Arboriculture & Urban Forestry 2018. 44(4):165–173

Container Type Affects Root Development of Chanticleer® Pear (*Pyrus calleryana* 'Glen's Form') During Landscape Establishment

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Abstract. While there are many advantages to producing woody plants in the industry-standard black plastic (BP) container, circling and girdling roots on plants grown in them may reduce transplant success, predispose plants to stress, shorten life span in the landscape, and increase the potential for the development of hazard trees. Plants grown in fabric containers may have fewer circling and girdling roots, possibly eliminating transplant problems sometimes seen with plants grown in BP containers. This study evaluated post-transplant root and shoot growth of *Pyrus calleryana* 'Glen's Form' (Chanticleer®) produced using three container types: black plastic, Root Pouch® (RP) and Smart Pot® (SP). Researchers found no container effects on aboveground growth one, two, and three years following transplant into the landscape. All trees doubled their root dry weight annually over the three-year study. No container effects were found for any measured root parameters one year after planting. However, two and three years following planting, trees grown in RP and SP containers showed greater total root growth beyond the original root ball than BP-grown trees. Three years after planting, 72% of all root growth of trees grown in BP containers was within the original root ball, while more than one-third of all roots of RP- and SP-grown trees were found outside of the original root ball. Researchers believe that fabric containers should be considered as alternatives to BP containers because they may enhance root growth of transplanted trees and reduce the formation of future circling and girdling roots.

Key Words. Black Plastic Container; Circling Roots; Deciduous Tree; Fabric Containers; Girdling Roots; Landscape Establishment; *Pyrus calleryana* 'Glen's Form' (Chanticleer®); Root Pouch®; Smart Pot®; Transplanting.

Container tree production is a popular way to grow ornamental trees and is more commonly used than field production in many parts of the United States. A national survey by the United States Department of Agriculture found that nursery crop sales in 2007 topped USD $6.5 billion (USDA 2007). Aboveground container nursery production makes up more than 75% of total nursery crop value in 17 of the top nursery producing states in the United States (USDA 2008); it's estimated that 80%–90% of woody plants produced in California, Florida, and Texas are grown in containers (Davidson et al. 2000). There are many advantages to producing woody plants in containers, including ease of handling at the nursery, uniformity in plant growth, ease of shipping, consumer appeal, ability to produce more plants on less land, shorter production cycles, production of a plant with an intact root ball, and a longer seasonal market for plant material, since field-grown plants have a narrow window when they can be harvested and shipped (Harris and Gilman 1991; Gilman and Beeson 1996; Davidson et al. 2000; Whitcomb 2004). Studies comparing field-grown to container-grown trees found better transplant success with those produced in containers if irrigation wasn't a limiting factor following planting (Harris and Gilman 1991; Harris and Gilman 1993; Gilman and Beeson 1996; Mathers et al. 2005).

The industry standard for container production is the black plastic (BP) container. Although lightweight, durable, efficient, and cost-effective, there are numerous disadvantages to using the BP container for nursery production. Circling and/or malformed roots, a common problem with plants grown in plastic containers, can negatively impact plant health and/or stability following planting in the landscape (Nichols and

Alm 1983; Gilman and Harchick 2014; Gilman et al. 2015). Roots deflected in plastic containers grow in many directions, causing constrictions and circling roots (Gilman et al. 2010a) and uneven root development (Marler and Davies 1987). Malformed roots that begin with container production can later lead to instability and possible tree failure (Lindström and Rune 1999; Gilman and Paz 2014; Gilman et al. 2015).

Because of the potential problems associated with plant production in BP containers, alternative container types have been developed, including those with air root pruning technology, bottomless containers, fabric containers, containers incorporating chemical compounds, and containers using mechanical deflection technology. Some researchers have observed fewer circling/girdling roots with alternative containers (Arnold and Struve 1989; Beeson and Newton 1992; Struve et al. 1994; Martin and Bhattacharya 1995; Marshall and Gilman 1998; Gilman 2001). Fabric containers may reduce the occurrence of circling roots because of the "air pruning" effect on roots intercepting the container wall (Jones 1987; Langlinais 1987; Reese 1987; Privett and Hummel 1992; Marshall and Gilman 1998; Gilman et al. 2010a), which stimulates secondary root branching and discourages root circling.

Nursery production studies examining the effects of container type on root and/or shoot growth have yielded mixed results. While some have found few differences in aboveground growth among various container types (Marshall and Gilman 1998; Owen and Stoven 2008; Neal 2009), O'Connor et al. (2013) found that Callery pear trees grown in fabric containers grew more in height and stem caliper than trees grown in BP containers after two years. Conversely, Ortega et al. (2006) found that pine trees grown in air-pruning containers had slower root and canopy growth.

Few studies have examined effects of container type on growth after planting in the landscape. Marshall and Gilman (1998) and Gilman et al. (2003), working with low-profile, air root-pruning containers, found increased caliper growth on red maple (*Acer rubrum* L.) roots five years after planting. Gilman et al. (2015) found that circling roots of container-produced *Ulmus* and *Acer* persisted for as long as five years after landscape planting.

The current study examined container effects on root and shoot growth of Chanticleer® pear, produced in the nursery using three container types (black plastic, Root Pouch®, and Smart Pot®), and for three years following planting in the landscape.

MATERIALS AND METHODS

Nursery Planting

Two-year-old, lightly branched bare-root whips of *Pyrus calleryana* 'Glen's Form' (Chanticleer) were planted into three container types on 07 May 2010 at the Colorado State University Plant Environmental Research Center (PERC), Fort Collins, Colorado, U.S. (USDA hardiness zone 5a) (40.56N, 105.08W). Prior to planting, roots were rehydrated by soaking in water for 30 minutes. Trees were root pruned to eliminate broken or crossing roots. The three container types used were: a) #15 standard black plastic container (BP) (Lerio Corp., Mobile, Alabama, U.S.), b) #15 fabric container (RP) (Root Pouch, Averna & Associates, Hillsboro, Oregon, U.S.), and c) #15 fabric container (SP) (Smart Pot, High Caliper Growing, Inc., Oklahoma City, Oklahoma, U.S.). The container substrate (pH of 6.8, EC of 3.7 mmhos/cm) was a locally produced nursery mix (Organix Supply, Inc., Platteville, Colorado, U.S.), which consisted of 40% composted wood products, 40% sphagnum peat moss, 10% dehydrated poultry waste, 5% bark fines, and 5% volcanic pumice by volume. After planting, trees were fertilized by topdressing each container with 250 g of Osmocote Pro® 19N–2.1P–6.6K (The Scotts Company, Marysville, Ohio, U.S.).

At planting, trees averaged 17.7 mm (SE ± 2.8 mm) in trunk caliper (diameter), measured at a point 15 cm above soil line and 161.4 cm (SE ± 17.1 cm) in height. Containers were placed on the ground on black woven cloth in three rows with 0.9 m spacing within rows and 1.8 m spacing between rows. Trees were attached by a 1.8 m bamboo stake to a wire trellis 1.2 m above ground to prevent them from blowing over. Trees were placed in a randomized complete block design, with five single-plant replicates per container type. Trees were pruned to correct branching structure and to remove damaged branches.

During the nursery establishment phase (first six months after planting in containers), trees were irrigated using a drip irrigation system to apply 5.7 L of water every other day. Height and caliper (measured at 15 cm above the container growing substrate surface) were measured monthly, from June to September 2010.

Landscape Planting

In October 2010, 27 trees (three single-plant replications of three container types to be harvested over three years) were planted into a *Poa pratensis* (Kentucky bluegrass) lawn. The soil type was a sandy clay loam, with a pH of 7.7, EC of 0.4 mmhos/cm, and 6.4% organic matter. Soil test results prior to planting (Colorado State University Soil, Plant, and Water Testing Laboratory; data not shown) indicated that all nutrients were present at levels adequate for turf and tree growth, so supplemental fertilizer was not added at planting. At the time of removal from containers, root balls were scored for matting, circling roots, and root ball integrity (Table 1).

Trees were planted on 1.8 m × 1.8 m spacing, in a randomized complete block design, with three replicates and trees per container type and replication. Trees were planted using best management practices in saucer-shaped holes approximately three times as wide as the root ball. Root balls were not shaved or washed prior to planting, but the bottom and sides of each root ball were scored using box cutters, and any visible circling roots were hand pruned. Trees were planted at 2.5 cm above soil grade. Trees were watered and mulched with a 5 cm depth of organic mulch (shredded bark) measuring 1.8 m in diameter, centered on the tree. Mulch was not applied over the top of the root ball. Mulch was kept free of weeds and grass with occasional applications of glyphosate. Trees were not staked at planting. Following planting, trees and turf were irrigated with an automated irrigation system (to prevent turf stress; 2.5 to 5 cm/week). The turf was mowed twice weekly (5 cm mowing height), during periods of active growth, and fertilized twice yearly with 48.8 kg N/ha. Throughout the study, trees were pruned only to remove broken branches. Tree height and caliper were measured monthly during the 2011 to 2013 growing seasons. New twig growth, measured on one randomly selected branch on the north, south, east, and west sides of trees was measured in autumn of each growing season. Total leader growth was measured from the previous point of growth to the tip of the current season's growth.

Table 1. Root ball characteristics of nursery-grown (six months) Chanticleer pear in three container types (2010).

	Root ball integrity[z]	Bottom root ball matting[y]	Circling roots[x]
Black plastic	4.9	1.5c	2.2c
Root Pouch	4.9	3.0b	3.7b
Smart Pot	4.3	4.0a	4.4a
	ns	***	**

[z] Root ball integrity (how well the root ball held together when removed from the container; scale of 1–5, with 5 holding together well).
[y] Root ball matting (matting on the bottom of the root ball; scale of 1–5, with 1 being many matted roots).
[x] Circling roots (frequency, based on a scale of 1–5; with 1 being many circling roots).
Notes: Means within a column for each measurement followed by different letters are significantly different at $P = 0.05$ using Tukey's LSD test; ns = not significant; single asterisk (*) indicates $P = 0.05–0.01$; double asterisk (**) indicates $P = 0.01–0.001$; triple asterisk (***) indicates $P \geq 0.001$.

Harvest Methods

Tree roots were removed from the ground in autumn of 2011, 2012, and 2013 (nine trees each year; three from each container type) by air spading, and also using water to loosen roots that were still attached to the soil. At harvest, all leaves were removed and oven-dried at 70°C for one week to determine total leaf dry weight. Root balls were washed to remove soil. Branches and trunk were separated from the root ball, weighed fresh, and then oven-dried at 70°C for one week to obtain dry shoot weight.

Each excavated root ball was placed on a template of its original container width and pruned to separate roots that had grown beyond the original root ball after planting. Roots were separated into two groups (inside and outside of the original root ball), oven-dried, and weighed. Following drying, roots were separated into fine (<2.0 mm) and coarse (≥2.1 mm) roots and weighed again.

All data were subject to analysis of variance (Version 9.4, SAS Institute Inc., Cary, North Carolina, U.S.) using a fixed effect model. Where significant effects were indicated, means were separated using Tukey's LSD test.

RESULTS

Nursery Study Effects on Roots

Container type did not affect tree height, caliper, root:shoot ratio, leader growth, branch growth, canopy width, or shoot, leaf, and total plant dry weight in the three years (2011–2013) following planting in the landscape in 2010 (Table 2).

In both 2011 and 2012, there were no container effects on total root ball weight, root weight inside and outside the original planting root ball, and total fine and coarse root weight (Table 3). However, in 2012, trees grown in RP and SP containers had a higher percentage of total root dry weight (30.0% and 27.3%, respectively) beyond the original root ball than trees grown in BP containers (21.4%) (Table 4). Trees from BP containers also had a greater percentage of their total coarse root dry weight growing within the root ball (77.0%), compared to trees produced in RP (68.7%) and SP (71.5%) containers. In addition, a lower percentage of total coarse roots growing outside the root ball were found for BP containers (19.8%) compared to RP (27.9%) and SP (25.4%) containers. While there were no container effects on root dry weight after the initial growing season (2011), by the second season after planting, trees that had been grown in BP containers produced a greater percentage of their total root dry weight within the boundaries of the original root ball than did trees produced in both fabric containers.

By the second season, total root ball dry weight of BP-grown trees was 24%–34% greater than that of RP- and SP-grown trees, respectively (Table 2). Trees grown in BP containers had 1.5 times more total and coarse root weight inside the original root ball than was measured for trees grown in the SP and RP fabric containers. Fully 72% of total root growth had occurred within the original planting root ball boundary for trees produced in BP containers, while trees produced in the fabric containers had 65 and 62.7% (RP and SP, respectively) of their roots growing within the original root ball (Table 3). More coarse roots were produced outside of the original root ball with the RP (33%) and SP (32.9%) containers, while BP-produced trees formed only 26.4% of their coarse roots outside of the original root ball.

DISCUSSION

Two growing seasons following transplant of Chanticleer pear trees from three container types, there were no container effects on above- or belowground plant growth (Table 2). However, container effects were found on post-transplant rooting in the third year, while seeing no container effects on aboveground growth. In the third year after planting, dry weight of excavated root systems of trees grown in BP containers was 24% greater than that of RP-grown trees and 32% greater than trees grown in SP containers (Table 2). While total root production might be considered a measure of establishment, the location (relative to the original root ball) of new root dry weight production following planting may be a more important indicator of transplant success.

The container in which the trees were originally grown appears to have influenced root production following planting into the landscape. The relative distribution of both fine (<2.0 mm diameter) and coarse (≥2.1 mm diameter) roots in the second and third years after planting (Table 3) differed among trees produced in SP and RP containers, compared to trees produced in BP containers. After the third year in the landscape, trees grown in the fabric containers had 25% (for RP) to 32% (for SP) greater dry root growth outside of the original root ball compared to trees grown in BP containers. In contrast, by the end of the third year, 72% of total dry root growth of trees grown in BP containers was concentrated within the boundaries of the original root ball, while more than one-third of root growth (dry weight) for trees grown in fabric containers was found outside of the original root ball (35% and 37% for RP and SP, respectively).

The concentrated root growth within the original root ball with trees grown in BP containers may reflect the condition of the root ball at the time of planting. Evaluations of root ball quality at planting (Table 1) showed greater incidence of circling roots and more root matting with BP trees than for the trees grown in the two fabric containers. Visible circling roots with BP-grown trees were obvious three years after transplanting, while trees grown in fabric containers had fewer noticeable circling roots and also produced root systems with greater lateral branching (Table 3; Table 4). Compared to trees produced in fabric containers,

Table 2. Shoot, root, and leaf growth of *Pyrus calleryana* 'Glen's Form' grown in three container types (black plastic, Root Pouch, and Smart Pot) and harvested after one, two, and three years following planting in the landscape.

Harvest year	Container type	Height (cm)	Caliper[z] (mm)	Root dry weight (g)	Shoot dry weight (g)	Leaf dry weight (g)	Total plant dry weight (g)	Root:Shoot ratio	Leader growth (cm)	Average branch growth (cm)	Average canopy width (cm)
2011	Black plastic	270	42.2	1248.2	1474.2	369.1	3091.5	0.70 (1:1.4)	47	29.7	94
	Root Pouch	267	42.1	1083.7	1567.7	384.1	3035.5	0.55 (1:1.8)	49	26.8	88
	Smart Pot	277	43.4	1235.5	1558.8	349.2	3143.5	0.65 (1:1.5)	42	30.1	88
2012	Black plastic	351	57.3	2984.4	3579.3	972.5	7536.2	0.65 (1:1.5)	77	27.5	108
	Root Pouch	329	57.2	2621.1	3576.1	978.7	7175.9	0.58 (1:1.7)	112	20.6	114
	Smart Pot	345	59.3	2704.3	3676.6	1026.7	7407.6	0.59 (1:1.7)	94	28.2	108
2013	Black plastic	438	75.8	5875.3a	8662.1	1877.7	16415.1	0.56 (1:1.8)	97	31.1	160
	Root Pouch	437	72.9	4719.4b	7878.4	1757.3	14355.1	0.49 (1:2.0)	93	38.5	142
	Smart Pot	410	72.1	4395.1b	7608.4	1635.1	13638.6	0.48 (1:2.1)	73	33.9	148

[z] Caliper measured at 15 cm above the soil surface.
Notes: Trees were planted into the landscape in October 2010. Means within years for each measurement followed by different letters are significantly different at $P = 0.05$ using Tukey's LSD test.

Table 3. Root weight and distribution of *Pyrus calleryana* 'Glen's Form' grown in three container types (black plastic, Root Pouch, and Smart Pot) and harvested after one, two, and three years following planting in the landscape.

Harvest year	Container type	Total root ball dry weight (g)	Total dry weight root growth outside root ball (g)	Total dry weight roots inside root ball (g)	Total fine roots (<2.0 mm) inside root ball (g)	Total coarse roots (≥2.1 mm) inside root ball (g)	Total fine roots (<2.0 mm) outside root ball (g)	Total coarse roots (≥2.1 mm) outside root ball (g)	Total fine roots (g)	Total coarse roots (g)
2011	Black plastic	1248.2	105.9	1142.3	161.6	980.7	25.8	80.1	187.4	1060.8
	Root Pouch	1083.7	117.9	965.7	112.7	853.0	24.4	93.5	137.1	946.5
	Smart Pot	1235.5	125.5	1113.0	147.0	966.1	33.4	92.1	180.4	1058.1
2012	Black plastic	2984.4	642.7	2341.7	45.5	2296.3	50.8	591.8	96.3	2888.1
	Root Pouch	2621.1	779.8	1841.3	34.3	1807.0	55.1	724.7	89.3	2531.8
	Smart Pot	2704.3	749.7	1954.3	33.7	1920.6	49.1	700.6	82.8	2621.2
2013	Black plastic	5875.3a	1655.4	4220.0a	32.5	4187.5a	93.0a	1562.4	125.5a	5749.9a
	Root Pouch	4719.4b	1660.0	3059.4b	26.8	3032.6b	92.8a	1567.2	119.7a	4599.8b
	Smart Pot	4395.1b	1638.1	2757.0b	35.9	2721.1b	192.3b	1445.8	228.2b	4166.9b

Note: Means within years for each measurement followed by different letters are significantly different at $P = 0.05$ using Tukey's LSD test.

Table 4. Percent root distribution of *Pyrus calleryana* 'Glen's Form' grown in three container types (black plastic, Root Pouch, and Smart Pot) and harvested after one, two, and three years following planting in the landscape.

Harvest year	Container type	Percent root growth beyond original root ball	Percent of total roots inside root ball that are fine (<2.0 mm)	Percent of total roots inside root ball that are coarse (≥2.1 mm)	Percent of total roots outside root ball that are fine (<2.0 mm)	Percent of total roots outside root ball that are coarse (≥2.1 mm)	Percent total fine (<2.0 mm) roots for entire root ball	Percent total coarse (≥2.1 mm) roots for entire root ball	Percent of total roots growing inside the root ball
2011	Black plastic	8.6	13.0	78.5	2.1	6.5	15.0	85.0	91.5
	Root Pouch	10.8	9.7	79.5	2.2	8.6	12.0	88.0	89.2
	Smart Pot	10.1	12.0	77.9	2.7	7.4	14.7	85.3	89.9
2012	Black plastic	21.4b	1.5	77.0a	1.7	19.8b	3.2	96.8	78.6a
	Root Pouch	30.0a	1.3	68.7b	2.1	27.9a	3.4	96.6	70.0b
	Smart Pot	27.3a	1.3	71.5b	1.8	25.4a	3.1	96.9	72.7b
2013	Black plastic	28.1b	0.6	71.4a	1.6b	26.4b	2.2	97.8	72.0a
	Root Pouch	35.0a	0.6	64.4a	2.0b	33.0a	2.6	97.4	65.0b
	Smart Pot	37.3a	0.8	61.9b	4.4a	32.9a	5.2	94.8	62.7b

Note: Means within years for each measurement followed by different letters are significantly different at $P = 0.05$ using Tukey's LSD test.

excavated tree root systems from BP containers had more visible circling roots and a greater percentage of new root growth within the original root balls; this suggests an increased potential for stem-girdling roots (SGRs) to form on those trees. Researchers suspect that there were hidden circling roots at the time of planting that were not pruned or corrected as part of the planting process. While researchers did not develop a rating system for root architecture, the measured percent distribution of new root growth for the three container types confirms that trees grown in the two fabric containers possess root systems with greater lateral growth and fewer roots concentrated within the circumference of the original planting root ball.

The presence of SGRs has been suggested as a predictor of tree failure (Johnson and Johnson 1999). Other studies have suggested that SGRs can arise from container-related circling roots present at planting, increasing the potential for future tree failure (Meilleur 2009). Johnson and Hauer (2000) found that 73% of lindens that failed in storms in Minnesota, U.S., broke at the point where SGRs had constricted the stems. In a North Carolina, U.S., study, 75% of 400 air-spaded trees were found to have SGRs (Meilleur 2007). Prior to planting trees in the current study, the only corrective procedure used to eliminate circling roots on the container root ball was vertically slicing the root ball on the outside several times, using a box cutter, and hand-pruning to remove any visible circling roots. Gilman et al. (2010b) and Gilman and Wiese (2012) found that shaving the roots from the outer periphery (2.5 cm) of the root ball leads to reduced circling and girdling roots. Had root shaving been practiced when transplanting trees in the current study, researchers may have observed improved root systems with trees grown in BP containers, since root shaving has been found to increase straight, radial root production from the trunk (Gilman et al. 2010b). This suggests an area of future research—to compare post-transplant root growth and architecture of shaved root balls of BP-grown trees with that of non-shaved fabric containers.

After the third year in the landscape, the largest percentage (94%+) of excavated roots for all three container types were coarse roots (≥2.1 mm diameter). However, researchers found more fine roots after the first year in the landscape (12%–13% of all roots for all container types) than in the second (approximately 3% for all container types) and third years (2%–5% for all containers). While the importance of fine-root development on establishment success of landscape trees is unproven, it's commonly stated that fine roots aid in tree establishment (Ham and Nelson 1998) and that fine roots are important for the absorption of water and nutrients (Persson 1983).

No container effects were found on height, caliper, total dry leaf, and shoot weight and twig and leader growth of trees harvested in 2011, 2012, and 2013 (Table 2). While it is difficult to define when a transplanted tree has become fully established in the landscape, the absence of measurable container effects on aboveground growth could be explained by the findings of numerous studies suggesting that newly transplanted trees use carbohydrates to regenerate new roots, and that top growth may be significantly reduced until the new root system is sufficiently regenerated (Watson 1985; Lauderdale et al. 1995; Gilman et al. 1998; Marshall and Gilman 1998; Ortega et al. 2006; Owen and Stoven 2008; Neal 2009). A study by Gilman (1997) found that in USDA zone 9 (Florida, U.S.), a 5.1 cm tree established in six months, while the same species in USDA zone 5 took 24 months to establish. Defining when a tree has become established and measuring transplant success remains difficult (Watson 1985; Gilman 1990; Struve et al. 2000). However, the most limiting factor following tree establishment is irrigation, as found by Gilman et al. (1998). Since trees in this study were not drought-stressed, irrigation was not a treatment factor. The trees can be assumed to be fully established after one year. Researchers found that there were differences among the containers and their root systems in years two and three but not the first year after transplant.

Researchers speculate that because neither soil moisture nor soil fertility were limiting factors in the study, they were not likely to see container effects on the height and caliper of trees following transplanting. Similarly, Gilman et al. (2010a) found few effects of container type on height and caliper when transplanted trees were given adequate irrigation and fertility, and Marshall and Gilman (1998) and Gilman et al. (2003) found no effects of container type on height and caliper of red maple five months and five years after planting in the landscape, respectively. Gilman et al. (2003) concluded that irrigation frequency for the first 24 weeks following transplant in Florida was a more important factor than container type in influencing establishment and aboveground plant growth. Because successful establishment of transplanted trees in Colorado and the semi-arid western United States requires the frequent application of irrigation, the effects of irrigation on aboveground growth might be expected to override measurable container effects on growth during the establishment period. Measuring aboveground growth 5–15 years following planting might reveal growth differences reflective of long-term container effects on rooting and the ability of those root systems to sustain optimal aboveground growth.

CONCLUSIONS

While a number of container studies have examined the root growth of trees and shrubs during nursery production, few have examined container effects on total root growth following transplanting in the landscape. The work published here appears novel in that researchers excavated complete, intact tree root systems and documented the location of new fine and coarse roots (relative to the original root ball) for three years following planting. Unlike Gilman et al. (2003), who found no container effects on rooting five years after red maples were planted in the landscape, researchers of the current study found significant quantitative container effects in the second and third year following planting.

This research, with Chanticleer pear and three container types, found that nursery production using BP containers resulted in circling roots both in the container and following transplanting in the landscape, consequently reducing the amount of lateral growth beyond the original root ball. Conversely, trees produced in fabric containers had fewer circling roots and root matting at planting, produced fewer circling roots, and had 25%–30% more roots outside of the original root ball than BP-grown trees. Because circling roots are more likely to lead to the development of stem-girdling roots as trees mature in the landscape, researchers suggest that growers consider the use of fabric containers as alternatives to black plastic because of the short- and long-term positive effects they can have on tree root growth. While circling and stem-girdling roots can be corrected at or possibly following planting, it can be argued that the use of alternative fabric containers during production to prevent these rooting problems could be easier, more effective, and less costly than doing so during or after planting the tree in the landscape.

An obvious limitation to this study is that it was conducted with one tree species; researchers are not suggesting that similar container effects will occur with all other tree species. Also, root growth was examined over just three growing seasons. Long-term studies (5–10 years) using additional species are necessary to determine if the container effects observed with the one species occur with other species, and if the beneficial effects extend beyond two to three years following planting. When container-grown trees have produced circling or matted roots, pruning or shaving to remove circling, matted, or deformed roots at the time of landscape planting may discourage continued circling root growth, while encouraging more lateral root production—important for stabilizing landscape trees (against wind) following planting (Gilman and Wiese 2012; Gilman et al. 2015). The authors recommend that nursery producers more carefully consider the potential benefits of growing trees in fabric containers and that end-users be receptive to planting trees that have been produced in fabric containers.

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Résumé. Bien que les avantages soient nombreux à produire des plantes ligneuses dans des contenants de plastique noir (PN) qui constituent la norme dans l'industrie, le développement de racines encerclantes chez les végétaux ainsi cultivés peut réduire le taux de succès des plantations, prédisposer ces plantes au stress, réduire leur espérance de vie utile une fois plantés, et accroitre le risque de développer des arbres potentiellement dangereux. Les plantes cultivées dans des contenants en tissu peuvent avoir moins de racines encerclantes, éliminant possiblement les problèmes de transplantation quelquefois constatés avec les végétaux produits en contenants PN. La présente étude évalue la croissance, après transplantation, des racines et des pousses de poiriers *Pyrus calleryana* 'Glen's Form' (Chanticleer®) cultivés dans trois types de contenants : plastique noir (PN), Root Pouch® (RP) et Smart Pot® (SP). Les chercheurs ne constatèrent aucun impact, découlant du type de contenant utilisé, sur la croissance des pousses lors de la première, de la seconde ou de la troisième année suivant la transplantation en pleine terre. Tous les arbres ont doublé annuellement le poids sec de leurs racines durant les trois années de l'étude. Aucun impact, découlant du type de contenant utilisé, ne fut observé pour les paramètres mesurés des racines chez les arbres transplantés depuis un an. Cependant, chez les végétaux transplantés depuis deux et trois années, ceux cultivés dans des contenants RP et SP ont montré une croissance plus grande, excédant la masse originale de racines, que les arbres produits en PN. Trois ans après leur transplantation, 72% de toute la croissance racinaire des arbres cultivés en PN avait été générée à l'intérieur de la masse originale de racines tandis que plus du tiers de toutes les racines des arbres cultivés en RP et SP s'étaient développées à l'extérieur de la masse originale de racines. Les chercheurs estiment que les contenants en tissu devraient être considérés en tant que solutions alternatives aux contenants PN puisqu'ils peuvent améliorent la croissance racinaire des arbres transplantés et réduisent le développement de racines encerclantes.

Zusammenfassung. Während es viele Vorteile gibt, Gehölze in den industriell gefertigten schwarzen Standard-Plastik-Containern (BP) zu produzieren, können die dabei entstehenden Würge- und Ringwurzeln den Verpflanzungsfortschritt reduzieren, die Pflanzen einem Stress aussetzen, die Lebensspanne in der Landschaft verkürzen und das Potential zu Entwicklung von Problemen erhöhen. Die in Pflanzcontainern aus Gewebe gezogenen Pflanzen haben weniger Würge- und Ringelwurzeln und möglicherweise dadurch weniger Probleme nach der Verpflanzung als die in BP-Containern gezogenen Gehölze. Diese Studie bewertet das Wachstum von Wurzeln und Trieben bei of *Pyrus calleryana* 'Glen's Form' (Chanticleer®) nach der Verpflanzung aus drei verschiedenen Container-Typen: schwarzes Plastik, Root Pouch® (RP) und Smart Pot® (SP). Die Forscher fanden keine Container-Effekte im oberirdischen Wachstum in bis zu drei Jahren nach der Verpflanzung. Alle Bäume verdoppelten jährlich ihr Wurzeltrockengewicht innerhalb dieser dreijährigen Studie. Es wurden im ersten Jahr nach der Verpflanzung für keine der gemessenen Wachstumsparameter der Wurzeln containertypische Effekte gemessen. Dennoch, im zweiten und dritten Jahr nach der Verpflanzung zeigten die Bäume aus den RP- und SP-Containern ein größeres totales Wurzelwachstum außerhalb des ursprünglichen Ballens als die in BP-Container gezogenen Bäume. Drei Jahre nach der Verpflanzung waren 72 % des Wurzelwachstums von Bäumen aus BP-Containern innerhalb des ursprünglichen Wurzelballs, während mehr als ein Drittel aller Wurzeln aus in RP- und SP-Containern gezogenen Bäumen außerhalb des ursprünglichen Wurzelballen gefunden. Die Forscher glauben, dass Gewebecontainer als Alternative zu BP-Containern betrachtet werden können, weil sie das Wurzelwachstum von verpflanzten Bäumen vergrößern und die Formation von Würge- und Ringwurzeln verringern können.

Resumen. Si bien hay muchas ventajas para producir plantas leñosas en contenedor estándar de plástico negro (BP), las raíces circundantes y estranguladoras de las plantas cultivadas en ellas pueden reducir el éxito del trasplante, predisponer a las plantas al estrés, acortar la vida en el paisaje e incrementar el potencial para el desarrollo de árboles de riesgo. Las plantas cultivadas en contenedores de tela pueden tener menos raíces enrolladas, posiblemente eliminando los problemas de trasplante que a veces se ven con las plantas cultivadas en contenedores de BP. Este estudio evaluó el crecimiento post-trasplante de raíces y brotes de *Pyrus calleryana* 'Glen's Form' (Chanticleer®) producido utilizando tres tipos de contenedores: plástico negro, Root Pouch® (RP) y Smart Pot® (SP). Los investigadores no encontraron efectos de contenedor en el crecimiento sobre el suelo uno, dos y tres años después del trasplante en el paisaje. Todos los árboles duplicaron su peso seco de raíz anualmente durante el estudio de tres años. No se encontraron efectos de contenedor para ningún parámetro de raíz medido un año después de la plantación. Sin embargo, dos y tres años después de la plantación, los árboles cultivados en contenedores RP y SP mostraron un mayor crecimiento total de la raíz más allá de la bola raíz original que los árboles cultivados con BP. Tres años después de la siembra, el 72% de todo el crecimiento de raíces de árboles cultivados en contenedores de BP estaba dentro del cepellón original, mientras que más de un tercio de todas las raíces de árboles desarrollados con RP y SP se encontraron fuera del cepellón original. Los investigadores creen que los contenedores de tela deben considerarse como alternativas a los contenedores de BP porque pueden mejorar el crecimiento de las raíces de los árboles trasplantados y reducir la formación de futuras raíces circundantes y estranguladoras.