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Advances on Protected Culture of Berry Crops in Florida

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Abstract

Protected culture of berry crops has increased steadily in Florida in the last few years. In particular, strawberry (*Fragaria x ananassa*) and southern highbush blueberry (*Vaccinium corymbosum* x *V. darrowi*) have been the most planted under structures. These crops are harvested during the winter months when preferential prices are available to growers. High tunnels are the preferred protected culture structure for these crops due to their relatively lower price than greenhouses and their effectiveness for freeze protection. This paper summarizes current research on freeze protection, soilless culture, and planting densities of strawberries. A five-year study revealed that marketable fruit weight increased by an average of 51% in all 15 validations when strawberries were produced inside high tunnels in comparison with yields in open fields. There was a strong correlation (r = 0.81) between the number of nights with cold weather (≤2°C) requiring freeze protection versus the increase on marketable fruit weight in all cases. Another study indicated that establishing a high density of strawberry (54,450 plants·ha^{-1}) failed to increase yields in comparison with 43,560 plants·ha^{-1}. Comparisons of soilless media in vertical and horizontal systems were performed using perlite, coconut coir, pine bark, and a commercial potting mix. These results indicated that for vertical systems, coconut coir, perlite, and potting mix are reliable growing media for strawberry production in a screen house. In contrast, these data suggested that for horizontal systems all four growing media were appropriate to producing the crop at a commercial level.

Protected Culture and its Potential in Florida

It has been widely demonstrated that using protective structures for production of fruit crops offers major advantages from the standpoint of improving yield and quality of horticultural crops. Among those advantages, protected culture could reduce the effects of rain and wind injury and freezing weather, as well as ameliorating plant and fruit damage due to certain pests, such as diseases, insects, weeds, and nematodes (Chism, 2002; Jett, 2007; Kadir et al., 2006; Ozdemir and Kaska, 1997; Voca et al., 2007). Although, these structures may have similar structural features, they could be divided into three types: a) greenhouses, b) tunnels, and c) screen houses. Greenhouses are permanent units covered with glass and/or plastic that could be either passively or actively-ventilated with air conditioners, cooling pads and/or electric fans. In turn, tunnels and screen houses are temporary structures with passive ventilation achieved through partial or total removal of sides and doors. The main difference between these two types of structures is that tunnels have plastic or near-impermeable roofs whereas screen houses possess highly porous ceilings, such as anti-insect nets or shade cloths.

In Florida, strawberry and blueberry are the main berry crops grown for fresh market consumption. In 2010, 3600 ha (8800 acres) of strawberries were mostly planted in west-central Florida, generating about US$362 million in gross sales (U.S. Department of Agriculture, 2010). At the same time, southern highbush blueberry production is mostly concentrated in Florida's northern and central counties and has steadily increased in the last ten years reaching about 1400 ha (3500 acres) (Florida Department of Agriculture and Consumer Services, 2011). Both crops are produced in open fields with the main

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harvesting occurring mostly in the winter months of the year. This allows Florida strawberry and blueberry growers to take advantage of the high fruit prices when other states do not have production due to cold weather. In spite this competitive advantage, increasing competition from international markets has prompted growers to seek alternative production systems that could enhance crop yield and quality, as well as fruit earliness. Protected culture may be an alternative to fulfill those goals.

Scarce references exist on the effects of protected culture on berry crops in Florida. However, a recent study found that high tunnels advanced fruit earliness by almost a month in comparison with open-field production of two southern highbush blueberry cultivars (Santos and Salame-Donoso, 2012). At the same time, irrigation needed for freeze protection under protected cultivation decreased significantly. In strawberry, small-plot research compared high tunnel and open field production in Florida (Salame-Donoso et al., 2010). In that study, high tunnels improved strawberry early and marketable fruit weight by averages of 28% and 54%, respectively. Their results indicated that protection against freezing weather may have been the principal reason for the observed marketable yield increase. However, grower field validations are needed to determine the effects of these types of structures on fruit yield over several planting seasons.

Although official statistics are lacking on the use of protected culture for horticultural crops, production of strawberry and blueberry under protective structures was almost non-existent ten years ago. On the other hand, that trend has reversed in the last few years. For instance, in 2006 there were less than 30,000 strawberry plants grown under structures in Florida, while currently there are more around 500,000 plants mostly under high tunnels. A similar situation occurred with blueberry production under high tunnels, which rose from about 3000 plants in 2007 to more than 120,000 plants today. The planted area of both crops over time is presented in Table 1. Because of this rapid change in adoption, technology on cultural practices for growing both crops must be generated to improve the likelihood of adoption and expansion of protected culture. Some of the most frequently-asked aspects of berry crop production under protected culture in Florida were: a) freeze protection, b) planting densities, c) soilless culture, and d) yield patterns and earliness. The objective of this paper is to summarize current research and extension activities on the use of protected culture for strawberry production in Florida.

Strawberry Production under Protected Culture

Protection against freezing conditions. A long-term study was established at several farms the west-central region of Florida to investigate the effectiveness of high tunnels in providing protection against freezing injury. Total marketable yields were recorded from 2007-08 to 2011-12 (five strawberry growing seasons), resulting on 15 validations over locations and seasons (Table 2). Plots ranged between 10 m of row to 2 ha and the planting densities in each location

Table 1. Planted area of strawberry and blueberry under protective structures from 2007 to 2011 in Florida. Data based on farm visits to production areas in west-central and north Florida.

Crop	2007		2009		2011	
	Greenhouses	Tunnels	Greenhouses	Tunnels (ha)	Greenhouses	Tunnels
Strawberry	0	0.6	0.1	1.0	0.2	6.1
Blueberry	0	0	0	1.0	0	32.0

Table 2. Relative marketable yield increase of strawberry under high tunnels and days of freezing or near freezing temperatures (≤2°C) over five growing seasons (2007 to 2012) in west-central Florida in selected farms.[z]

Farms	2007-08		2008-09		2009-10		2010-11		2011-12		Average	
	(%)	(days)	(%)	(days)	(%)	(days)	(%)	(days)	(%)	(days)	(%)	(days)
1	62	15	49	23	75	30	72	19	2	9	52	19
2	--	--	--	--	101	33	71	19	10	10	61	21
3	--	--	--	--	--	--	110	21	5	10	58	16
4	--	--	--	--	--	--	--	--	8	12	8	12
Average	62	15	49	23	88	32	84	20	6	10	51	18

Pearson correlation coefficient: r = 0.81; n = 15

[z] Relative yields calculated as the proportion of the total marketable fruit weight in high tunnels over the total marketable fruit weight in the open fields.

was 43,560 plants·ha^{-1}. Planting beds were 0.68 m wide at the base, 0.61 m wide at the top, 0.25 m high, and spaced 1.22 m apart on centers. In early September of each season, pressed beds were fumigated with methyl bromide plus chloropicrin or 1,3-dichloropropene plus chloropicrin at a recommended rates to eliminate soilborne diseases, nematodes and weeds in the soil. Within 1 min of fumigation, beds were covered with black polyethylene mulch and a single line of drip irrigation tubing (1.7 L·m^{-1} per h, 30 cm between emitters; T-Tape Systems International, San Diego, CA) was buried 2.5 cm deep on bed centers. Within each farm, the same cultivars were planted inside and outside the structures. Each location was considered a replication for the purpose of this comparison. Fertilization and irrigation scheduling was the same within a farm.

The experimental areas were equipped with 15.1 L·min^{-1} sprinklers for frost protection and crop establishment. As a general rule, growers turned the sprinkler irrigation on at ≤2°C to protect the crop against freezing conditions (Perry, 2001). This practice usually lasts between 8 to 12 h, depending on the severity of the freezing conditions. Plots were established from bare-root transplants in late September or early October of each season and they were set 0.38 m apart in double rows and a distance of 0.38 m between rows. High tunnel dimensions varied between 8 and 8.5 m wide, 4.8 to 5.3 m high, and 67 to 100 m long. The structures were made of galvanized steel and arches were located approximately every 2 to 2.3 m apart. The vertical sections of each arch were between 2 and 2.3 m tall. The roofs and sides of the structures were covered with heavy-duty, clear polyethylene plastic (0.15 mm thick) and the high tunnels were completely closed between 12 and 24 h before a forecast freeze to accumulate heat. No supplementary sprinkler irrigation was needed during all 15 validations, which saved approximately 5000 m^3·ha^{-1} per freezing night. The structures were reopened when inside temperatures reached 7°C, assuming that another freezing or near freezing event was not forecast for that same night.

Total marketable fruit weight consisted of between 20 and 30 harvests during each season. Fruit were harvested at least twice per week, starting on the second or third week in December of each season. A marketable fruit was defined as a fruit with attached calyx, a minimum of 80% red surface, over 10 g in weight, and free of physical defects, insects or diseases. The percentage of marketable fruit increase was recorded for each farm. Marketable yields in the two environments across years and farms were compared with a paired t-test (P<0.05). Results are presented as relative yields, which were the resulting proportion of the total marketable yields in high tunnels over the same variable in open fields (Statistix Analytical Software, Tallahassee, FL). Pearson linear correlation was performed to determine the degree of association of increases on relative yields due to high tunnels and the number of freezing or near freezing nights (≤2°C) when growers turned their sprinkler irrigation systems on to protect the strawberry plants.

This validation study revealed that marketable fruit weight increased by an average of 51% in all 15 cases when strawberry were produced inside high tunnels in comparison with yields in open fields (Table 2). Interestingly, there was a strong correlation (r = 0.81) between the number of nights with cold weather (≤2°C) requiring freeze protection versus the increase on marketable fruit weight in all 15 validations. These findings suggested that fruit and flower injury may have occurred in plots in the open fields due to constant water hitting and freezing on these structures.

Planting densities and cultivars under high tunnels. Because of the cost of protective structures, using the space efficiently is a principal concern for growers aiming to improve net returns. Therefore, a study was conducted over two strawberry seasons (2009-10 and 2010-11) to assess the effect of planting densities on commonly-grown cultivars inside high tunnels. General land preparation, fumigation, bed formation, and pest management procedures were followed as previously described and according to current recommendations for Florida (Peres et al., 2009). High tunnel specifications were as follows: 8.5 m wide, 4.8 to 5.3 m high, and 100 m long. Ventilation and freeze protection procedures were as previously described.

Bare-root plants of 'Florida Radiance', 'Strawberry Festival' and 'Winter Dawn', were obtained from a certified nursery in Canada and transplanted in the first week of October of each season. Transplants were established using 10 days of sprinkler irrigation for 8 $h \cdot day^{-1}$ (15.1 $L \cdot min^{-1}$ per sprinkler head) to cool down crowns and provide moisture for new root development. This practice uses approximately 57,000 $L \cdot ha^{-1}$ per h of watering.

Two planting densities (43,560 and 54,450 $plants \cdot ha^{-1}$) were achieved by fixing the between-bed distances to 1.22 m and only changing the in-row distances between 30 and 38 cm. Treatments were arranged in a split-plot design with four replications, with the planting densities in the main plots. Experimental units had 20 plants per plot. After establishment, plants were irrigated twice per day with an irrigation cycle in the morning between 8:00 and 9:00 AM and another in the early afternoon from 1:00 to 2:00 PM. After transplant establishment, drip irrigation cycles were 15 min from October to mid-November, 30 min from mid-November to early December, and 45 min from early December to the end of the season. Fertigation was applied through drip irrigation lines beginning 10 d after transplanting. Fertilization and pest control were achieved following current crop recommendations (Peres et al., 2009).

Early marketable fruit weight was the cumulative marketable weight of the first 10 harvests, whereas total marketable fruit weight consisted of 20 harvests during each season. Fruit were harvested twice per week, initiating on the second or third week in December of each season. Treatment effects were examined for significance ($P<0.05$) with the general linear model (Statistix Analytical Software, Tallahassee, FL). Means were compared with a Fisher's protected least significance difference (LSD) test at the 5% significance level.

The data indicated that neither the two factors nor their interaction influenced early marketable fruit weight, demonstrating that decreasing the in-row distances from 38 to 30 cm between plants failed to improve early yield, regardless of cultivars (Table 3). Furthermore, total marketable fruit weigh decreased by 12% when plants were planted closer together (30 cm) than at 38 cm between plants. This response could be explained by increased pressure on limited growing resources, such as space, water, and nutrients, when adding 25% more plants.

Vertical and horizontal soilless culture.

Table 3. Effects of planting densities and cultivars on the early and total marketable fruit weight of strawberry. Balm, Florida, USA, 2009-10 and 2010-11 seasons.

	Marketable fruit weight (t·ha^{-1})	
	Early	Total
Planting densities (plants·ha^{-1})		
43,560	4.3	7.4a
54,450	5.2	6.6 b
Significance (*P*<0.05)	NS	*
Cultivars		
Florida Radiance	4.4	6.4 b
Strawberry Festival	4.6	6.6 ab
Winter Dawn	5.4	8.0 a
Significance (*P*<0.05)	NS	*

[z] Mean separation within columns by Fisher's protected least significant difference test (*P*<0.05). Values followed by the same letter in the same column do not differ at the 5% significance level. NS and * = non-significant and significant, respectively.

The use of soilless (hydroponic) systems for strawberry production has steadily increased over the last decade. These systems are used inside protective structures and can be horizontal or vertical. They provide advantages from both environmental and economic standpoints, such as: a) better use of irrigation water and fertilizers; b) reusable growing media; c) reduced soil-borne pests and no soil fumigation required; and d) efficient use of limited space. A limitation of these systems is their increased initial costs for containers, media, and plumbing materials. The selection of a soilless medium depends on its structure and origin, nutrient and water retention capacity, and biological activity. More research is needed to determine the appropriate soilless media for vertical and horizontal soilless systems for strawberry production. Thus, two studies were conducted to determine the performance of strawberry grown in soilless media in horizontal and vertical production systems.

These two preliminary studies were conducted during the 2011-12 strawberry season. The trials were conducted under an enclosed 100 m^2 screen house structure incorporating a white antivirus 50-mesh insect net (American Farm Systems, Jemison, AL). The structure was built using wooden poles for support, 4 m tall in the center and 2.7 m at the sides. Two soilless systems were used: a) a horizontal system, which consisted in wooden boxes with a volume of 160 L per box, and b) a vertical system with three levels of 3.75-L containers per plot (Verti-Gro® Hydroponic Growing Systems, Summerfield, FL). The media used were fine-grade coconut coir (Botanicoir, London, UK), 2.5-cm diam pine bark (Elixson Wood Products, Starke, FL), perlite, and potting mix (65% sphagnum peat moss + 35% perlite, vermiculite, and dolomitic limestone, Fafard 2; Fafard, Agawam, MA).

Bare-root 'Strawberry Festival' strawberry transplants from Canadian nurseries were planted in mid-October 2011. No preplant fertilizer was used. After transplanting, overhead irrigation was used for 8 h for the first 10 d to ensure plant establishment. Fertilization and pest control was done according to crop requirements. For the vertical system, fertigation was applied through a single emitter per tower (250 mL·min^{-1}), while two drip tape lines were used for the horizontal system (1.7 L·m^{-1} per h, 30 cm between emitters; T-Tape Systems International, San Diego, CA). The screen house area was equipped with 15 L·min^{-1} sprinklers for frost protection and crop establishment.

Treatments consisted of the four soilless media for each separate layout (vertical and horizontal systems). The experimental design for each experiment was a randomized complete block with four replications and 12 plants per plot. Marketable fruit weight and number were collected twice per week for a total of 25 harvests during the season. Early yield was considered as the fruit weight and number for the first six harvests, and the total yield included all the harvests. Harvesting started on late December. Collected data were analyzed using the general linear model procedure. Treatment means were separated using a Fisher's-protected least significant difference test at the 5% level.

For the vertical growing system, there were no significant differences among treatments for early fruit number per plant (average 9.6), but there were significant differences among treatments for early fruit weight. There were no early fruit weight differences among containers filled with coconut coir, potting mix and perlite, ranging between 126.1 and 172.9 g/plant. Plants growing in pine bark produced lower early fruit weight than those growing in coconut coir and potting mix. The potting media affected the total fruit number and weight in the vertical system (Table 4). Containers filled with coconut coir or potting mix had higher total fruit number and weight than those filled with pine bark, averaging 34.2 fruit per plant and 548 g/plant, respectively.

In the horizontal systems, there were no significant differences among treatments on early and total fruit number and weight per plant. For early fruit, treatments averaged 7.2 fruit per plant and 121.4 $g{\cdot}plant^{-1}$ on fruit number and weight, respectively, whereas each plant produced approximately 46 fruit and 784 g during the season. These results indicated that for vertical systems, coconut coir, perlite, and potting mix are reliable growing media for strawberry production in a screen house. In contrast, this preliminary data suggested that for horizontal systems all four growing media were appropriate to produce a crop to a commercially-acceptable level. Although both studies were conducted separately, the media, source of plants, timing, and cultural management were similar. In this case, fruit yields in the vertical system were lower than those obtained in the

Table 4. Effects of soilless media for vertical and horizontal production systems on early (six harvests) and total fruit weight (25 harvests) for strawberries in Balm, FL, 2011-12 season.

Media	Early fruit weight		Total fruit weight	
	Fruit no./plant	g/plant	Fruit no./plant	g/plant
		Vertical system		
Pine bark	6.7	89.1 b	21.8 b	295.4 b
Coconut coir	11.4	172.9 a	33.7 a	527.0 a
Potting mix	11.0	162.0 a	34.7 a	568.6 a
Perlite	9.2	126.1 ab	29.4 ab	418.1 ab
P<0.05	NS	*	*	*
		Horizontal system		
Pine bark	5.8	97.0	46.0	781.4
Coconut coir	6.3	107.9	45.5	785.1
Potting mix	8.9	155.4	47.1	795.6
Perlite	7.9	125.1	46.1	771.9
P<0.05	NS	NS	NS	NS

Values followed by the same letters do not significantly differ at the 5% level, according to the Fisher's-protected least significant difference test. NS and * = non-significant and significant, respectively.

horizontal system, which indicated a need for modified fertilization, irrigation, and management practices for production in the vertical layout. Therefore, more research is needed to address the relatively low yields in the vertical system compared with the horizontal setting.

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Sink priority on 'Hayward' kiwifruit vines

An experimental system based on girdled shoots was used to assess how vegetative competition alters the growth of 'Hayward' kiwifruit. Each shoot was pruned to length so that it contained four source leaves and a sink consisting of either a single fruit, a vegetative regrowth, or one fruit and a vegetative regrowth. Vegetative competition had the greatest effect on fruit growth when it occurred about five weeks after flowering, when fruit growth is maximal. When a single fruit was in competition with a defoliated vegetative shoot, fruit size at harvest was reduced by 50%, whereas competition 20 days later reduced the fruit size by only 28%. Our results show that vegetative growth has a higher sink priority than fruit for both fresh weight and dry weight (DW) for the first 120 days after flowering, the time when most fruit growth occurs. Furthermore, during this period vegetative growth had a higher sink strength for DW than fruit. As a consequence of sink priority, when there is competition for limited resources, shoot growth continues at the expense of fruit growth. Abstract from: W.P. Snelgar, P.E.H Minchin, P. Blatmann and A.J. Hall, 2012. New Zealand Journal of Crop and Horticultural Science 40(4):253-263.