Container Type and Overwintering Treatments Affect Substrate Temperature and Growth of Chanticleer® Pear (*Pyrus calleryana* 'Glen's Form') in the Nursery[1]

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Abstract

The container most used for nursery tree production is black plastic (BP). High substrate temperatures occurring in BP can injure or kill roots; BP-grown trees often develop circling and malformed roots. Root injury sustained during production may negatively affect tree health after planting in the landscape. Many containers are available for nursery production, but few studies have examined the merits of alternative container types for production. We compared the growth of *Pyrus calleryana* Decene. 'Glen's Form' (Chanticleer®) in three container types: black plastic, Root Pouch® (RP) and Smart Pot® (SP), over two growing seasons and under two overwintering treatments (consolidated or lined out). After the first growing season, there were no differences in height or dry leaf, shoot and root weight among the three containers. Following the second growing season, caliper, height, leaf area, percent leaf moisture, and root ball quality differed among container type. After the 2010–2011 winter, consolidated trees produced larger root and shoot systems (35.3 and 36.4%, respectively) than trees that were lined out. Substrate temperature maxima and fluctuations during winter and summer were greatest for BP containers compared to RP and SP. The potential advantages of producing trees in fabric containers merit consideration from nursery producers.

Index words: container nursery production, container type, black plastic container, Root Pouch®, Smart Pot®, root morphology, nursery tree production, root quality, root circling, root matting, substrate temperatures, overwintering treatments.

Species used in study: *Pyrus calleryana* 'Glen's Form' (Chanticleer®).

Significance to the Nursery Industry

Nursery producers are under increasing pressure to maintain production efficiency and grow high-quality plants in a cost effective manner. One cost saving measure may be to switch from solid plastic containers to fabric containers. Due to increasing costs of materials and petroleum, growing consumer interest in sustainable or recyclable products, and awareness that black plastic containers may negatively affect root system structure, nursery growers are looking for alternatives to black plastic containers. We evaluated Chanticleer pear trees in two fabric container types relative to standard black plastic containers over two growing seasons. Pears grown in the fabric containers had greater height and caliper growth and fewer circling roots. Trees not consolidated into a block for overwintering suffered more damaged compared to trees that were placed in a consolidated block. Fabric containers should be considered as a production alternative to solid plastic containers.

Introduction

Above-ground container tree production is a popular way to grow ornamental trees and is used more commonly than field production in many parts of the United States (12). Some advantages of container production include ease of mobility and handling, less space needed than field-grown trees, greater consumer acceptance, increased productivity attributed to increased production density and shortened rotation times, year-round harvest, and production of difficult-to-transplant taxa. Container production has also expanded the types of taxa that can be economically produced. A major reason for the adoption of container production is reduced transplant shock expressed as increased transplant survival and reduced establishment time (16). Transplant shock associated with field-grown material results from the loss of root mass associated with harvesting; up to 95% of the original root volume is lost when field grown trees are harvested according to national standards (35).

Disadvantages of container production include: additional costs for substrates, fertilizer, water, labor and efforts to overwinter materials. Circling and/or malformed roots are often seen with container-grown trees, which can negatively impact the tree health and stability many years following transplanting into the landscape (7, 29). Finally, it is estimated than 350 million pounds of black plastic (BP) containers are thrown away each year (24).

Traditionally, the majority of container nursery stock has been grown in BP containers. There are numerous production challenges associated with container nursery stock, the most important being the prevention of root malformation caused by circling and matting roots (36) and root injury resulting from extreme winter and summer substrate temperatures. Post-production challenges associated with production in plastic containers include transplant survival and establishment success in the landscape. Poor transplant success (root malformation and poor growth into the native soil) can often be attributed to root-related problems that occur during the production process—especially when trees are grown in plastic containers (17).

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The optimum temperature range for tree root growth is between 15 to 27C (59 to 81F) (32). Plants growing in black plastic pots can be subjected to excessively high or lethal root temperatures during the summer (19). At soil temperatures greater than 30C (86F), root damage occurs and growth and plant health declines (14, 22). In the southern United States, root temperatures have been reported to reach 58C (136F) (22), but these extreme temperatures may only last for a short time. However, temperatures at 42C (108F) have been found to last for several hours (30), causing permanent damage to plant roots. Also, extremely cold temperatures can injure roots. Temperatures fluctuating around freezing can cause severe damage to actively growing root systems. Further, the often extreme temperature fluctuations seen in BP containers are a problem for plant root systems. In northern zones, winter substrate temperatures can be modified by overwintering stock in polyhouses, or consolidating plant material, then covering them with wood mulch, straw or other materials. While effective, the labor required for annual winter consolidation and the spring re-spacing is expensive, as are material costs for the purchasing, installing and disposing of poly films (34).

Without careful management, container production can result in moderate to severe root malformation. Root malformation is harmful and can be detrimental to tree growth, and often goes undetected during production (9). Root malformation is pernicious in that it is usually first diagnosed when established trees fail, with potentially catastrophic consequences (6). The smooth sides of BP containers contribute to the formation of circling and/or misshapen roots (1, 4, 9). The negative effects of container production on root growth may be minimized by transplanting into larger containers, if detected and corrected during up-canning, but this is a labor intensive and costly process. Plastic containers that rely on air root-pruning are only partially effective in controlling root malformation (9). The use of alternative container types, including fabric containers, may minimize root malformation during production, as well as eliminate the need to correct container-related root problems prior to planting. They may also increase transplant success and more rapid establishment after planting in the landscape.

This research used *Pyrus calleryana* Decene. 'Glen's Form' (Chanticleer®) to compare the effects of container type during nursery production and overwintering on plant growth and survival using two fabric containers (Root Pouch®, Averna & Associates, Hillsboro, OR; and Smart Pot®, High Caliper Growing-Root Control, Inc., Oklahoma City, OK) and BP containers. We hypothesized that the use of fabric containers would reduce the severity of root zone temperature fluctuations relative to BP, reduce root malformation and/or defects, and enhance tree growth rate. Our research examined the feasibility of two overwintering production schemes—leaving plants lined out or consolidating them together. It was our goal to determine which container type and overwintering technique in the nursery produced larger and more vigorous trees, with root balls exhibiting minimal root circling and malformation.

Materials and Methods

Two-year-old, lightly branched whips of Chanticleer® pear (Bailey Nurseries, Inc., St. Paul, MN) were planted on May 7, 2010 at the Colorado State University Plant Environmental Research Center (PERC), Fort Collins, CO (USDA hardiness zone 5a) (40.56 N, 105.08 W). Prior to planting, roots were rehydrated by soaking in water for 30 minutes. Trees were root pruned to eliminate broken or compromised roots, and planted into three types of containers: (a) 66 liter (#15) standard black plastic container (BP) (Lerio Corp., Mobile, AL), (b) 66 liter (#15) fabric container (RP) (Root Pouch®, Averna & Associates, Hillsboro, OR), and (c) 66 liter (#15) fabric container (SP) (Smart Pot®, High Caliper Growing, Inc., Oklahoma City, OK). The container substrate (pH of 6.8, EC of 3.7 and 39.6% organic matter) was a locally produced nursery mix (Organix Supply, Inc., Platteville, CO), which consisted of 40% composted wood products, 40% sphagnum peat moss, 10% dehydrated poultry waste, 5% bark fines and 5% volcanic pumice. After planting, trees were fertilized by topdressing each container with 250 g (8.8 oz) of Osmocote Pro® 19N-2.1P-6.6K (The Scotts Company, Marysville, OH).

Five trees were destructively harvested for baseline measurements. At planting trees averaged 17.7 mm (SE ± 2.8 mm) (0.7 in) in trunk caliper (diameter) measured at a point 15.2 cm (6 in) above soil line and 161.4 cm (SE ± 17.1 cm) (5.3 ft) in height. Containers were placed on the ground on black woven cloth in three rows on 0.9 m (3 ft) within row spacing between containers, and 1.8 m (6 ft) spacing between rows. Trees were attached by a 1.8 m (6 ft) bamboo stake to a wire trellis (3/32 gauge) 1.2 m (4 ft) above ground to prevent them from blowing over. Trees were placed in a randomized complete block design, with five replicates per container type and overwintering treatment. Trees were pruned to correct branching structure and remove damaged branches.

Throughout the study, trees were irrigated using a drip irrigation system with 12 in-line emitters per container. The drip system was constructed using 1.3 cm (0.5 in) black plastic tubing (one line for each container type) for main lines, with 0.6 cm (0.25 in) black spaghetti tubing connecting to 0.6 cm (0.25 in) tubing with in-line emitters (12 per container) on 15.2 cm (6 in) spacing. Irrigation was scheduled to automatically come on for approximately 15 minutes in the early morning (Model 62040, Orbital® Irrigation Products, Inc., Bountiful, UT). Trees received 5.7 liters (1.5 gal) of water every other day during the 2010 season; irrigation was increased to 5.7 liters (1.5 gal) every day during 2011 since trees had increased in size. In November 2010, trees were randomly moved to two overwintering treatments from December 2010 to April 2011. Trees either, (a) remained in the plot during winter as they were during the growing season ('lined out'), but were moved together so that trees were pot-to-pot, or (b) consolidated into a rectangular block in which containers were touching. Trees in neither overwintering configuration were protected with mulch or plastic and experienced fluctuating ambient winter temperatures. Trees were irrigated by hand, as needed, throughout the winter months. In April 2011 containers were moved from the overwintering treatments and re-spaced on 0.9 m (3 ft) centers on the wire trellis.

Substrate temperature was measured during December 2010 to April 2011 (winter) and May 2011 to October 2011 (summer) using thermocouples at two locations in the containers: depth of 5 cm (2.5 in) in the center and a depth of 5 cm (2.5 in) and 5 cm (2.5 in) in from the container edge on the southwest side of the containers. Thermocouples were constructed by soldering the junction of iron-constantan thermocouple wire (Type J, 20 gauge, fiberglass insulated;

Tempco Co., Part # TCWR-1010, Wood Dale, IL), which were then coated using a thermally conductive polyester epoxy resin (Evercoat Premium Marine Resin, Evercoat Company, Cincinnati, OH) to prevent corrosion of the junction. Thermocouples were attached to thermocouple multiplexers (Model AMT25T, Campbell Scientific Inc., Logan, UT); temperatures were recorded every minute and averaged per hour with a datalogger (Model CR200X, Campbell Scientific Inc., Logan, UT). Air temperature was recorded hourly at a campus weather station, located approximately 0.8 km (0.5 mi) from the research site.

Height and caliper (measured at 15 cm (6 in) above the container growing substrate surface) were measured monthly from June to September in 2010 and 2011. At the end of the first growing season in September 2010, 30 trees were destructively harvested. Tree leaf area (LiCor Model Li-3100, Milwaukee, WI) was estimated from subsample leaf area measured using leaves (the second leaf down from the terminal growing tip of the branch or leader) randomly collected from each side of the tree and from the central leader. At harvest, all remaining leaves were removed, weighed fresh, and oven-dried at 70C (158F) for one week to calculate percent leaf moisture. Total tree leaf area was extrapolated for individual trees using the subsample leaf area and whole tree dry weights.

Measurements at harvest included: fresh and dry shoot weight, fresh and dry washed root weight, new twig growth (measured on randomly selected branches on the north, south, east and west sides of trees, along with central leader), and total new twig growth, which was calculated by totaling individual shoot measurements (not including the leader measurements). Root ball quality was evaluated for four criteria using a visual rating system (9): substrate integrity (how well the root ball held together once removed from the container; scale of 1 to 5, with 1 = root ball totally disintegrated at removal and 5 = root ball held together well), root ball quality (scale of 1 to 5, with 1 = heavy peripheral rooting on outside of root ball, and 5 = no or few peripheral roots), root ball matting (scale of 1 to 5 with 5 = no or few visible roots on the bottom of the root ball, and 1 = heavy root matting) and visible deflected roots (visual presence of deflected roots on the outer periphery of the root ball; yes or no scale). In addition, oven-dried root balls were dissected to determine the percentage of fine (≤ 2 mm diameter; 0.08 in) and coarse (> 2.1 mm diameter; 0.083 in) roots.

All plant and temperature data were subject to analysis of variance [SAS Institute Inc., Cary, NC, version (9.2)] using a fixed effects model of analysis of variance. Least significant means were compared using the Tukey Range test.

Results and Discussion

Substrate temperature results (winter of 2010–2011). Overwintering treatment significantly affected substrate temperatures in the winter of 2010–2011 (Fig. 1). In early winter (mid-December 2010 to mid-January 2011), neither overwintering treatment was consistently colder or warmer than the other. However, over the 18-week period, lined out containers averaged 0.5C (0.9F) warmer than the consolidated containers. Once average substrate temperature exceeded 0C (32F) in late January 2011, lined out containers were consistently warmer than consolidated containers.

Container type also affected substrate temperature during the same time period (Fig. 2). On dates when significant differences in temperature were found, substrate temperatures in BP containers were consistently warmer than those in RP or SP containers. During the week of January 16, 2011, average weekly substrate temperatures in all containers averaged –4.7C (23.5F). Weekly average substrate temperatures increased after the week of January 16, 2011, with substrate temperatures of the BP containers consistently warmer than RP and SP. If you compare warming trends among container types over a ten week period in late winter to early spring (January 16 to March 13, 2011), the substrate temperature in BP containers increased 15.8C (28.6F), RP containers increased 14.6C (26.3F) and SP containers increased 14.4C (25.9F). Over the 18-week period, average weekly substrate temperatures in BP containers were 1.1C and 1.3C (1.9 and 2.3F) warmer than RP and SP substrate temperatures, respectively.

There were also significant interaction effects for container type by overwintering treatment during January to March 2011 (data not shown). Weekly average substrate tempera-

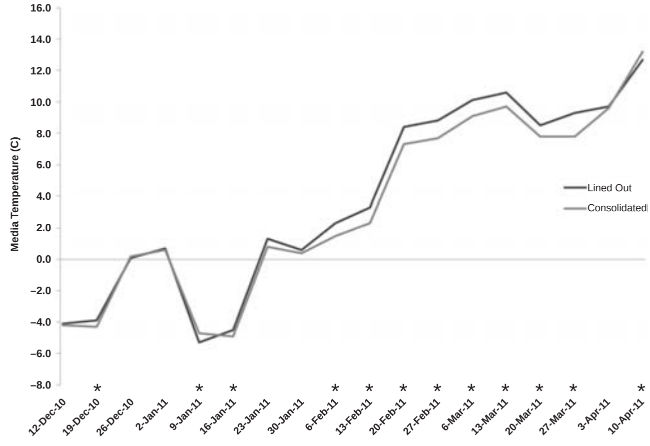

Fig. 1. Average weekly substrate temperature for overwintering treatments of Chanticleer® pear (2010–2011); *indicates significant difference at that date (*$Pr \geq F$ 0.05*).

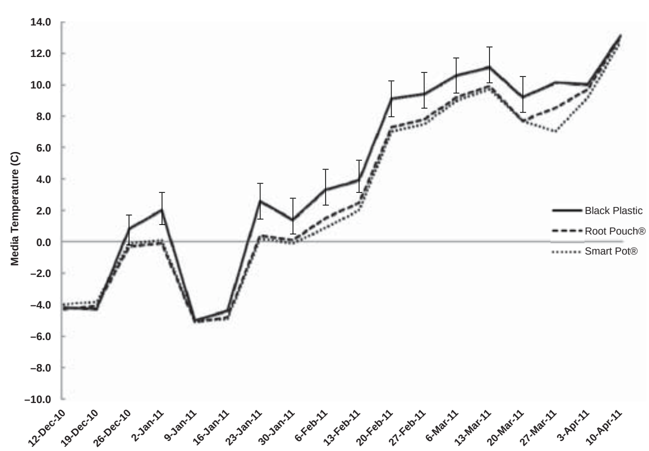

Fig. 2. Average weekly substrate temperature for Chanticleer® pear grown in three container types (2010–2011); error bars indicate significant differences between black plastic and fabric (Root Pouch® and Smart Pot®) containers at that date (*$Pr \geq F$ 0.05*).

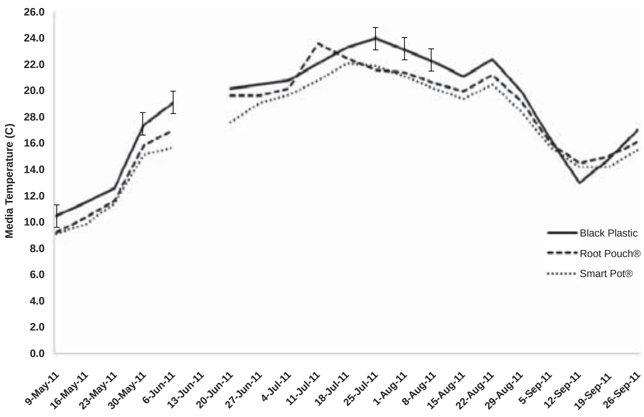

Fig. 3. Average weekly substrate temperatures in three container types from May to September 2010; error bars indicate significant differences between black plastic and fabric (Root Pouch® and Smart Pot®) containers at that date (*Pr ≥ F 0.05*). Note: Dataloggers damaged by water for June 6 to June 20, 2011, period.

tures in BP containers for both overwintering treatments were consistently warmer than the two fabric container types. Lined out BP container substrate was consistently warmer than the consolidated BP substrate; however, significant differences only occurred four times during the 18 week period. On average (for the 18 week winter time period), the substrate temperature for BP containers in the lined out overwintering treatment were 1.4C (2.5F) and 1.7C (3.1F) warmer than RP or SP substrate temperatures, respectively. For consolidated treatments, the substrate temperature in BP containers was 0.7C (1.3F) and 0.9C (1.6F) warmer than RP or SP substrate temperatures, respectively.

Substrate temperature results (summer 2011). Container type affected weekly average substrate temperature in only six of the 20 weeks during the May 9 to September 26, 2011 period (Fig. 3). Substrate temperatures in BP containers tended to be warmer through the spring and summer growing season, but differences were seldom significant. Average substrate temperatures in the three container types remained in the optimal temperature range for root growth, between 15 and 27C (59 to 80F), as described by other researchers (5, 18). However there were periods where temperatures reached levels that may have caused root injury or death (data not shown).

Container effects on tree growth (2010 and 2011). Tree caliper increased monthly June to September in 2010 for trees in all container types, with BP-grown trees having significantly greater caliper at all dates in 2010 than trees grown in RP or SP containers (Table 1). Trees grown in BP increased in caliper by 83.1% from May 2010 to September 2010; RP-grown trees increased by 74.0% and SP by 76.2%.

Tree height increased monthly with all container types (Table 1). Trees grown in BP were significantly greater in height when measured in June compared to RP- and SP-grown trees; however, no differences in height were observed among container types at later sampling dates in 2010 (Table 1). Trees grown in BP increased in height by 40.0% from May to September in 2010; RP-grown trees increased in height by 37.7%, and SP-grown trees in by 37.4%. Although caliper growth was significantly greater for trees in BP containers for all dates during the 2010 growing season, the differences at the end of the growing season was only 5.0 and 3.7% greater in BP-grown trees, compared to trees grown in RP and SP, respectively. The significantly greater caliper of the BP trees may be the result of more rapid substrate warming, causing greater establishment growth rates at the beginning of the study. Differences in height were only significant in June

Table 1. Effect of container type and overwintering treatment on height (cm) and caliper[z] (mm) of Chanticleer® pear over three growing seasons[y].

	2010				2011				2012			
	June[x]	July	August	Sept	June	July	August	Sept	June	July	August	Sept
Height (cm)												
Black Plastic	197.0a	200.0	223.9	226.0	238.4b	240.7b	250.9b	252.2b	257.4b	262.1b	270.2c	271.5b
Root Pouch®	185.9c	197.9	224.1	222.3	249.1a	256.7a	274.7a	277.9a	292.4a	301.9a	305.4b	306.8a
Smart Pot®	190.9b	197.1	222.4	221.8	249.6a	258.2a	273.6a	280.1a	297.1a	309.6a	321.2a	322.0a
Caliper (mm)												
Black Plastic	23.1a	26.0a	28.9a	32.4a	31.6	33.4	35.5	36.6b	38.5b	41.1b	42.7c	44.2b
Root Pouch®	22.8a	25.3b	28.3b	30.8b	31.4	33.8	36.7	39.4a	43.2a	44.8a	45.0b	47.9a
Smart Pot®	21.9b	24.4c	27.5c	31.2b	31.0	33.9	36.7	39.3a	43.8a	46.5a	48.4a	49.8a
Overwintering treatment												
Height (cm)												
Lined Out	na	na	na	na	242.1	245.9	254.7	255.7	267.6	276.1	281.5	282.1
Consolidated	na	na	na	na	249.3	257.8	278.1	287.0	297.0	306.3	316.3	315.8
					*	**	***	*	*	**	**	*
Caliper (mm)												
Lined Out	na	na	na	na	31.1	32.8	35.0	36.9	40.5	42.6	43.3	45.4
Consolidated	na	na	na	na	31.6	34.6	37.5	41.0	43.1	45.6	47.4	49.2
					ns	**	***	**	ns	*	*	*

[z]Caliper measured at 15 cm (6 in) above the container growing substrate surface.

[y]Trees planted into containers in May 2010.

[x]Means within a column for each measurement followed by different letters are significantly different at *Pr ≥ F 0.05*; ns = not significant; *Pr ≥ F*: * 0.05–0.01; ** 0.01–0.001; *** ≥ 0.001

Table 2. ANOVA results for effects of three container types on growth of Chanticleer® pear in a nursery setting (2010 and 2011 harvests).

	Final height (cm)	Final caliper (mm)[z]	Dry shoot weight (g)	Dry root weight (g)	Root: shoot ratio	Dry leaf weight (g)	Percent leaf moisture	Estimated total leaf area (cm^2)	Leader growth (cm)	Average twig growth (cm)	Root ball integrity[y]	Bottom root ball matting[x]	Circling roots[w]
2010													
BP	226.0	32.4a	483.8	446.7	0.95	141.2	66.3	11577	31.2	17.0	4.9	1.5c	2.2c
RP	222.3	30.8b	527.2	477.4	0.90	158.0	66.4	12889	33.9	18.5	4.9	3.0b	3.7b
SP	221.8	31.2b	492.0	439.1	0.92	148.8	66.6	11951	27.5	17.2	4.3	4.0a	4.4a
	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	**
2011													
BP	252.2b	36.6b	1217.4	1246.8	1.01a	291.6	54.3c	11355	43.9	25.7	4.3	1.8b	1.7b
RP	277.9a	39.4a	1363.3	1082.9	0.81c	361.5	56.1b	11829	52.6	31.5	4.8	3.2a	4.3a
SP	280.1a	39.3a	1295.9	1149.7	0.90b	338.1	56.7a	11490	50.5	31.1	4.7	3.5a	4.6a
	*	*	ns	ns	*	ns	**	ns	ns	ns	ns	*	***

[z]Means within a column for each measurement followed by different letters are significantly different at $Pr \geq F$ *0.05*; ns = not significant; $Pr \geq F$: * 0.05-0.01; ** 0.01-0.001; *** ≥ 0.001.

[y]Root ball integrity (how well the root ball held together when removed from the container; scale of 1–5, with 5 holding together well).

[x]Root ball matting (matting on the bottom of the root ball; scale of 1–5, with 1 being many matted roots).

[w]Circling roots (frequency, based on a scale of 1 to 5; with 1 being many circling roots).

2010; height was otherwise not affected by container type. Other studies have found that height and caliper generally do not differ based on container type (21, 26). While there was no significant container effect on root:shoot ratio for trees harvested in September 2010, there was for the root:shoot ratio for trees harvested in September 2011 (Table 2). Trees grown in BP during 2010 had a root:shoot ratio of 1.01, while trees grown in RP and SP were 0.81 and 0.90, respectively.

At the conclusion of the 2010 growing season there were no container effects for dry leaf weight, dry shoot and root weight, estimated total leaf area, leader and branch growth measurements, and root ball integrity (Table 2).

Container type significantly affected root growth. Differences were observed for bottom root ball matting, with trees in BP having the greatest amount of matted roots, compared to RP- and SP-grown trees (Table 2). Trees grown in BP containers also had the greatest incidence of deflected roots, compared to trees grown in RP or SP containers (Table 2). The greater incidence of bottom root ball matting on trees planted in BP containers was found in a similar study by Gilman et al. (9), which compared rooting in BP containers with seven other container types, including SP. We also observed that the root balls of BP-grown trees also had significantly more deflected roots (Table 2).

While trees planted in BP containers displayed greater growth in 2010 than those grown in both fabric containers, the opposite was observed for both height and caliper in 2011. In 2011 the BP-grown trees increased in caliper by 12.9%, while RP- and SP-grown trees increased by 27.9 and 26.0%, respectively (Table 1). Similarly, BP-grown trees increased in height by only 11.6% in 2011, compared to 25 and 26.3% increases for RP- and SP-grown trees, respectively (Table 1). We suspect the decreased growth of BP-grown trees is due to the trees in BP containers breaking dormancy earlier, as seen by earlier flower and leaf emergence compared to the fabric containers. This early growth was subsequently injured by a hard spring frost, while the trees in RP and SP containers remained dormant during the fluctuating spring temperatures and did not suffer frost injury. As previously mentioned, substrate temperatures in BP containers averaged 1.4 to 1.7C (2.5 to 3.1F) warmer than RP or SP containers during the winter and spring period. A study on four varieties of shrubs done by Neal (25) in New Hampshire found that BP containers compared to fabric containers had similar average winter temperatures and had warmer maximum temperatures than fabric containers.

Percent leaf moisture (leaf fresh weight-dry leaf weight / fresh weight × 100) was significantly different among container types in 2011, with RP (56.1%) and SP (56.7%) tree leaves being significantly higher in leaf moisture than those of BP trees (54.3%) (Table 2).

Overwintering effect on summer tree growth (2011 and 2012). The overwintering method during the 2010–2011 winter—lining out versus consolidating—significantly affected tree growth in 2011. Consolidated trees had greater average leader growth (67.7 cm; 26.7 in) compared to the lined out trees (29.5 cm; 11.6 in), as well as greater average twig growth (35.9 cm; 14.1 in) for consolidated trees, compared to 22.9 cm (9.0 in) for lined out trees (Table 3). As with leader and twig growth, there was a significant overwintering effect on total leaf dry weight; consolidated trees had significantly greater leaf weight (407.8 g; 0.9 lb) compared to lined-out trees (252.9 g; 0.6 lb). There was also a significant overwintering effect on shoot dry weight, with consolidated trees producing 36.4% greater dry shoot weight (1491.1 g; 3.3 lb) than lined-out trees (1093.3 g; 2.4 lb) (Table 3). Similar results were found for height and caliper on summer tree growth in 2012 following the 2011–2012 winter (Table 1).

As with shoot growth, there was a significant overwintering effect on root production. Consolidated trees produced 35.3% greater dry root ball weight (1333.9 g; 2.9 lb) compared to lined-out trees (985.7 g; 2.2 lb) (Table 3). Substrate integrity for consolidated trees was also greater than that of lined out trees. The interaction of container type by overwintering treatment was also significant. Root balls from BP containers in the lined out treatment were significantly less stable than BP in the consolidated group. However, the substrate integrity of RP and SP trees were not as negatively affected by overwintering treatment.

The greatest differences in tree growth were likely the result of the overwintering treatments, but container type

Table 3. **Effects of overwintering treatment on shoot and root growth of Chanticleer® pear (averaged over container type) grown in containers for two seasons.**

	Height (cm)[z]	Caliper (mm)	Dry shoot weight (g)	Dry root weight (g)	Dry leaf weight (g)	Percent leaf moisture	Estimated total leaf area (cm^2)	Leader growth (cm)	Average twig growth (cm)	Root ball integrity	Root ball matting	Circling roots
Lined Out	255.7	36.9	1093.3	985.7	252.9	55.7	12036	30	23	4.2	2.7	3.6
Consolidated	287.0	41.5	1491.1	1333.9	407.8	55.7	11079	68	36	4.9	2.9	3.5
	*	**	***	***	***	ns	ns	***	***	***	ns	ns

[z]Means within a column for each measurement are significantly different at *Pr ≥ F 0.05*; ns = not significant; *Pr ≥ F*: * 0.05-0.01; ** 0.01-0.001; *** ≥ 0.001.

also had some effects. Trees in the consolidated group had significantly greater leader growth, dry leaf weight, dry root weight and average twig growth. At this time, we are unaware of any research that has examined substrate temperatures in various methods of overwintering nursery stock. During the coldest part of the winter (December 2010 to January 2011), substrate temperatures in BP containers were significantly warmer in both overwintering treatments than the fabric containers likely due to greater absorption of solar radiation. Those differences were most pronounced in the lined out overwintering treatment. The difference between substrate temperatures in BP from fabric containers in lined out treatments was approximately twice as great as the difference in the consolidated treatment. This could result in the lined out trees staying warmer and experiencing greater temperature fluctuations, which could negatively impact winter hardiness, root growth and overall plant vigor.

There were significant container effects on the percent leaf moisture, dry shoot weight, root ball quality and root ball matting. Trees in BP containers had smaller leaf area compared to trees in RP or SP. This is likely due to the early spring growth that occurred with trees growing in BP containers, which we speculate is due to earlier deacclimation. Deacclimated plant tissues are more susceptible to injury or death by a late frost (15); the resulting injured or dead tissue is often called 'winter injury'. When emerging leaves experience cold injury, the rapidly expanding cells form ice crystals that rupture the leaf structure (33).

The cause of the lower leaf moisture percentages in trees grown in BP containers could be due to the reduced ability of these trees to absorb moisture due to rooting volume and/or abnormalities. Substrate temperatures of woody plants grown in BP containers have been widely researched by many individuals (2, 5, 10, 11, 13, 18, 22, 23, 27, 28, 30, 31). Research has demonstrated that root zone temperatures lower than –5C (23F) can be lethal for mature roots of woody ornamentals (11). Our trees experienced temperatures below this point frequently during the early winter of 2010–2011. While summer substrate temperature averages were below damaging temperatures of 30C (86F) (13, 28), there were many occurrences of individual containers reaching above this point throughout the summer of 2011. One of the highest substrate temperatures recorded was 54C (129F). These periods of lethal temperatures likely resulted in root death and loss of plant vigor, including shoot growth (13, 28).

Root ball quality and matting were significantly different for trees grown in BP containers. Studies have shown that container type has a direct effect on root morphology (3, 8). Black plastic containers often encourage roots that are kinked and grow along the sides or bottom of the container (9). Air pruning of roots is a common response to trees grown in fabric containers (20). This happens when a root tip reaches a pocket of air; the air causes tip desiccation, which forces the root to branch (37). Fabric containers have been proven to be a good alternative to BP containers for this reason. Our research confirms this—both fabric containers had significantly fewer circling roots and bottom root ball matting compared to trees in BP containers.

Our research concludes that fabric containers likely have a place in the nursery industry, and may produce trees with better developed root systems. Whether fabric containers will replace the majority of black plastic containers depends on nurseries adopting alternative containers. In addition, our research suggests that nursery producers must continue to consolidate plant material in northern climates; trees left lined out were smaller and more likely experienced winter injury, which decreased overall plant growth. One option that growers may consider is that since trees in BP containers were taller with greater caliper during the first growing season, likely due to the container warming more quickly to accelerate root growth, compared to trees in RP or SP containers, growers could start whips in BP containers and then transplant to fabric containers the second season. This would give the tree an initial growing advantage. Drawbacks to fabric containers include ease of mobility (the containers are soft-sided and root ball damage may occur during transit) and degradation of the material. In addition, fabric containers may require more labor during planting and upshift compared to black plastic and irrigation inputs may be greater. However, these may be factors nurseries can account for and have success. Our research suggests that the benefits of using fabric containers may outweigh potential downsides to their use and should be considered by nursery producers as viable alternatives to black plastic containers. Further research is needed to examine container effect on landscape establishment (study currently in process at Colorado State University), irrigation and fertilizer requirements. Also, our research focused only on one species; other plant taxa may respond differently to production and overwintering treatments in alternative containers.

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