Accelerator™ Containers Alter Plant Growth and the Root-zone Environment[1]

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Abstract

Five species of trees, *Fraxinus velutina* Torr., *Pistacia chinensis* Bunge, *Platanus occidentalis* L., *Quercus virginiana* Mill., and *Ulmus parvifolia* Jacq., were first grown in conventional black plastic liner containers (0.45 liter, 0.41 qt) then transplanted to black plastic containers filled with 25 liters (7 gal) of substrate and grown to marketable size. The same species were grown in Accelerator liners and then transplanted to open bottom, air-root pruning, cylindrical, aluminum (Accelerator) containers filled with equal volumes of substrate. Plant growth characteristics, root-zone temperatures, and substrate moisture status were measured. As with many container technologies, responses were species dependent. Growth of *Q. virginiana* was reduced in Accelerator liner containers compared to conventional black plastic liners. Root coverage on the periphery of the rootballs were reduced on *U. parvifolia* grown in 25 liter (7 gal) containers compared to those in black plastic containers. Growth of *U. parvifolia*, *F. velutina*, and *Q. virginiana* were similar in the larger black plastic and Accelerator containers. Growth of *P. chinensis* and *P. occidentalis* were greater in the larger Accelerator containers than in the larger conventional black plastic containers. Root-zone temperatures, particularly at the periphery of the rootball, were significantly reduced on warm days in Accelerator containers compared to those in black plastic containers. Substrate in Accelerator containers were slightly drier than that in black plastic containers.

Index words: container production culture, air root pruning, root-zone temperatures.

Species used in this study: *Fraxinus velutina*, *Pistacia chinensis*, *Platanus occidentalis*, *Quercus virginiana*, *Ulmus parvifolia*.

Significance to the Nursery Industry

Accelerator containers offer an alternative to chemically-treated containers or fabric bags as a root growth controlling technology to avoid circling root development during container production of trees. Species with requirements for extremely well-drained substrate or those with problematic taproots may respond well to production in open bottom Accelerator containers. Species sensitive to high root-zone temperatures may benefit from production in Accelerator containers with reflective aluminum side walls compared to conventional black plastic containers.

Introduction

A number of alternative containers designed to reduce the amount of root deformation associated with plant growth in containers have entered the market in recent years (1). Strategies range from disruption of the smooth inner surfaces of the container wall by various raised ridges or insertion of sharp angles (22) to the coating of interior surfaces (5, 6) or direct incorporation of root inhibiting chemicals into the container walls (4, 18, 19). Another strategy used the small holes in between woven strands as root girdling methods for mechanically pruning roots as they emerge from fabric bag containers (1, 2). Many early root pruning strategies incorporated air pruning of tap roots during seedling propagation. All of these methods have been successfully utilized in one or more production system, but also carried limitations. Accelerator™ containers (Accelerator Growers Association, Boca Raton, FL) are constructed of reflective aluminum and utilize an air root pruning mechanism to control root growth similar to that originally developed in low profile containers by Milbocker (16, 17). However, Accelerator containers include anchor fabric panels to help eliminate blow-over (2) and have reflective surfaces that may influence substrate temperatures.

Root architecture problems are not the only limitation associated with production of container-grown plants. Rootballs are often exposed above ground and/or placed on surfaces that raise the ambient root-zone temperature due to reflected or radiated heat from gravel or black plastic sheeting surfaces. Researchers (10, 11, 20, 23) have documented the potential for supraoptimal root-zone temperatures of woody ornamental species under typical container production environments in the southern United States. The reflective properties of the aluminum walls on Accelerator containers might be useful in reducing absorption of heat from solar radiation, but are untested in this regard.

The objectives of this study were: 1) to test the effects of Accelerator versus conventional black plastic containers on the growth of five species of shade trees common to the regional nursery trade, and 2) to sample root-zone temperatures and substrate moisture tension to determine if differences occurred between the root-zone environments in the container types.

Materials and Methods

After stratification at 4C (38F), seeds of *Fraxinus velutina* (sown December 26, 1996), *Platanus occidentalis* (December 26, 1996), *Ulmus parvifolia* (January 30, 1997), and *Pistacia chinensis* (January 30, 1997) were planted in 9 cm (3 in) deep flats containing 1.7 cm (0.5 in) screened composted pine bark. Germination occurred in a greenhouse set at 25/18C (77/65F) day/night temperatures. After germination, night interruption was provided to promote vegetative growth using 100 watt incandescent light bulbs sus-

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pended 0.5 m (19 in) above the containers on 1 m (39 in) centers from 00:00 to 04:00 hr.

On January 31, 1997, *Quercus virginiana* seeds were direct sown into mean 7.6 cm (3.0 in) diameter by 8.9 cm (3.5 in) tall black plastic liners (TLC Polyform Inc., Moorow, GA) and into mean 8.5 cm (3.3 in) diameter by 10 cm (3.9 in) tall Accelerator grower containers filled with 0.45 liters (0.41 qt) of substrate. The Accelerator liner containers (Accelerator Growers Assoc., Hold Em Inc., West Palm Beach, FL) consisted of a 36 cm (14 in) long by 10 cm (4 in) wide by 0.4 mm (0.02 in) thick undulate piece of aluminum alloy, polished on the outer surface, coiled into a cylinder and fastened in place by two rivets. Seedlings of *F. velutina* (transplanted January 29, 1997), *P. occidentalis* (January 30, 1997), *P. chinensis* (March 25, 1997), and *U. parvifolia* (April 28, 1997) were transplanted at the second true leaf stage from germination flats to both liner containers. Liner containers were filled with substrate consisting of milled pine bark:coconut coir pith (3:1 by vol) amended with 4.7 $kg \cdot m^{3}$ (8 $lb \cdot yd^{-3}$) 18N–3P–8K Osmocote 6 month controlled release fertilizer (Scotts Co., Marysville, OH), 3.6 $kg \cdot m^{-3}$ (6 $lb \cdot yd^{-3}$) dolomitic limestone (Vulcan Materials Co., Tarrant, AL), 4 $lb \cdot yd^{-3}$ (1.8 $kg \cdot m^{-3}$) gypsum (Standard Gypsum Corp., Fredericksburg, TX), and 0.9 $kg \cdot m^{-3}$ (2 $lb \cdot yd^{-3}$) Micromax micronutrients (Scotts Co.). Flats of black plastic and Accelerator liners were randomly intermixed on greenhouse benches. Seedlings were hand watered as needed in the greenhouse and fertigated weekly with 200 $mg \cdot liter^{-1}$ (ppm) of N from a complete 24N–3.5P–13K fertilizer (24–8–16, Scotts Co.).

Platanus occidentalis, *Q. virginiana*, *F. velutina*, and *P. chinensis* liners were moved outdoors under 55% light exclusion on March 25, 1997, and to full sun exposure on a light tan washed river rock gravel surface two weeks later. *Ulmus parvifolia* liners were moved outdoors on April 28, 1997. Seedlings were irrigated twice daily with 1.3 cm (0.5 in) of a solution containing 50 $mg \cdot liter^{-1}$ (ppm) N from a 24N–3.5P–13K fertilizer (Scotts Co.) via overhead application.

On June 6, 1997, 15 plants of each species grown in plastic and Accelerator liners were transplanted to larger containers. The plants from plastic liners were transplanted to larger black plastic containers (Classic 4000, Nursery Supplies Inc., Chambersburg, PA) filled with 25 liters of substrate. The black plastic containers were 36 cm (14.25 in) tall with a flared lip on sidewalls that sloped from a diameter of 36 cm (14.2 in) at the top to 33 cm (13.0 in) at the base of the containers. Using a mean diameter of 34.5 cm (13.6 in), the height to width ratio is 1.04:1.00. Plants grown in Accelerator liners were transplanted to larger Accelerator containers. At transplant, 10 additional liners of each container type and species were destructively harvested to determine shoot height, trunk diameter, and root and shoot dry mass. Total plant (root + shoot) dry mass and root:shoot ratio (root / shoot dry mass) were calculated for each plant.

The larger 40.7 cm (16 in) tall by 30.5 cm (12 in) wide cylindrical Accelerator containers (Accelerator Growers Assoc., Hold Em Inc., West Palm Beach, FL) were constructed from a 104 cm (41 in) long by 40.7 cm (16 in) wide by 0.4 mm (0.02 in) thick undulate piece of aluminum alloy, polished on the outer surface, coiled into a cylinder and fastened in place by two 1.3 cm (0.5 in) screws. Peaks of the undulations were 7.5 cm (3 in) apart and were 2 cm (0.8 in) deep. Outward facing undulations had a series of vertical 3.0 cm (1.2 in) tall by 0.7 cm (0.28 in) wide and horizontal 0.7 cm (0.29 in) tall by 1.9 cm (0.75 in) wide slits running up and down the container to act as air root pruning locations. The undulations served to direct the roots to the pruning slits. The side walls of the Accelerator containers had no vertical slope from top to bottom. The height to width ratio for the containers was 1.33:1.00. A non-woven fabric cloth (style S700, 110 mil thickness, Hold Em Inc., West Palm Beach, FL) was placed beneath the open bottom of the Accelerator containers. Containers were then filled with a composted pine bark:organagro bio-solids compost:sharp sand (8:1:1 by vol) substrate (Custom Potting Soil, Vital Earth Resources, Gladewater, TX) containing 3.6 kg (8 lb) dolomitic lime, 1.4 kg (3 lb) gypsum, and 0.68 kg (1.5 lb) micropak micronutrients per 0.8 m^3 (1.0 yd^3).

Fifteen single plant replications of black plastic and Accelerator containers of each species were placed on 1.5 m (5 ft) centers in full sun exposure on a light tan washed river rock gravel surface in a completely random design. Individual species were grown in adjacent plots so as to not induce shading effects due to differential growth rates, hence each species was treated as one of five experiments conducted concurrently. Plants were trained to a single leader on 1.9 m (6 ft) stakes. Stakes were attached to a wire trellis as plant canopy size increased to prevent repeated blow-over. Individual containers were top-dressed with 23N–1.7P–6.6K (23–4–8 High N Southern Formula, Scotts Co., Marysville, OH) at the rate of 6.8 kg $N \cdot m^{-3}$ (12 lb $N \cdot yd^{-3}$) on March 25, 1998. Each container was drenched to runoff with a solution containing 50 $mg \cdot liter^{-1}$ (ppm) of chelated Fe (Sprint 138, CIBA-GEIGY Corp., Greensboro, NC) on July 31, 1998. Plants were scouted weekly for pests, treated as needed, and weeded manually.

Seedlings were fertigated twice daily during the active growing season with 1.3 cm (0.5 in) of a solution containing 50 $mg \cdot liter^{-1}$ (ppm) N from a 24N–3.5P–13–K fertilizer (Scotts Co.) and irrigation water was adjusted to a target pH of 6.5 via injection of sulfuric acid. Fertigation was applied using two microsprinklers (#9 spot spitters, Roberts Irrigation, San Marcos, CA) per container. Calculations for the 1.3 cm (0.5 in) application were based on the larger diameter plastic container surface area, but equal volumes of water were applied to each container type at any particular irrigation event. Fertilizer injection was discontinued after September 30 each year and resumed on February 15. Early and late in the growing season irrigation was reduced to once per day, and irrigation was applied only as needed during the winter.

Substrate moisture conditions were monitored in two black plastic and two Accelerator containers by placing Model 2725A Jet Fill Tensiometers (Soilmoisture Equipment Corp., Santa Barbara, CA) 15 cm (6 in) deep and 2.5 cm (1 in.) to the south of the crown of the *Ulmus parvifolia* seedlings in the centers of the containers. Soil moisture measurements were recorded in early afternoon.

Root-zone temperatures were monitored on the same two black plastic and two Accelerator containers as used to monitor soil moisture using 10.2 cm (4 in) Cole-Parmer 400 series thermistor penetration probes attached to a Digi-Sense® scanning thermocouple thermometer (Cole-Parmer, Vernon Hills, IL). Three probes were placed in each container type in the same relative positions: the center probe adjacent to the south side of the seedling crown, the midpoint probe half way from the seedling to the periphery of the container [18.0 cm (7.1 in) from the periphery for plastic containers and 15.2 cm (6 in) for Accelerator containers], and the outside probe placed in the substrate 1 cm (0.4 in) inside the south wall of each container. Temperatures were recorded at 60 minute intervals from February 26 through March 30, 1998. Ambient air temperatures were recorded using a Grow Weather™ station with Grow Weather Link software (Davis Instruments Corp., Haywood, CA).

Pistacia chinensis and *P. occidentalis* were harvested on April 26, 1998. *Ulmus parvifolia*, *F. velutina*, and *Q. virginiana* were harvested on November 1, 1998. Trunk diameter at 15 cm (6 in) above the root collar and shoot height were measured for all plants. Ten plants of each species and container treatment combination were destructively harvested to determine root and shoot dry masses. Root:shoot ratios were calculated (root / shoot dry mass). Percentage of the rootball periphery covered by deflected roots was estimated on a 0 = none, 1 = 0 < x < 10 %, 2 = 11 % < x <20 %, … 10 = 91 % < x < 100 %.

Each species was considered to be a separate study and data were analyzed for each species as five concurrent experiments. Each study was analyzed as a completely randomized design containing fifteen single plant replications of each treatment for non-destructive growth measures, or ten single plant replications for dry mass determinations. Significant ($P < 0.05$) container effects were determined using the general linear models procedures in SAS and, for significant effects, treatment means were compared utilizing the least squares means procedure (21).

Results and Discussion

As with most container technologies, responses were species dependent. Accelerator containers induced a statistically significant ($P < 0.05$) increase in trunk diameter of *F. velutina*, and decreases in height of *Q. virginiana* and *P. occidentalis*, root mass of *U. parvifolia*, shoot and total dry mass of *Q. virginiana*, and root:shoot ratios of *F. velutina* when grown in liner containers (Table 1). However, with the exception of a general reduction in the size of *Q. virginiana*, seedlings grown in Accelerator containers, differences within a species were of little magnitude at the liner (0.45 liter, 0.41 qt) stage.

Growth responses were more pronounced for some species when grown in larger containers, with substantial increases in height, trunk diameter, and total dry mass of *P. chinensis*, height and trunk diameter of *P. occidentalis*, and root:shoot ratios of *Q. virginiana* grown in Accelerator containers compared to those in black plastic containers (Table 2). Growth of *U. parvifolia*, aside from root ratings, and growth of *F. velutina* were unaffected during production in 7 gal (25 liter) containers compared to seedlings in black plastic containers (Table 2). Only root:shoot ratios were altered for *Q. virginiana* (Table 2). Thus, Accelerator containers induced species-specific responses with little alteration of size of *U. parvifolia*, *F. velutina*, and *Q. virginiana* seedlings, while growth was enhanced in *P. chinensis* and *P. occidentalis* compared to production in 7 gal (25 liter) black plastic containers. Marshall and Gilman (13) found no significant differences in red maple (*Acer rubrum* L.) seedlings grown in Accelerator versus standard black plastic containers for 70 weeks.

Growth of *P. chinensis* seedlings may have been favored by the drier (–6.8 kPa versus –5.2 kPa) substrate in Accelerator versus black plastic containers. *Pistacia chinensis* is an very drought tolerant species native to East Asia that is frequently utilized in arid landscapes, sometimes becoming persistent and/or adventive on droughty sites (3, 15).

Differential growth responses of *Platanus occidentalis* seedlings were probably not typical of long-term usage of Accelerator versus black plastic containers. The differential responses were more likely attributable to root system decline. Root decline occurred on nearly all of the sycamores grown in black plastic containers in the nursery following a hot rainy period in early summer 1997. Only a few of the sycamores in the Accelerator containers exhibited stress symptoms. Many of the sycamores in black plastic containers were severely stunted or killed, hence final dry masses and root ratings were not taken for this species (Table 2).

Table 1. Growth responses of five species of trees in conventional 0.45 liter (0.41 qt) black plastic liners and open_bottom aluminum Accelerator containers.

				Tissue dry mass[y]			
Species	Container	Height[y] (cm)	Trunk diameter[y] (mm)	Root (g)	Shoot (g)	Total (g)	Root / shoot (g / g)
Ulmus parvifolia	Conventional	26.0a[z]	2.7a	1.82a	2.73a	4.55a	0.69a
	Accelerator	27.2a	2.9a	1.15b	1.92a	3.77a	0.61a
Fraxinus velutina	Conventional	62.7a	6.5b	8.73a	11.22a	19.95a	0.82a
	Accelerator	63.2a	7.3a	6.07a	10.42a	16.49a	0.59b
Pistacia chinensis	Conventional	22.8a	2.5a	1.03a	2.78a	3.81a	0.40a
	Accelerator	21.6a	2.4a	0.92a	2.14a	3.07a	0.43a
Quercus virginiana	Conventional	18.3a	1.9a	3.12a	1.79a	4.90a	1.80a
	Accelerator	15.4b	2.0a	2.07a	0.98b	3.04b	2.39a
Platanus occidentalis	Conventional	39.4a	5.2a	2.53a	4.33a	6.86a	0.66a
	Accelerator	33.9b	4.8a	2.18a	5.02a	7.20a	0.46a

[z]Means within a species and column followed by the same letter are not significantly different at $P < 0.05$.
[y]n = 10.

Table 2. **Growth responses of five species of trees in conventional black plastic containers and open_bottom aluminum Accelerator grower containers containing 25 liters (7 gal) of substrate.**

Species	Container	Height (cm)^x	Trunk diameter (mm)^x	Root rating^y (1–10)^z	Tissue dry mass^z Root (g)	Shoot (g)	Total (g)	Root / shoot (g/g)
Ulmus parvifolia	Conventional	225a^w	22.0a	3.7a	548a	661a	1209a	0.81a
	Accelerator	213a	21.8a	1.5b	457a	628a	1085a	0.74a
Fraxinus velutina	Conventional	208a	29.7a	5.2a	988a	538a	1526a	1.73a
	Accelerator	186a	30.4a	5.1a	773a	519a	1292a	1.47a
Pistacia chinensis	Conventional	188b	18.1b	1.0a	118a	340a	458b	0.35a
	Accelerator	219a	23.0a	1.0a	186a	474a	660a	0.39a
Quercus virginiana	Conventional	185a	24.3a	1.6a	252a	484a	736a	0.51b
	Accelerator	164a	24.8a	1.1a	358a	535a	893a	0.74a
Platanus occidentalis	Conventional	60b	6.8b	—^{v}	—	—	—	—
	Accelerator	165a	23.7a	—	—	—	—	—

^{z}n = 10.

^{y}Root ratings indicating the proportion of circling and deflected roots at the rootball : container wall interface, 0 = no deflected or circling roots, 1 = 1% to 10% of the rootball covered with deflected or circling roots, 2 = 11% to 20 %, … 10 = 90% to 100 % or the rootball covered with deflected or circling roots.

^{x}n = 15.

^{w}Means within a species and column followed by the same letter are not significantly different at $P < 0.05$.

^{v}Root ratings and tissue data were not collected on *P. occidentalis* due to root system decline.

Tissue samples from the affected *P. occidentalis* sent to Dr. Larry Barnes (Texas Agric. Ext. Ser. Plant Pathologist, Plant Diagnostic Lab., Texas A&M Univ., College Station, TX) indicated infestations of the sycamore roots by an *Alternaria* Nees sp. fungus. No other pathogens were isolated from the roots. While *Alternaria* is typically a secondary pathogen on roots, we have repeatedly had *Alternaria* isolated from the crown and roots of *P. occidentalis* seedlings exhibiting damping off symptoms in germination flats at our nursery. Control of the disease only occurred when fungicides that were effective on *Alternaria* were utilized. However, Koch's postulates were not tested in either situation, hence a casual agent could not be positively identified.

Root ratings, based on percent coverage of peripheral portions of the rootball by deflected or circling roots, were utilized as a measure of container efficacy in reducing root deformation. Significant differences in root deformation among container types were found only for *U. parvifolia* in larger containers (Table 2). Percent root surface coverage of rootballs was reduced for *U. parvifolia*. These data do not reflect the entire effects of the Accelerator containers on root morphology. Differences in percent root surface coverage of rootballs was not observed on most species (Table 2). Visual inspection revealed that root deflection did frequently occur at the container wall:substrate interfaces for both Accelerator and plastic containers. However, the presence of roots circling more than a few inches horizontally was infrequent on Accelerator containers. Longer deflected lateral roots at the rootball periphery occurred on several plants in black plastic containers. Marshall and Gilman (13) reported similar results with a greater proportion of vertically deflected roots on Accelerator rootballs than horizontally deflected roots.

Mean absolute temperature differentials from the periphery to the center of the container were greater ($P < 0.01$) for rootballs in plastic (5.9C, 10.6F) versus Accelerator containers (4.1C, 7.4F). The most substantial temperature differentials between the two container types were evident at the periphery of the rootballs. The least variation between container types was evident at the midpoint between the center and periphery of the containers (Fig. 1). Temperatures on the exterior edges of the Accelerator containers were at least 5C (9F) cooler than that for black plastic containers on several days during the monitored period (Fig. 1A). Presumably, this was due to greater reflectivity of incoming solar radiation by aluminum surfaces of Accelerator containers versus black surfaces on plastic containers. It is also possible that high temperatures were moderated via gas exchange and/or moisture evaporation through the air root pruning slits in the containers, but this was not tested.

It is interesting to note the wide variation in temperatures at peripheral surfaces of the substrate within a day's time (Fig. 1A), from below freezing to near 40C (104F). While wide variation occurs among species as to injurious or lethal root-zone temperatures in soils (12), several researchers have reported that supraoptimal root-zone temperatures of from 32C (90F) to 40C (104F) could reduce photosynthetic rates or dry mass accumulation with container grown *Ilex crenata* Thunb. 'Rotundifolia' and *Pittosporum tobira* Thunb. (10, 11, 23). Results presented here confirm the potential for high root-zone temperatures to occur very early in the growing season, perhaps even before the threat of freeze damage is past. Surprisingly, some buffering of Accelerator rootballs from minimum temperatures was also evident with warmer minimums for Accelerator compared to plastic containers (Fig. 1A, 1C). Buffering of temperature differentials did not appear to be due to greater ground contact area on Accelerator containers, as Accelerator containers had a greater height to width ratio (1.33:1.00 versus 1.04:1.00) and smaller diameter container bottom [30.5 cm (12 in) versus 33.0 cm (13 in)] than the black plastic containers. Hence, any soil (gravel) contact buffering effect should have been greater with the

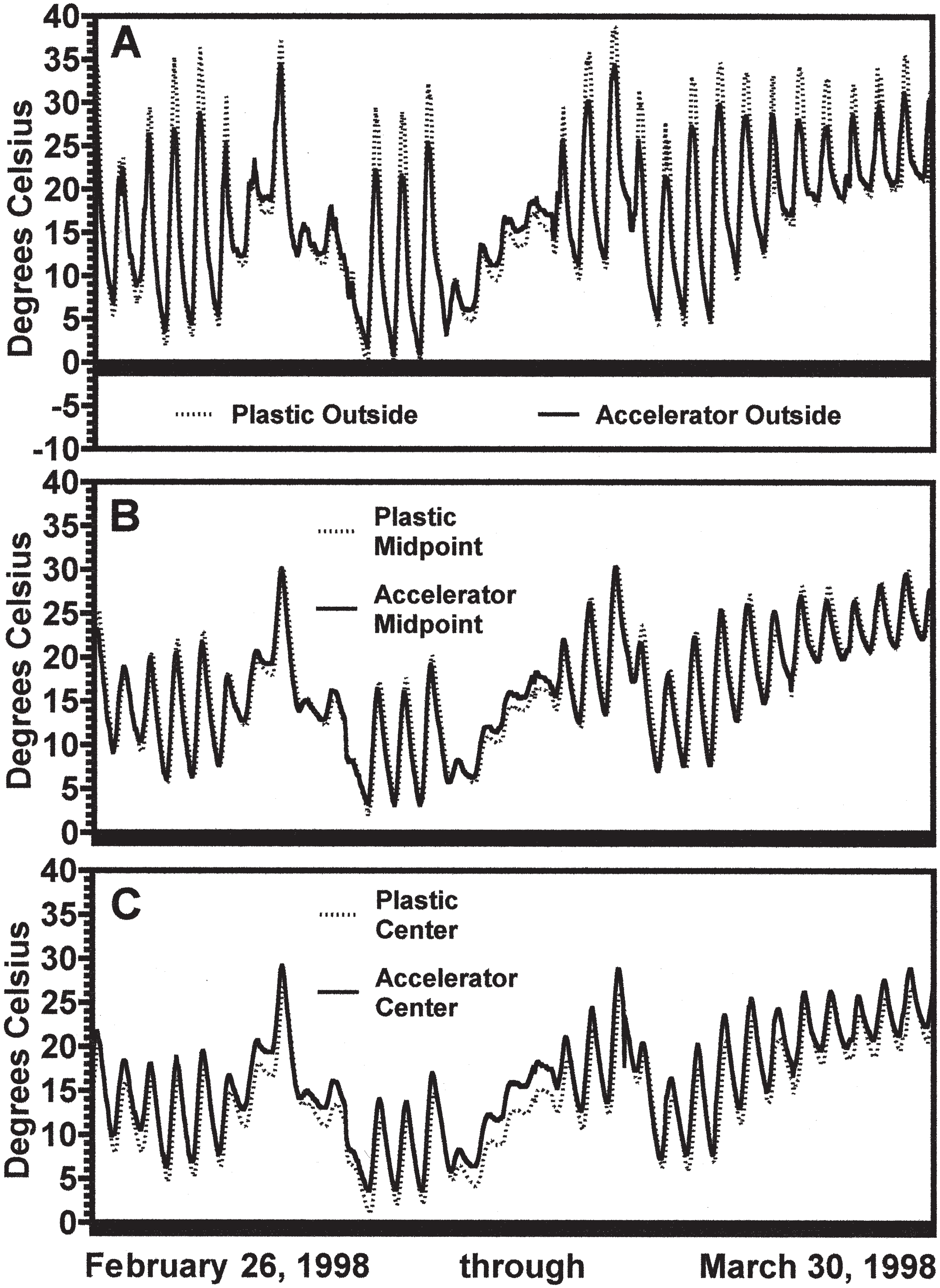

Fig. 1. **Temperatures from February 26, 1998, through March 30, 1998, measured 1 cm (0.4 in) inside the periphery of the rootball (A), midway from the periphery to the center (B), and adjacent to the crown of *Ulmus parvifolia* seedlings (C) grown in black plastic (——) or Accelerator (........) containers filled with 25 liters (7 gal) of substrate.**

black plastic containers since they had the greater contact area. Certainly these temperature data suggest that methods to reduce temperature fluctuations in the root-zone may be helpful in reducing the potential for freeze or heat injury during container production in warm temperate regions.

High temperature reductions may be particularly important when saturated soil conditions occur in conjunction with high root-zone temperatures. Such conditions might be mimicked in containers with heavy substrate following extensive rains or frequent irrigation in summer. An interaction was found for flood tolerance and supraoptimal root-zone temperatures in terms of growth, biomass accumulation, and survivorship for several woody swamp species (8, 14). It has been reported that combinations of high root-zone temperatures and saturated soil conditions adversely impacted root respiration, photosynthesis, transpiration, altered ethylene metabolism, and increased electrolyte leakage from root tissues (7, 9). Interactions among moisture levels that might reduce available oxygen in container substrate and elevated root-zone temperatures are poorly understood for nursery crops, as studies have typically addressed one factor or the other, but not both. In this study, high moisture and high temperature in the root-zone appear to have predisposed *P. occidentalis* to root system decline.

Upon approaching marketable size, plants in Accelerator containers tended to wilt sooner after irrigation that those grown in conventional black plastic containers. Mean soil moisture tensions were more negative in Accelerator containers (–6.8 kPa) compared to black plastic containers (–5.2 kPa). This suggests that more frequent irrigation may be required with the Accelerator containers. This might result in greater water use than with conventional containers. It was uncertain whether the more negative substrate tension was due to increased drainage from open bottom containers and/or air root pruning slots, increased moisture loss via gas exchange through air root pruning vents, or greater depletion of moisture by plants in Accelerator containers compared to conventional containers.

Drawbacks to the prototype Accelerator containers observed in this study included increased blow-over relative to conventional containers, more rapid drying of the substrate, and a propensity for weed growth in the air root pruning vents. With frequent rocking motions during windy periods, substrate tended to work out of the cylinder where it met the fabric mat base resulting in some substrate loss.

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