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Temperature Conditioning and Container Size Affect Early Season Fruit Yield of Strawberry Plug Plants in a Winter, Annual Hill Production System

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Abstract. **The demand for plug transplants by the Florida winter strawberry (*Fragaria* ×*ananassa* Duch.) industry may increase as water conservation during plant establishment becomes more important and the loss of methyl bromide fumigant makes the production of bare-root transplants more problematic. A study was conducted during the 1995–96 and 1996–97 seasons to determine the effect of container size and temperature conditioning on the plant growth and early season fruit yield of 'Sweet Charlie' strawberry plants. Plants in containers of three sizes (75, 150, and 300 cm^3) were grown in one of two temperature-controlled greenhouses (35 °C day/25 °C night or 25 °C day/15 °C night) for the 2 weeks just prior to transplanting into a fruiting field at Dover, Fla. Plants exposed to the 25/15 °C treatment had significantly higher average root dry weights at planting in 1995 and 1996 than did plants exposed to the 35/25 °C treatment. Plants exposed to the 25/15 °C treatment also had higher average fruit yields than the plants exposed to the 35/25 °C treatment (48% and 18% higher in 1995–96 and 1996–97, respectively). The effect of container size on plant growth and yield was variable. Plants propagated in the 150- and 300-cm^3 containers tended to be larger (at planting) than the plants propagated in the 75-cm^3 containers, but the larger container sizes did not result in consistently higher yields.**

Bare-root transplants with 3–4 leaves are the standard transplant used for the annual establishment of the 2500 ha of strawberries grown in west central Florida. A disadvantage of this type of transplant is that it needs extensive overhead irrigation for its successful establishment on black plastic-covered raised beds (Stanley et al., 1991). During planting in early October, Florida growers typically operate their sprinkler irrigation systems 7 h per day for 7 to 10 d to ensure plant establishment. This practice uses large amounts of water, much of which comes from the Floridan aquifer—a resource that has been severely depleted in recent years because of below average rainfall and a rapidly growing population (www.swfwmd.state.fl.us). Plug or tray transplants, in comparison to leafy bare-root transplants, require 1000 times less water for establishment (G.J. Hochmuth et al., 2001). Also, because plugs are produced using sterile potting mixes, they are less likely to have soil borne diseases, such as Phytophthora crown rot and Verticillium root rot. Bare-root transplants are produced in soil that has been fumigated to eliminate soil pathogens, but the standard fumigant used by many nurseries, methyl bromide, will no longer be available after 2005. The main disadvantage of plug plants is their high cost, which is generally double that of bare-root plants.

West central Florida has a long fruiting season (November–April), but it is usually the early season (November–February) fruit that commands the highest prices (Florida Agricultural Statistics; www.nass.usda.gov/fl). Florida and California researchers (Albregts, 1968; Chandler et al., 1989; Kirschbaum et al., 1998; Voth, 1989) have shown that high early season yields can be obtained with bare-root strawberry transplants that have large diameter crowns or have been exposed to low temperatures prior to digging. Little research has been published, however, on the influence of transplant size or pretransplant temperature on the performance of plug transplants. Durner (1999) did find that conditioned (short-day, low temperature treated) plug plants of 'Sweet Charlie' strawberry had higher December and January yield than non-conditioned plug plants, when grown in a greenhouse in New Jersey. NeSmith and Duval (1998) noted that the onset and duration of the flowering period can be affected by container size in some crops. The standard plug plant currently used in Florida has a soil volume of ≈75 cm^3. This type of transplant, if it has a crown diameter of 8 mm or larger, has compared favorably with bare-root transplants, in terms of early yield (Hochmuth et al., 2001). The objective of the present study was to determine the effect of container size and pretransplant temperature on early season fruit yield of strawberry transplants grown in a winter, annual hill production system.

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Materials and Methods

A 3 × 2 factorial experiment was conducted, with three container sizes and two preplant temperature regimes. 'Sweet Charlie' runner tips with two or three leaves and several root initials were collected from mother plants being grown in a greenhouse (Bish et al., 2001). These tips were then rooted under mist in Speedling Todd 100 plastic foam trays, and after 2 weeks transplanted on 25 July 1995 and 1996 into containers made from three different lengths of 5.4 cm i.d. polyvinyl chloride pipe. The three lengths were 3.25, 6.5, and 13 cm, which corresponded to 75-, 150-, and 300-cm^3 container volumes. The containers were sealed on the bottom with nylon screen (0.6 mm). The potting mix used was a mixture of 1 vermiculite : 1 perlite. Twenty-eight containers were grouped together to form an experimental unit. Water and fertilizer was supplied to the containers via capillary mats. Plants were grown for 8 weeks in a greenhouse on the campus of the Univ. of Florida in Gainesville [32 °C day/25 °C night; natural (long-day) photoperiod; 30% shade cloth, which resulted in an average light intensity of 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during full sun]. On 19 Sept., 2 weeks prior to field transplanting, the plants were placed in one of two air-conditioned greenhouses. The air temperature in one of the greenhouses was maintained at 35 °C day/25 °C night (to approximate ambient air temperatures in Florida) while the air temperature in the other greenhouse was maintained at 25 °C day/15 °C night (to approximate ambient air temperatures at high elevation or high latitude nursery sites). The greenhouses were not shaded, resulting in an average light intensity of 1100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during full sun. The natural photoperiod during this 2-week period ranged from 12 h 14 min (19 Sept.) to 11 h 49 min (3 Oct.).

Plants were removed from the greenhouse on 3 Oct. 1995 and 1996 and transported to the Univ. of Florida's Gulf Coast Research and Education Center at Dover (24 km east of Tampa), where they were planted in two-row, raised beds that had been fumigated with methyl bromide (98%)/chloropicrin (2%) at a rate of 269 $kg \cdot ha^{-1}$, and covered with black polyethylene mulch. Three replications of each of the six treatments were arranged in a randomized complete-block design. Each plot contained 20 plants, spaced 30 cm apart within and between rows. Plants were irrigated with overhead sprinklers for 1 h immediately after planting. Thereafter, drip irrigation was used. Standard cultural practices were followed throughout the season, as described by Maynard and Olson (2000).

One plant from each plot was taken just before planting, and one 3 weeks after planting, and divided into leaves, roots, and crown. The dry weights of these tissues were recorded. Ripe fruit from the plots were harvested, graded, and weighed weekly from November through February. These data were analyzed by analysis of variance.

Results and Discussion

Preplant temperature regime did not significantly affect the crown and leaf dry weights of plants at planting, but it did influence root dry weights (Table 1). Plants exposed to the 25/15 °C treatment had significantly higher average root dry weights at planting in 1995 and 1996 than did plants exposed to the 35/25 °C treatment. These results differ from those of Kirschbaum et al. (1998), who found that the average leaf and crown, but not root, dry weight of northern-propagated bare-root ‘Sweet Charlie’ plants were significantly greater than those of southern-propagated plants. The average maximum/minimum air temperature for the month of September was 19/11 °C in the northern propagation area and 32/23 °C in the southern propagation area. Any differences in root mass between northern and southern propagated plants may have been eliminated by the digging process. Plants were dug mechanically, which could have resulted in extensive root pruning.

The effect of container size on crown, leaf, and root dry weights at planting was variable (Table 1). Container size did not have an effect on crown dry weight at planting in 1995–96, but in 1996–97 plants in 300-cm^3 containers had greater average crown dry weight at planting than plants in smaller containers. In 1995–96, the average leaf dry weight of the plants in 300-cm^3 containers was greater at planting than the average leaf dry weight of plants in smaller containers, but in 1996–97 container size had no clear effect on leaf dry weight. In 1995–96, plants in the 75-cm^3 containers had the lowest average root dry weight, followed by plants in the 150-cm^3 containers. Plants in the 300-cm^3 had the highest average root dry weight. In 1996–97, the average root dry weight of plants in 150- and 300-cm^3 containers were similar and higher than the average root dry weight of plants in the 75-cm^3 containers.

Preplant temperature regime did not have an effect on the average dry weights of plants three weeks after planting in 1995–96, but did in 1996–97. Plants exposed to the 25/15 °C treatment had significantly higher average crown, leaf, and root dry weights 3 weeks after planting than did plants exposed to the 35/25 °C treatment (Table 2).

Container size had no detectable effect on the average crown and leaf dry weights of the plants 3 weeks after planting (Table 2). It did, however, affect the average root dry weight of plants exposed to the 25/15 °C treatment in 1995–96. Plants that had been grown in the 300-cm^3 containers had significantly greater average root dry weight than plants that had been grown in the 75- or 150-cm^3 containers.

Preplant temperature regime had a significant effect on total (November through February) fruit yield (Table 3). Plants exposed to the 25/15 °C treatment had a 48% higher average fruit yield in 1995–96 and an 18% higher fruit yield in 1996–97 than the plants exposed to the 35/25 °C treatment. These higher total yields were due to higher yields in November, December, and February. This is exactly what Kirschbaum et al. (1998) found with ‘Sweet Charlie’ bare-root plants. In that study, the northern-propagated plants (i.e., the plants that had been exposed to relatively low temperatures prior to transplanting) had significantly higher November–December and February yields than the southern-propagated plants.

As with plant dry weights, the effect of container size on fruit yield was variable (Table 3). In 1995–96, the total fruit yield of plants from 300-cm^3 containers was significantly higher than the yields of plants from 75-cm^3 containers, while in 1996–97, the plants from 150 and 75-cm^3 containers produced the highest total yields. The higher total yield of the plants from 300-cm^3 containers in 1995–96, compared to the yield of plants from 75-cm^3 containers, was due to greater fruit production in January and February.

There was a significant container size × pretransplant temperature regime interaction for November and December yield in 1996–97 (Table 3). Plants from the 150-cm^3 containers exposed to the 25/15 °C temperature regime had the highest November yield, while plants from the 150- and 75-cm^3 containers exposed to the 35/25 °C temperature regime had the lowest November yield. These plants compensated, however, for their low November yields by producing 11% and 50% higher December yields, respectively, than their counterparts exposed to the 25/15 °C temperature regime.

All transplants were exposed to the same day lengths (≈12 h) prior to transplanting—

Table 1. Effect of pretransplant temperature regime and container size on strawberry crown, leaf, and root mean dry weights at the time of planting in the fruiting field.[z]

Factor	Dry weights (g) Crown 1995–96	Crown 1996–97	Leaf 1995–96	Leaf 1996–97	Root 1995–96	Root 1996–97
Temperature regime (day/night °C)						
25/15					0.20 a	0.28 a
35/25					0.16 b	0.19 b
Container size (cm^3)						
75			0.73 b		0.12 c	0.14 b
150			0.86 b		0.17 b	0.41 a
300			1.16 a		0.26 a	0.37 a
Temperature × container size						
25/15 75		0.15 c[y]		0.61 bc		
25/15 150		0.13 c		0.60 bc		
25/15 300		0.23 b		0.88 ab		
35/25 75		0.07 d		0.45 c		
35/25 150		0.12 c		1.03 a		
35/25 300		0.32 a		0.82 ab		
Significance						
Temperature	NS	NS	NS	NS	**	*
Container size	NS	***	***	*	***	***
Interaction	NS	***	NS	*	NS	NS

[z]Only values for significant main effects and interactions are presented.
[y]Mean separation within factors within columns by LSD at $P \leq 0.05$.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Effect of pretransplant temperature regime and container size on strawberry crown, leaf, and root mean dry weights 3 weeks after planting in the fruiting field.[z]

Factor	Dry weights (g) Crown 1995–96	Crown 1996–97	Leaf 1995–96	Leaf 1996–97	Root 1995–96	Root 1996–97
Temperature regime (day/night °C)						
25/15		0.28 a[y]		2.30 a		1.00 a
35/25		0.15 b		1.37 b		0.52 b
Temperature × container size (cm^3)						
25/15 75					0.533 b	
25/15 150					0.587 b	
25/15 300					0.757 a	
35/25 75					0.570 b	
35/25 150					0.560 b	
35/25 300					0.567 b	
Significance						
Temperature	NS	**	NS	**	NS	***
Container size	NS	NS	NS	NS	*	NS
Interaction	NS	NS	NS	NS	*	NS

[z]Only values for significant main effects and interactions are presented.
[y]Mean separation within columns by LSD at $P \leq 0.05$.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Effect of pretransplant temperature regime and container size on strawberry mean fruit production.[z]

	Marketable fruit wt ($t\cdot ha^{-1}$)									
	Nov.		Dec.		Jan.		Feb.		Total	
Factor	1995–96	1996–97	1995–96	1996–97	1995–96	1996–97	1995–96	1996–97	1995–96	1996–97
Temperature regime (day/night °C)										
25/15	3.05 a[y]		5.94 a				10.79 a	9.73 a	21.61 a	23.34 a
35/25	0.09 b		3.82 b				8.01 b	7.11 b	14.56 b	19.73 b
Container size (cm^3)										
75					0.98 b		8.16 b	9.80 a	15.68 b	22.45 a
150					2.11 b		9.45 ab	9.02 a	18.10 ab	23.33 a
300					3.61 a		10.59 a	6.44 b	20.47 a	18.83 b
Temperature × container size										
25/15 75		2.42 bc		4.35 cd						
25/15 150		3.94 a		4.50 cd						
25/15 300		3.03 b		4.08 de						
35/25 75		0.62 d		6.53 a						
35/25 150		1.18 d		5.00 bc						
35/25 300		2.06 c		3.56 e						
Significance										
Temperature	***	***	**	**	NS	NS	**	*	***	*
Container size	NS	***	NS	***	**	NS	*	*	**	*
Interaction	NS	**	NS	**	NS	NS	NS	NS	NS	NS

[z]Only values for significant main effects and interactions are presented.
[y]Mean separation within factors within columns by LSD at $P \leq 0.05$.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

day lengths that are considered conducive to floral initiation when air temperatures are between 15 and 25 °C (Hancock, 1999). Plants exposed to the 25/15 °C temperature regime began accumulating more root mass and may have begun initiating flowers during the two week treatment period, while plants exposed to the 35/25 °C regime did not. This would explain the higher November yields of the 25/15 °C treated plants. Kirschbaum et al. (1998) notes that an adequate level of carbohydrate in the roots appears to be fundamental for early fruiting in strawberry.

The effect of container size on early season yield was less consistent than that of temperature regime. Two factors may have contributed to this inconsistency: 1) Weather differed markedly between the seasons of this study. Overall, 1995–96 was cooler and wetter than average, while 1996–97 was warmer and drier than average (Stapleton et al., 2001). 2) It was noted during the transplanting operation that some of the plants in the deeper containers did not have root systems that reached to the bottom of the container. This indicates that the plants in the deeper containers may not have had sufficient time to exploit the larger volumes of soil. Plants may need longer than 10 weeks to derive maximum benefit from a 150- or 300-cm^3 container. Strawberry transplants for greenhouse fruit production in western Europe are grown in trays with cell sizes of 280 to 300 cm^3 (Philip Lieten, personal communication). These plants typically remain in the trays for 4 months before they are transplanted into a fruit production system.

The present study has demonstrated the importance of temperature conditioning (exposure to air temperatures in the 15 to 25 °C range) for high early season yield of strawberry plug plants grown in a winter annual hill production system. Large scale conditioning in an air-conditioned greenhouse would be impractical, but the same effect could be obtained by growing plug plants outdoors in a high elevation (e.g., western North Carolina) (Stapleton et al., 2001) or high latitude (e.g., Nova Scotia) location for several weeks (mid to late September) prior to planting in central Florida. This study has also shown that container size can affect plant growth and yield. Additional research is needed, however, to examine how factors such as length of time in the container and container shape interact with container volume to affect root and crown growth and early fruit yield.

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