc., 1999-2001).

Early yield. The results from our greenhouse studies indicate that the type of soilless media influenced the early yield of plants during both seasons. The marketable yield was sig-

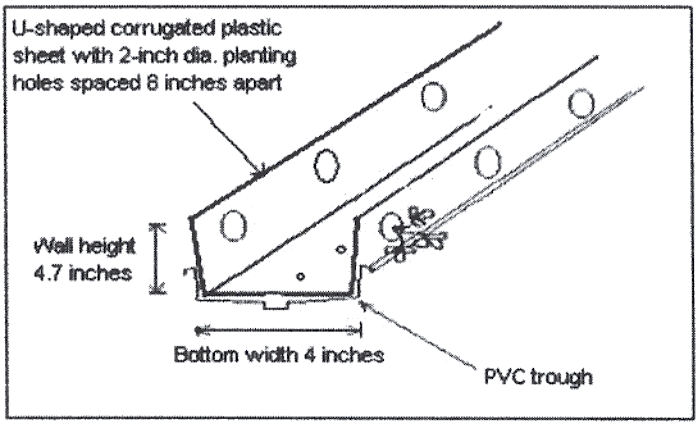

Fig. 2. Polygal® Hanging Bed-pack trough system for strawberry production.

nificantly higher when plants were grown in perlite than with peat-mix or pinebark (data not shown). During both seasons, there was no difference between the early yield of GH plugs and FG plugs (data not shown).

During Fall 2000, the growing system influenced the early yield of FG plugs. Greater yields were obtained when plants were grown in Polygal troughs than with 'bag on gutter' or 'bag on ground' (Table 1). On the other hand, the early yield of GH plugs was not influenced by the type of growing system. During Fall 2001, the kind of growing system did not influence the early yield from either plug type.

Total yield. The type of soilless media and growing system influenced the total yield during both seasons, wherein, in Fall 2000, plants grown in Polygal troughs produced higher yields in peat-mix and pine bark than in perlite (Table 2). Plants grown in 'bag on ground' produced higher yields in peat-mix and perlite than in pine bark. The soilless media did not affect the yields of plants grown in 'bag on gutter'.

During Fall 2001, plants grown in 'bag on gutter' produced higher yields in peat-mix and perlite than in pine bark, and the yields of plants grown in 'bag on ground' were higher in peat-mix than in pine bark, but not significantly different from those obtained in perlite (Table 2). On the other hand, the total yield of plants grown in Polygal troughs was not influenced by the type of soilless media. During both seasons, the total yield of FG plugs was significantly higher than that of GH plugs (data not shown).

Soilless media. Most soilless media are inert and free from weed seeds and pathogens. Hence, there is no need for methyl bromide. In central Europe, strawberries are grown commercially in a wide variety of soilless media such as peat moss, coconut coir, perlite, rockwool, or pine bark (Lieten, 2001). Besides the ability of a media to promote good plant growth and yield, the cost (Cantliffe et al., 2001) and availability of the soilless media is an important factor in soilless culture. In our study, plants grown in pine bark produced yields that were comparable to plants grown in peat-mix and perlite. Also, pine bark is easily available in Florida, and is relatively inexpensive (\$6.50 per yd^3) compared to perlite (\$31 per yd^3) and peat (\$53 per yd^3). On a per acre basis, using pine bark (\$850 per acre) could reduce the cost incurred on soilless media by 85% compared with using a 2:1 mixture of peat:perlite (\$5,500 per acre).

Growing containers (systems). Strawberries can be grown in polyethylene bags, plastic pots, PVC troughs, or styrofoam containers of various shapes and sizes. Growing containers should be arranged in such a way that sunlight is distributed evenly throughout the plant canopy and plant population density and yield are maximized. Vertically arranged growing systems usually accommodate more plants per unit area than horizontal systems, but have problems with sub-optimal light levels in the lower sections, resulting in reduced yield and plant growth (Takeda, 1999). Growing systems arranged in a single horizontal tier (usually in the north-south direction) can also accommodate high plant population densities up to 2.8 plants per ft^2 (Paranjpe et al., 2003) and, since all plants are at the same height, light distribution is uniform. In addition to enabling high yields and uniform light distribution, a growing system should lend itself to spatial adjustments in order to facilitate cultural practices, and should have the ability to be reused over multiple seasons. Polyethylene bags degrade within a short time and cannot be used for more than one season. Also, they are bulky and difficult to handle, especially when they are suspended above the ground. On the other hand, trough systems such as the Polygal® Hanging Bed-pack system are easy to handle and can be raised or lowered easily to a desirable height to facilitate cultural operations such as transplanting, scouting, and harvesting. Although the initial cost of trough systems is high (\$1 per ft), their cost on

Table 1. Effect of plug type (PT) and growing container (GC) on the early and total marketable yield per plant of 'Sweet Charlie' strawberry grown during Fall 2000 and Fall 2001 in a passively ventilated greenhouse located in Gainesville, Fla.

		Marketable yield ($lb \cdot plant^{-1}$)[z]			
		Fall 2000		Fall 2001	
PT	GC	Early	Total	Early	Total
GH[y]	Bag on gutter	bc			
	Polygal troughs	ab			
	Bag on ground	abc			
FG[z]	Bag on gutter	bc			
	Polygal troughs	a			
	Bag on ground	c			
	$LSD_{(0.05)}$				

[z]Marketable yield was obtained from fruit that weighed more than 10 g, and were not deformed or diseased.
Note: Means with same letters within a column are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

Table 2. Effect of growing container (GC) and soilless media (SM) on the early and total marketable yield of 'Sweet Charlie' strawberry grown during Fall 2000 and Fall 2001 in a passively ventilated greenhouse located in Gainesville, Fla.

		Marketable yield (lb·plant^{-1})^z			
		Fall 2000		Fall 2001	
GC	SM	Early	Total	Early	Total
Bag on gutter	Peat-mix		0.97 a		1.02 a
	Pinebark		0.94 ab		0.92 bc
	Perlite		0.90 abc		1.03 a
Polygal troughs	Peat-mix		0.87 bc		0.91 bc
	Pinebark		0.87 bc		0.90 bcd
	Perlite		0.76 de		0.89 cd
Bag on ground	Peat-mix		0.87 bc		0.93 b
	Pinebark		0.74 e		0.87 d
	Perlite		0.84 cd		0.90 bcd
$LSD_{(0.05)}$			0.09		0.03

^{z}Marketable yield was obtained from fruit that weighed more than 10 g, and were not deformed or diseased.
Note: Means with same letters within a column are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

a per-season basis is reasonable since they can be re-used over 4-5 seasons.

Plug transplants. Plug transplants are preferred over bare-root transplants in protected strawberry cultivation, since plug transplants establish quickly and do not need large quantities of water for establishment. Also, plug transplants have a survival rate of almost 100%, have reduced risks of soil-borne diseases, reduced pesticide requirements (Durner et al., 2002), and produce greater early yields compared to bare root transplants (Hochmuth et al., 1998; Takeda, 1997).

In spite of the advantages associated with plug transplants, very few U.S. growers are using them due to their higher cost. Plug transplants delivered to the farm generally cost about $0.14 each, compared with $0.08 each for bare-root transplants (Durner et al., 2002). However, minimal need for over-head irrigation during the establishment period, resulting in fewer disease problems should justify the higher cost, and growers may soon change over to using plug transplants. Precocity of short-day strawberry cultivars can be enhanced by conditioning the plugs at low temperatures and short photoperiods. In a study conducted in 1997 by Bish et al. 1997, 'Sweet Charlie' plugs conditioned at temperatures of 77 °F day/59 °F night for 2 weeks flowered earlier and produced greater early and total yields in the field compared with plugs subjected to 95 °F day/77 °F night temperatures.

Results from our greenhouse studies indicate that both commercially available non-conditioned field-grown plugs as well as conditioned greenhouse-grown plugs produced similar early yields under protected culture. On the other hand, the total yield obtained from non-conditioned field-grown plugs was higher than greenhouse-grown conditioned plugs during both seasons. Although previous studies have shown that conditioning leads to increased early yields in field strawberry production (Bish et al., 1997), the lack of difference between the early yields of conditioned and non-conditioned plugs in our greenhouse study could have been, in part, due to some degree of natural chilling experienced by the non-conditioned plugs at the higher elevation nursery in North Carolina. Moreover, the 4-month-old greenhouse-grown plugs used in this study were approximately 45 d older than the field-grown plugs, and this extended period in the cell-pack trays led to a root bound condition that may have adversely affected their performance over the long run. This observation is similar to the one made by Hamann and Poling (1997), who noted that plugs grown in small cell-packs (200 cm^3) and conditioned for excessively long periods (25-30 d) in addition to the 4-week period necessary for establishment, can develop a rootbound condition that may adversely affect their performance. Thus, under soilless culture, younger plug transplants (2-2.5 months old) with a healthier root system may perform better than older (4 months old) plug transplants.

Plant Density

Since the investment going into a greenhouse operation is high, maximum utilization of greenhouse space is critical to obtain maximum returns. In Fall 2001, eight plant densities ranging from 0.86·ft^{-2} to 2.04·ft^{-2} (37,462 to 88,862 plants per acre), and in Fall 2002, twelve plant densities ranging from 0.86·ft^{-2} to 2.55·ft^{-2} (37,462 to 111,078 plants per acre) (Table 3) were evaluated for their effect on fruit yield and quality of 'Sweet Charlie' strawberry grown in soilless culture in a passively ventilated greenhouse. Strawberry plants were grown in Polygal® Hanging Bed-pack troughs that were suspended 6 ft above the ground level (Fig. 3) and filled with 1 inch^2 sieved pine bark. Plant densities were derived by spacing the troughs 26, 24, 22, 20, 18, or 16 inches apart (center-to-center) and by spacing the plants 7 inches or 14 inches apart within each row.

In Fall 2001, the early and total yield per ft^2 increased linearly with plant density (Table 3). In Fall 2002, the yield per ft^2 did not show a linear increase since there was a reduction in the yield per plant at the narrowest (16 inches) row spacing (data not shown), resulting in reduced yield per ft^2 at plant densities of 1.39 per ft^2 and 2.55 per ft^2 (Table 3). The maximum yield of 1.96 lb/ft^2 (7,115 12-lb flats per acre) obtained at the 2.26 per ft^2 plant density was approximately three times greater than a 10-year average yield of 2,392 12-lb flats per acre (FDACS, 2002) obtained in field production. Our research suggests that the yield per plant is adversely affected at 16 inches between-row spacing, and, between-row spacing

Table 3. Effect of within row spacing (WRS) and between row spacing (BRS) of 'Sweet Charlie' strawberry on early (November-January) and total (November-March) marketable fruit yield per ft^{2} in a passively ventilated greenhouse located in Gainesville, Fla., during Fall 2001 and Fall 2002.

WRS (inches)	BRS (inches)	Plant density (plants·ft^{-2})	Marketable yield (lb·plant^{2})[z] Fall 2000 Early	Fall 2000 Total	Fall 2001 Early	Fall 2001 Total
	16	2.55	—	—		
	18	2.26	—	—		
	20	2.04	0.88 a	1.82 a		
	22	1.86	0.86 a	1.70 b		
	24	1.70	0.76 b	1.57 c		
	26	1.57	0.67 c	1.43 d		
14	16	1.39	—	—		
	18	1.23	—	—		
	20	1.11	0.47 d	1.03 e		
	22	1.00	0.43 d	0.93 f		
	24	0.93	0.39 e	0.87 g		
	26	0.86	0.39 e	0.82 h		
	$LSD_{(0.05)}$		0.08	0.04		

[z]Marketable yield was obtained from fruit that weighed more than 10 g, and were not deformed or diseased.
Note: Means with same letters within a column are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

within a range of 18-22 inches with 7 inches within-row spacing would result in maximum yield per unit area under protected strawberry culture in north-central Florida using the Polygal® trough system.

Cultivars

Most strawberry cultivars are bred for production in open fields, and limited information on the performance of these

Fig. 3. Density study: 'Sweet Charlie' strawberries growing in Polygal® Hanging Bed-pack troughs.

Table 4. Early (November-January) marketable yield of seven strawberry cultivars grown in a passively ventilated greenhouse located in Gainesville, Fla., during Fall 2002.

	Early marketable yield[z]			
Cultivar	($oz \cdot fruit^{-1}$)	(% from total)	($lb \cdot plant^{-1}$)	(12-lb $flats \cdot acre^{-1}$)
FL 97-39				
Carmine				
Camarosa				
Treasure				
Earlibrite				
Sweet Charlie				
Strawberry Festival				

[z]Marketable yield was obtained from fruit that weighed more than 10 g, and were not deformed or diseased.
Note: Means with same letters within a column are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

cultivars under protected cultivation in the U.S. is presently available. In Fall 2002-03, a cultivar study was conducted at the UF Protected Ag Project greenhouse in Gainesville, Fla., for evaluating the fruit yield and quality, and susceptibility to aphids and powdery mildew for seven strawberry cultivars. In October, plug transplants were planted at a density of 2.04 per ft^2 in Polygal® Hanging Bed-pack troughs filled with pine bark. No insecticides or fungicides were used. However, biological control insects and mites were used for controlling arthropod pests. The early yield (November-January) obtained from selection FL 97-39 was significantly greater than from 'Strawberry Festival','Earlibrite' and 'Sweet Charlie', but not significantly different from 'Carmine', 'Camarosa' and 'Treasure' (Table 4). The total yields (November-March) obtained from FL 97-39 and 'Carmine' were significantly greater than 'Camarosa' and 'Sweet Charlie', but not significantly different from 'Strawberry Festival', 'Treasure', and 'Earlibrite' (Table 5). Percent marketable yield for 'Treasure' was higher than for 'Camarosa' and 'Sweet Charlie', but not significantly different than for 'Strawberry Festival', FL 97-39, 'Carmine', and 'Earlibrite' (Table 5).

Although FL97-39 was among the highest producing clones for early and total yields, this selection showed very high susceptibility to powdery mildew. 'Earlibrite' also had high susceptibility to powdery mildew, whereas the rest of the cultivars had moderate susceptibility. Aphid infestations were most severe in 'Sweet Charlie' and 'Carmine', whereas the rest of the cultivars sustained significantly lower levels of aphid infestation.

Cultivar selection for protected strawberry cultivation should be location specific. The climate (especially the range of temperature and humidity) during the production season plays an important role in reducing or increasing the risk of fungal diseases such as powdery mildew and botrytis fruit rot. The choice of cultivar also depends on the desired period for peak production. For protected strawberry cultivation in north-central Florida, a combination of early yielding cultivars such as 'Carmine' and 'Treasure' along with more steady yielding cultivars such as 'Strawberry Festival' and 'Camarosa' may be good choices.

Conclusions

Protected strawberry culture appears to offer a viable alternative to methyl bromide dependant strawberry production in the field. Passively ventilated high-roof greenhouse structures that can retain heat during winter and keep heating costs at a minimum, and can maintain ambient temperature during warmer months are ideal for winter strawberry production in north-central Florida. Soilless substrates such as peat-mix, perlite, or pinebark can eliminate the need for methyl bromide soil fumigation and perform well in protected strawberry culture in north-central Florida. The low cost and easy availability of pine bark makes it an economical choice for Florida growers. Specialized growing systems such as the Polygal® Hanging Bed-pack trough system accommodate high plant densities that result in high yield per unit area. They are easy to install, facilitate ease of harvest, and

Table 5. Total (November-March) marketable yield of seven strawberry cultivars grown in a passively ventilated greenhouse located in Gainesville, Fla., during Fall 2002.

		Total marketable yield[z]		
Cultivar	($oz \cdot fruit^{-1}$)	(% from total)	($lb \cdot plant^{-1}$)	(12-lb $flats \cdot acre^{-1}$)
FL 97-39				
Carmine				
Strawberry Festival				
Treasure				
Earlibrite				
Camarosa				
Sweet Charlie				

[z]Marketable yield was obtained from fruit that weighed more than 10 g, and were not deformed or diseased.
Note: Means with same letters within a column are not significantly different by duncan's Multiple Range Test ($P \leq 0.05$).

can be re-used for multiple seasons. For maximum marketable yields per unit area, growers in north-central Florida should space their plants 18 to 22 inches apart between rows and 7 inches apart within rows. Additional cultivar trials need to be conducted, but 'Carmine', 'Treasure', 'Strawberry Festival', and 'Camarosa' appear to be good choices for protected culture in north-central Florida. Using more than one cultivar can result in steadier production (e.g., 'Carmine' and 'Treasure' for high early and mid-season yield, and 'Strawberry Festival' and 'Camarosa' for high late season yield). Biological control of two-spotted spider mites, aphids, and thrips using *N. californicus*, *A. colemani*, and *N. cucumeris* respectively, can reduce the use of pesticides, and potentially enable growers to market the berries as 'pesticide free'.

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