Propagation Container Type, Time in Container, and Root Pruning Affect Root Development of Young *Acer rubrum*[1]

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Abstract

Numerous propagation containers have been developed in an effort to reduce root deformities on tree and shrub nursery stock. Root attributes in containers are also impacted by retention time in the container. A popular shade tree, *Acer rubrum* L., was grown in 6 different propagation containers for two time periods and root pruned or not before shifting to 10 liter (3 gal) black plastic containers to evaluate root system quality. Root pruning when shifting into larger 10 liter (3 gal) containers resulted in more structural roots, adventitious roots from cuts, and woody second-order roots, growing closer to the substrate surface due to a reduced angle of departure from the trunk. Root pruning improved root system quality by increasing the number of straight, radially-oriented roots growing from all propagation containers except for Ellepots placed in contact with other Ellepots which had an equivalent high number of straight roots without pruning. By many measures, all propagation container types produced nearly equivalent root systems provided root balls were mechanically pruned by shaving off roots on the periphery when shifting to 10 liter (3 gal) containers. However, root pruning when shifting had no effect on mortality or trunk diameter growth in 10 liter (3 gal) containers. Without root pruning, the propagation container type and retention time had a large influence on root morphology in 10 liter (3 gal) containers.

Index words: Accelerator®, adventitious roots, ascending roots, circling roots, descending roots, Ellepot®, RootMaker®, smooth-sided container, straight roots, tangent roots.

Species used in this study: *Acer rubrum* L.

Chemicals used in this study: 5,000 ppm IBA with Celluwet thickening agent.

Significance to the Nursery Industry

Trees grown in containers for an extended period can develop deformed roots which are kinked or grow around, up, or down the sides of the root ball, which can lead to less stable trees in the landscape. Thus, the main goal of this study was to evaluated strategies for producing container-grown trees with straight, non-deformed roots in the root ball, starting in the propagation container. Number of roots growing straight from the trunk in 10 liter (3 gal) containers was not impacted by propagation container type when cuttings were retained for 10 weeks before shifting to 10 liter (3 gal) containers. Root defects generally increased when trees were retained in the propagation container for a long period of time (26 weeks). Growing in a propagation system such as Ellepots that discourages formation of deflected roots, or removing deflected roots by pruning away the outside periphery of the liner root ball when shifting from any propagation system to a larger container both resulted in high-quality root systems. However, Ellepots should not be used to grow trees as inserts in smooth plastic propagation containers because defects develop that match those in the smooth containers.

Introduction

Dunn et al. (11) and Salonius (27) showed a direct relationship between length of time tree seedlings were retained in propagation containers and the development of deformed root systems. Deformations in the root system can lead to poor rooting out resulting in unstable trees (19). For example, Scots pine (*Pinus sylvestris* L.) trees planted from 75 ml (2.7 oz) containers developed spiraling roots when in propagation containers, causing them to be less stable in the soil 7–9 years after planting than naturally regenerated trees (20). Other root defects such as downward deflected roots were later recognized as causing problems with stability following planting jack pine (*Pinus banksiana* Lamb.) (10). Many studies on conifer seedlings show that root deflection in propagation containers can contribute to long-term growth problems after planting in the forest (17). Roots on shade trees in larger containers also deflect around or downward and proliferate at the bottom of containers (23), probably because of suitable air, nutrition, and water but the impacts on health and anchorage are poorly documented.

Balisky et al. (5) referred to evidence that root deformation occurred on trees growing in walled container systems before root density had increased sufficiently to facilitate normal extraction, handling, and transportation. The findings of Selby and Seaby (28), concerning the short period after seed germination when seedlings develop lateral roots from the primary tap root, are relevant to root deformation. These authors attributed poor anchorage of out-planted pines to the lack of properly oriented lateral support roots and the inability of these seedlings to generate new lateral roots large enough to support the tree. The root segment growing against the container wall can lose the capacity to generate secondary roots when retained in plugs for too long resulting in aggressive root growth primarily from the bottom of the container once planted into soil (27). For this reason Lindström et al. (21) tested a stabilized or reinforced substrate that could be easily removed from the container 8–12 weeks after seed germination thus preventing most container-induced root deflections. Burdett (8) tested a mesh-walled air-pruning container that encouraged roots to be distributed evenly along the sides of the liner plug. A number of growers still use these today.

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Plants grown in containers for an extended period often had deformed roots which kink or grow around the bottom or down the sides of the root ball. Ribs and other physical obstructions were introduced to deflect roots downward. The 'cage' or 'shell' of deflected roots that resulted from these modifications encouraged new roots to grow primarily down and out the bottom of the liner root ball once planted to field soil (27). Although horizontal obstructions built into the propagation container wall can result in more root tips (32), it remains uncertain how this impacts the morphology of young, developing tree root systems in larger nursery containers or in field soil after planting.

Rooting cuttings in copper treated containers in one representative study resulted in a greater percentage (40%) of roots emerging from the top one-third of the liner plug compared to trees grown in untreated containers (18%); there were also more roots in the interior of the root ball plug and fewer on the outside forming an imprint (29). Some of the latest containers have various slits and holes on the bottom and/or sides for roots to be air pruned (24). Trees produced in a nearly wall-less container (Jiffy pellets Jiffy®, Jiffy Products of America, Inc., Norwalk, OH) had more root tips and straighter lateral roots growing close to the substrate surface compared to SM pots which deflected roots down (10). Presence of root tips close to the surface resulted in more evenly distributed roots after planting into field soil.

Mechanical root pruning strategies at planting have been tested to reduce root defects in containers with varying results. Harris et al. (15) reported root pruning treatments on the tap roots [5, 10, or 15 cm (2, 4, 6 in) below soil] on pin oak (*Quercus palustris* Muenchh.) liners from containers produced more roots (> 2 mm diameter) compared to controls but did not affect total root length following planting. In contrast, Krasowski and Owens (18) found that root systems in mechanically pruned *Picea glauca* (Moench) Voss trees produced greater root growth than non-pruned controls or chemically root pruned treatments despite the reduction in root ball dimension as a result of the pruning. However, many of these roots grew downward away from the soil surface.

Until recently (e.g., 1, 14), most studies in horticultural literature comparing root systems on shade trees grown in different propagation container types report root mass, but not root morphology. Yet there appears to be evidence in the forestry literature that root morphology is more important than root mass to the health and anchorage of trees as they become established. Since straight lateral roots are associated with well-anchored trees (27), the main goal of the present study was to evaluate methods of producing trees with straight, non-deformed roots in containers. Specific objectives were to determine impact of propagation container type, retention time in container (10 vs. 26 weeks), and root pruning when shifting to a larger container on root development of red maple (*Acer rubrum* L.). This tree was chosen due to the popularity of maples for shade tree planting in many parts of temperate North America and Europe. A second objective was to determine if root attributes in propagation containers can be used to predict root system quality of trees in finished 10 liter (3 gal) containers.

Materials and Methods

On August 10, 2008, in Gainesville, FL (USDA hardiness zone 8 b), the bottom 3 cm (1.2 in) of about 1000 *Acer rubrum* 'Florida Flame' stem cuttings 12–15 cm (4.7–5.9 in) long (5–6 nodes) were coated with 5,000 ppm IBA with Celluwet thickening agent (Griffin Laboratories, Valdosta, GA) before insertion into one of six different propagation container types in an effort to develop a variety of root system forms (Table 1). Substrate consisted of 50% super fine pine bark, 30% Florida peat, and 20% horticultural perlite. Propagation container types were as follows: SM black plastic çontainers were 10 mm (0.4 in) apart with 21 containers per tray, AC® black plastic containers were 30 mm (1.2 in) apart in the manufacturer's 18-container holder tray (AC), RM black plastic containers were 15 mm (0.8 in) apart with 4 per tray (6 trays were grouped together) (RM), Ellepot paper containers were arranged touching each other (EPP) 5 across by 9 deep in a perforated plastic Daisy 1020 tray (27 × 53 cm, 10.6 × 20.9 in), Ellepot paper containers were arranged 1 cm (0.4 in) apart (EPS) 4 across by 7 deep in the

Table 1. Attributes of 6 propagation container types planted with *Acer rubrum*.

Container name/material (abbreviation)	Container manufacturer	Interior dimensions	Volume cm³ (in³)	Shape
Smooth/plastic, model X-21STPP (SM)	Landmark Plastic, Inc., Akron OH	70 mm (2.8 in) diameter 90 mm (3.5 in) tall	282 (17.1)	Tapered cone/ round bottom
Accelerator®/plastic with large holes, model AP-L2PT (AC)	Nursery Supplies Inc., Chambersburg PA	55 mm (2.2 in) diameter 90 mm (3.5 in) tall	219 (13.3)	Tapered cone/ flat open bottom
RootMaker®/plastic with holes and ridges, model 4-pack (RM)	RootMaker Inc., Huntsville AL	68 mm (2.7 in) square 95 mm (3.7 in) tall	189 (11.6)	Square, tapered, stepped sides
Ellepot-to-pot/paper[z] (EPP)	Ellegaard, Esbjerg, Denmark	50 mm (2.0 in) diameter 90 mm (3.5 in) tall	137 (8.4)	Cylinder
Ellepot-spaced/paper[z] (EPS)	Same as above	50 mm (2.0 in) diameter 90 mm (3.5 in) tall	137 (8.4)	Cylinder
Ellepot-in-smooth/paper[z] in smooth plastic container (EPSM)	Same as above	50 mm (2.0 in) diameter 90 mm (3.5 in) tall	137 (8.4)	Cylinder in square plastic

[z]Ellepot paper made by Ahlstrom Stalldalen AB, Stalldalen, Sweden, from spruce, pine, and polyester long fibers, 27 $g \cdot m^{-2}$, 190 microns thick, 1320 $N \cdot m^{-1}$ dry tensile strength in machine direction, 2.0 N tear strength.

Table 2. Definitions of shoot and root [those > 1 mm (0.04 in) diameter] attributes measured when trees were harvested from 6 propagation containers.

- Trunk caliper: stem diameter measured at substrate surface.
- Tree height: distance from substrate surface to tip of terminal bud.
- Number of leaves/buds: number of live leaves (for 10 week retention time harvest) or live buds (for 26 week harvest).
- Root symmetry rating: 1 = asymmetrical with most roots on one side; 5 = radially symmetrical distribution of mother roots (roots growing directly from stem).
- Roots emerging at surface: one or more roots emerging from the stem just under, at, or above the substrate surface.
- Number of roots emerging from top half or bottom half of the buried portion of the stem cutting (mother roots).
- Root branchiness rating: a visual rating with 1 = few secondary roots growing from mother roots, and 5 = many secondary roots growing from mother roots.
- Diameter of 5 largest roots measured 1 cm from trunk which was beyond any sudden swelling at base of root.
- Root angle top half of stem cutting: angle of departure downward from horizontal of each mother root growing from the top half of the stem cutting.
- Root angle bottom half of stem cutting: angle of departure downward from horizontal of each mother root growing from the bottom half of the stem cutting.
- Number of roots and total length of roots penetrating container side wall.
- Number and total length of roots growing out of container bottom.
- Number of roots and total length of roots deflected and growing up the container wall at less than 45 degrees from vertical.
- Number of roots and total length of roots deflected and growing around the container wall at less than 45 degrees from horizontal.
- Number of roots and total length of roots deflected and growing down the container wall at less than 45 degrees from vertical.
- Length of roots prior to deflection by container wall in the top half and bottom half of the root ball.

Note: Data reported in Tables 4–6.

same plastic Daisy 1020 tray, and Ellepot paper containers were placed inside an Ellepot 32-cell black plastic tray (cells had smooth sides) 5 mm (0.2 in) apart (EPSM). Trays were arranged in a randomized fashion on 3 plastic mesh benches 80 cm (31.5 in) from the ground in a climate-controlled greenhouse through October 21, 2008. Misting was provided regularly to encourage turgid tissue.

Ten trees randomly chosen from each container type the week of October 22, 2008 (10 weeks retention time in containers), were washed of substrate. Roots > 1 mm (0.04 in) in diameter were characterized for many attributes (Table 2) in an attempt to find a predictor of quality on the finished root ball in 10 liter (3 gal) containers. Tree height, number of live leaves, and trunk diameter (caliper) at substrate level (measured with a micro-caliper) were also recorded. On October 22, 2008, thirty liners of each propagation container type were transferred (shifted) into 10 liter (3 gal) black plastic smooth-walled containers [20 cm (8 in) across at the top × 22 cm (8.7 in) deep; Nursery Supplies, Inc., Chambersburg, PA] without root pruning, and placed on a gravel bed in a randomized complete block design with one tree from each of the 6 container types in each of 30 blocks. The paper remained on the root ball for the three Ellepot treatments. Controlled release fertilizer (18-5-10, Harrells, Inc., Lakeland, FL) was incorporated into the substrate (60% pine bark:30% Florida peat:10% sand) prior to shifting to the 10 liter (3 gal) container (18 lbs·yd^{-3}), and no other fertilizer was applied. Trees in 10 liter (3 gal) containers were overhead irrigated three times daily in the growing season, less in the dormant season. Roots remained inside 10 liter (3 gal) containers without rooting into the ground. Shoots were pruned once to maintain one dominant leader until harvested. Remaining liners in propagation containers were moved outside the greenhouse and placed in full sun on elevated wire mesh benches in a randomized fashion and hand watered nearly daily.

Another ten liners randomly chosen from each propagation container type were washed of substrate during the week of February 9, 2009 (26 weeks retention time in containers), and roots were characterized as before (Table 2). Tree height, number of live buds, and caliper at substrate level were recorded. Remaining trees (30) from each propagation container type were shifted into the same 10 liter (3 gal) containers described above. Root balls on 15 trees per treatment were root pruned by removing the outer 5 to 7 mm (0.2 to 0.28 in) of the root ball sides and bottom with a sharp scissors (Fiskars, item #FSK01004342) with roots cut by one person to standardize procedure. Remaining 15 trees were not root pruned when shifted into the 10 liter (3 gal) containers. Substrate in the propagation container was positioned a few mm below the surface of the 10 liter (3 gal) container substrate to account for some substrate settling. Trees were placed on the same gravel bed in a randomized complete block design (6 container types × 2 root pruning treatments × 15 blocks = 180 trees).

Five randomly-chosen blocks from both groups (retained 10 or 26 weeks in propagation containers) were harvested 10 months after shifting into the 10 liter (3 gal) containers (6 container types × 5 blocks at 10 weeks = 30 trees, and 6 container types × 2 root pruning treatments × 5 blocks at 26 weeks = 60 trees). Trunk caliper 15 cm (6 in) above substrate, and tree height were measured. A new pruning saw was inserted vertically into the root ball on each tree 2.5 cm (1 in) inside the periphery of the 10 liter (3 gal) container. The saw was pushed up and down all around the root ball for two complete rotations (720 degrees) to ensure all roots were cut to the bottom of the root ball. The root ball was lifted out of the container and the peripheral 2.5 cm (1 in) of substrate and roots was peeled free and discarded. The bottom 2.5 cm (1 in) of the root ball was cut off with the saw once the periphery was discarded. The roots and substrate growing on the periphery and bottom were removed because the main objective of the project was to characterize the morphology of roots as they emerged from the liner; root mass and total root length was not of interest. Substrate was washed from the root system with city water pressure and mechanical manipulation with hands. All substrate was removed including that within the volume of the propagation container. Each root system was labeled and photographed from the top and sides. Roots were measured for many attributes to characterize morphology (Table 3).

Root and shoot attributes on finished liners in propagation containers (2 retention times × 6 propagation container types = 12 treatment combinations) and on finished 10 liter (3 gal) containers (2 retention times × 6 container types = 12

Table 3. Definitions of root attributes measured when trees were harvested from root balls in 10 liter (3 gal) containers.

- Percent of the trunk circled with roots > 2 mm (0.08 in) diameter in top half of root ball evaluated at position of propagation container.
- Cull: tree does not meet grade according to Florida Grades and Standards for Nursery Plants (2); i.e. there was at least one root (> 1/10 trunk caliper) in the top half of the root ball that circled more than one-third trunk circumference.
- Root symmetry rating: a visual rating with 1 = radially asymmetrical distribution of main [> 2 mm (0.08 in) diameter measured 2.5 cm from periphery of 10 liter (3 gal) container] roots with most on one side of root ball, and 5 = radially symmetrical distribution.
- Original liner imprint rating: a visual rating with 1 = little imprint, few mother roots deflected by propagation container, and 5 = strong imprint, most mother roots deflected by and retaining the shape of the propagation container.
- Number of ascending roots > 1 mm (0.04 in) and > 2 mm (0.08 in) diameter: number of roots growing up (at > 5 degree angle from horizontal) toward the substrate surface as they emerged from the propagation container into substrate of the 10 liter (3 gal) container.
- Number of roots > 1 mm (0.04 in) diameter growing tangent to trunk in the top half of root ball.
- Number of roots > 2 mm (0.08 in) diameter deflected in any direction by the propagation container wall.
- Number of lateral roots > 1 mm (0.04 in) from descending roots: number of roots > 1 mm (0.04 in) diameter growing (typically horizontally) into the 10 liter (3 gal) substrate from the segment of mother roots deflected downward by the propagation container wall.
- Number and length of straight roots from trunk: number and length of roots > 2 mm (0.08 in) diameter [measured 2.5 cm (1 in) inside the 10 liter (3 gal) container periphery] growing from the trunk at an angle less than 45 degrees from horizontal with less than a 45 degree deflection at the position of the propagation container following the largest root at forks.
- Diameter of the 5 largest roots at the trunk measured just beyond any swelling at their base.
- Angle of 5 largest roots at trunk: angle from horizontal of the 5 largest mother roots measured by drawing a straight line from the point of emergence at the trunk to the point where that root was cut at harvest 2.5 cm (1 in) inside periphery of 10 liter (3 gal) container wall following the largest root at forks.
- Number and diameter of mother roots at trunk: roots > 2 mm (0.08 in) diameter growing directly from the trunk measured just beyond any swelling at their base.
- Angle of mother roots at trunk, and main roots: angle from horizontal of all roots > 2 mm (0.08 in) diameter measured from trunk to the position of propagation container wall, and angle of the terminal 5 cm (2 in) long section of same root (main root) 2.5 cm (1 in) inside periphery of 10 liter (3 gal) container wall following the largest root at forks.
- Difference between mother root angle and main root angle: angle of mother root > 2 mm (0.08 in) diameter at trunk minus angle of the same root at root ball periphery following the largest root at forks.
- Depth and diameter of main roots 2.5 cm (1 in) inside container wall: depth and diameter of roots > 2 mm (0.08 in) diameter measured 2.5 cm (1 in) inside periphery of 10 liter (3 gal) container wall.
- Maximum angle in root ball with no main roots: maximum circumference of root ball (in degrees) without roots > 2 mm (0.08 in) diameter.

Note: Attributes measured following removal of 2.5 cm (1 in) of substrate and roots from the periphery of the 10 liter (3 gal) container root ball using a pruning saw; data reported in Tables 7–11.

treatment combinations) were both analyzed with two-way analysis of variance (ANOVA) in a randomized complete block design using the GLM procedure of SAS (version 9.2 SAS Institute, Cary, NC). The influence of root pruning trees from the 6 container types (2 root pruning × 6 container types = 12 treatment combinations) on root attributes in the 10 liter (3 gal) containers was also analyzed with two-way ANOVA in a randomized complete block design. Duncan's multiple range test in SAS was used to separate main effect means; interaction means were compared with LS means at $p < 0.05$. Pearson's correlation coefficient ($p < 0.05$ unless indicated) was used to correlate the values of selected attributes of trees in liners with those in 10 liter (3 gal) containers. Coefficients were calculated by assigning each of the 5 harvested 10 liter (3 gal) container root balls from a particular propagation type with the mean value (calculated from 10 replicates) of a root attribute from the propagation container.

Results and Discussion

Liners not root pruned at planting. Trees in EPP and EPS propagation containers produced smaller mean diameter in the 5 largest roots, had more roots penetrate the container wall, and grew more roots out the bottom of the root ball than trees in SM containers (Table 4). These same three attributes in AC and RM containers were similar to SM. The number and total length of roots deflected up, around, and down by container walls were approximately an order of magnitude greater in all four plastic containers compared to those made from paper only (i.e., EPP and EPS, Table 4). Total root length prior to deflection in the bottom half of the root ball was greater for trees in EPS and AC than trees in SM containers (Table 4). Total length of deflected roots (sum total length of those deflected up, down, and around) was an order of magnitude smaller for paper container treatments (EPP and EPS) compared to all others.

Increase in total deflected root length with time in all propagation containers (10 vs. 26 weeks) was almost exclusively due to increased length of upward deflected roots (Table 5). Most deflected mother roots first grew downward after deflection and reached the bottom before they grew up along the propagation container wall. Some roots were deflected upward when they first contacted the side wall, whereas others generated second order roots that grew upward from points along mother roots proximal to container walls. EPP and EPS containers dramatically reduced number and length of deflected roots presumably due to a combination of root tip die-back that occurred as a result of growing through the paper and into the air outside the container (i.e., air pruning), and growth of some of these roots into adjacent containers. Orlander (25) and Ortega et al. (26) also found that air-pruning resulted in fewer deflected roots in the propagation container.

Six root attributes had interactions between container type and retention time in propagation container (Table 6). More roots emerged from the top half of the stem cutting only in SM containers, and fewer roots emerged from the top half only in AC, when trees remained in containers 26 weeks compared to 10 weeks. More roots emerged from the bottom half of the stem cutting at 26 weeks than 10 weeks retention time only in EPSM containers. Number of roots deflected around the container wall increased with retention time only for SM, EPSM, and RM. Total length of roots deflected around the container wall increased with retention time only for EPSM containers. Total length of live roots growing outside the wall of the propagation containers was less for trees growing in containers for 26 weeks than 10 weeks for EPP and EPS. More roots were deflected down

Table 4. **Mean separation of root attributes of rooted cuttings in 6 propagation container types averaged across 10 and 26 week retention times.**

Propagation container type	Diameter 5 largest roots at trunk (mm)	No. roots penetrating container wall	No. roots out bottom of container	Length of live roots outside (mm)	No. roots deflected up wall	Length of roots deflected up wall (mm)
SM	1.9a[z]	0c	0.4c	0c	9.4a	466a
EPP	1.5b	2.4b	2.6ab	123b	0.0d	0c
EPS	1.6b	6.0a	3.4a	290a	0.2d	7c
EPSM	1.5b	0.8c	0.5c	0c	2.8c	138bc
AC	1.8ab	0.6c	1.2bc	3c	3.3c	163b
RM	1.7ab	0.1c	0.5c	0c	6.0b	257b
Propagation container type	**No. roots deflected around wall**	**Length of roots deflected around wall (mm)**	**No. roots deflected down wall**	**Length of roots deflected down wall (mm)**	**Length of roots prior to deflection bottom of root ball (mm)**	**Total length of deflected roots (mm)**
SM	4.6ab	208b	20.9a	921a	464b	1595a
EPP	0.05c	3d	0.5d	20e	573ab	22c
EPS	0.4c	15cd	1.1d	41de	695a	62c
EPSM	6.8a	265ab	13.1c	750ab	592ab	1153ab
AC	2.1bc	130c	17.0b	533bc	709a	799b
RM	7.3a	331a	11.4c	364cd	518ab	952b

Note: Root attribute descriptions in Table 2.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 20 trees averaged across 10 and 26 weeks retention time in propagation container.

Table 5. **Mean separation of root attributes of rooted cuttings in propagation containers retained 10 or 26 weeks averaged across 6 container types.**

Retention time in propagation container	Trunk caliper (mm)	No. leaves/buds	Diameter 5 largest roots at trunk (mm)	Root angle bottom of stem cutting	No. roots out bottom	Length of roots out bottom
10 weeks	4.3b[z]	9.0b	1.4b	59.1a	2.4a	91a
26 weeks	4.6a	12.7a	1.9a	55.2b	0.4b	0b
Retention time in propagation container	**No. roots deflected up wall**	**Length of roots deflected up wall (mm)**	**Root length prior to deflection bottom of root ball (mm)**	**Total root length prior to deflection (mm)**	**Total length of deflected roots (mm)**	
10 weeks	2.2b	98b	656a	1174a	633b	
26 weeks	5.0a	249a	523b	982b	907a	

Note: Root attribute descriptions in Table 2.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 60 trees averaged across 6 propagation container types.

Table 6. **Mean separation for interactions of propagation container type and retention time in propagation container on root attributes of rooted cuttings.**

Propagation container type	Retention time in propagation container (weeks)	No. roots emerging from top half of stem cutting	No. roots emerging from bottom half of stem cutting	No. roots deflected around wall	Length of roots deflected around wall (mm)	Length of live roots outside container wall (mm)	No. roots deflected down wall
SM	10	9.3d[z]	15.4cd	3.3d	167bcde	0c	18.0b
	26	12.6abc	14.0cd	6.0c	250bcd	0c	24.2a
EPP	10	8.2d	15.6bcd	0.1h	5e	245b	1.0f
	26	10.3cd	13.5d	0i	0e	0c	0.3f
EPS	10	15.0a	17.1bc	0.1h	5e	579a	0.5f
	26	13.2ab	17.3bc	0.6gh	24de	1c	2.4e
EPSM	10	15.3a	13.1d	0.8fg	32de	0c	12.4cd
	26	13.0abc	18.9b	13.4a	520a	0c	13.9cd
AC	10	14.0ab	23.2a	1.6ef	71cde	7c	20.1b
	26	6.8d	19.0ab	2.8de	132cde	0c	14.4c
RM	10	11.1bcd	17.1bc	5.6c	279bc	0c	11.2cd
	26	11.9bcd	14.2cd	9.2b	389ab	0c	11.7cd

Note: Root attribute descriptions in Table 2.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 10 trees in each propagation container type × retention time-in-container combination.

with time only in SM pots and EPS. In contrast, fewer roots deflected down with time in AC.

Although more than 20 roots [> 1 mm (0.04 in) diameter] were deflected up, around, or down the periphery of the finished liner root balls in the four containers made from plastic (Table 4), eleven or less main roots [> 2 mm (0.08 in) diameter] were found in those positions 10 months later in 10 liter (3 gal) containers (Table 7). This indicated that only about ½ of the deflected roots in propagation containers developed into main woody roots in the finished 10 liter (3 gal) containers; the other half remained in what appeared to be a dormant state without growing as others found (11), or they died. Similar to red maple from seed (12), roots from cuttings in the current study that emerged close to the substrate surface often grew large at the expense of those borne deeper in the root ball (Fig. 1). Coutts et al. (10) also showed this trend on lodgepole pine (*Pinus contorta* Dougl.) and Sitka spruce (*Picea sitchensis* Bong. Carr.).

Despite the enormous reduction in the number and length of roots (averaged across 10 and 26 weeks) deflected up, down and around for EPP and EPS compared to other container types (Table 4), propagation container type had no impact on number of root culls or percentage of trunk with circling roots > 2 mm (0.08 in) diameter on finished trees in 10 liter (3 gal) containers (data not shown). Furthermore, correlation between presence of culls in the 10 liter (3 gal) and roots deflected around (r = 0.26, $p = 0.04$) or up (r = 0.36, $p = 0.03$) in the propagation container were weak. One reason for this may be that despite the almost total lack of deflected roots inside EPP and EPS liners, the abundant live roots that grew through the paper (Table 4) became pressed against it by the substrate when shifting into the 10 liter (3 gal) containers. No attempt was made to prevent this at shifting. This likely resulted in long segments of live flexible roots becoming reoriented in random directions including up, down and around the outside of the paper, similar to the other container types which deflected roots in this manner but on the inside surface of the plastic container wall.

No new mother roots emerged from the buried portion of the stem cutting between 10 and 26 weeks while trees were in propagation containers (data not shown) indicating mother roots from the stem cutting had finished forming by 10 weeks after propagation. Selby and Sealy (30) also found that lateral roots of *Pinus contorta* emerged from the tap root early and soon stopped emerging. It is not known if timing of root initiation differs for cuttings and seed propagated trees, or how initiation may vary across a wide number of species. Furthermore, liner imprint rating on finished 10 liter (3 gal) containers was not impacted by retention time in propagation container (data not shown) as Balisky et al. (5) also showed. However, Salonius et al. (27) found that roots grew slowly into soil when held in propagation containers for extended periods compared to younger liners; slow root growth hinders establishment and could impact anchorage (27).

Number of roots that descended along the propagation container wall in the liner was correlated with number of roots that grew upward (ascending roots) as they emerged from the liner root ball into the 10 liter (3 gal) container substrate (r = 0.33 for roots > 1 mm (0.04 in) diameter, r = 0.38 for roots > 2 mm (0.08 in) diameter; $p < 0.01$ calculated from all 60 non-pruned root systems). Number of ascending roots [> 1 mm (0.04 in) diameter] in the 10 liter (3 gal) substrate was correlated (r = 0.52, $p < 0.0001$) with number of roots growing tangent to the trunk indicating that the origin of at least some tangent roots was the mother roots or their secondary roots that grew upward into the substrate of the 10 liter (3 gal) container. An increase in the total number and total length of roots deflected by the propagation container wall resulted in (r = 0.68, $p < 0.0001$) an increase in the liner imprint rating on trees in 10 liter (3 gal) containers. These relationships provide good evidence that roots growing down the periphery of the propagation container wall should be eliminated because some of them ultimately grow tangent to the trunk close to the substrate surface. These can constrict the trunk which negatively impacts health (31) and reduces anchorage (20). The occurrence of roots that ascended into the 10 liter (3 gal) containers largely from roots deflected downward to the bottom of the propagation container was not surprising because roots on medium-aged and mature red maple typically develop only in the top 25 cm (9.8 in) of soil profile (22; 12). Furthermore, many of the largest roots in 10 liter (3 gal) containers were oriented downward resulting in a mostly vertical root system (Fig. 1) which is counter to their natural habit. Further study should evaluate how red maple and other taxa with this root form in a container adapt to the soil environment following planting into soil.

Trees propagated in EPP and EPS had a shallower root system measured at the periphery of the 10 liter (3 gal) container than trees grown in SM propagation containers (Fig. 1, Table 7) likely due to the much smaller portion of

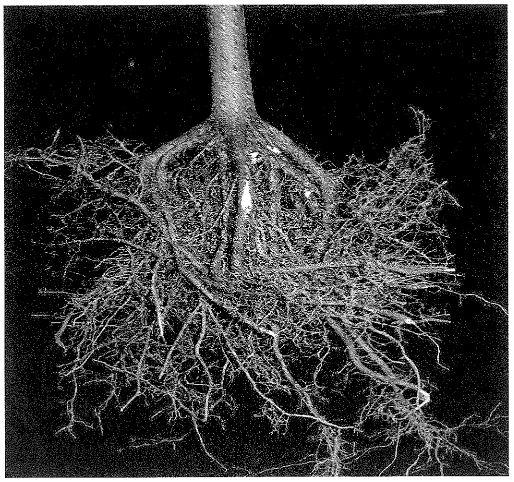
Table 7. Mean separation of root attributes after growing in 10 liter (3 gal) containers 10 months after shifting without root pruning from 6 different propagation container types averaged across 2 propagation retention times (10 and 26 weeks).

Propagation container type	Original liner imprint rating (1–5)[z]	No. ascending roots > 2 mm	No. roots > 2 mm deflected by propagation container wall	No. lateral roots > 1 mm from descending roots	Angle of 5 largest roots	No. mother (> 2 mm) roots at trunk	Depth main roots 2.5 cm inside 10 L container wall (mm)
SM	4.9a[y]	2.9a	10.8a	4.6a	79.0a	15.2bc	98a
EPP	1.6c	0.4c	2.3d	1.3c	47.7b	19.6a	75bc
EPS	2.9b	1.4bc	4.5c	1.4c	45.5b	16.5abc	71c
EPSM	4.6a	1.9ab	11.1a	2.3bc	73.8a	14.7c	93a
AC	3.6ab	2.8ab	7.3b	3.3ab	67.1a	18.6ab	90ab
RM	3.8ab	1.6b	8.1b	3.2ab	66.6a	15.3bc	86abc

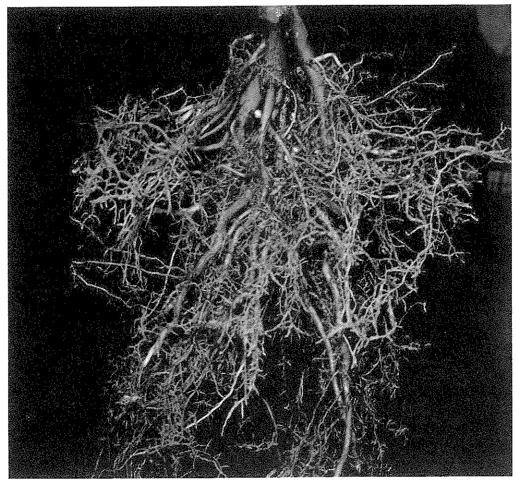
Note: Trees were not root pruned when shifted into 10 liter containers; root attribute descriptions in Table 3.

[z]1 = little imprint; 5 = strong imprint.

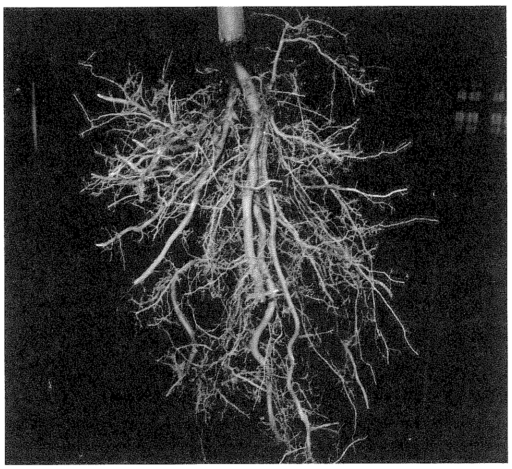
[y]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 10 trees averaged across 10 and 26 week retention times in propagation containers.



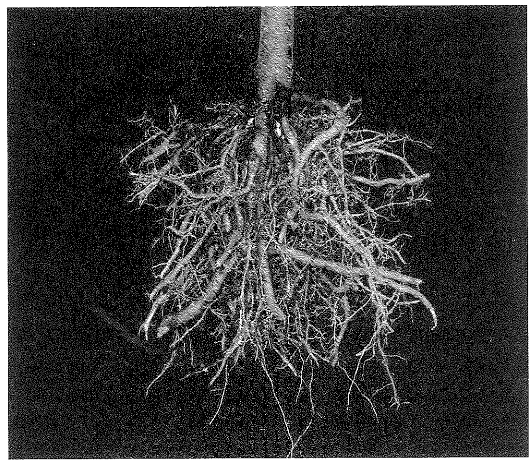
SM propagation liner into 10 liter (3 gal) container showing liner imprint from deflected (descending) mother roots and several main roots ascending from the bottom of the liner into the substrate of the 10 liter (3 gal) container.



RM liner into 10 liter (3 gal) container showing many mother roots growing downward with smaller roots growing horizontally.



EPP liner into 10 liter (3 gal) container showing little propagation container imprint, more shallow roots, and fewer descending roots.



AC liner into 10 liter (3 gal) container showing a circling root and a combination of descending and horizontal mother and main roots.

Fig. 1. Root systems (with many non-woody roots removed) 10 months after shifting into 10 liter (3 gal) containers from four of six propagation container types.

the root system deflected downward by the paper wall (Table 4). This shallow root system more closely mimicked a red maple root system found in nature (22). Due to warmer, more ideal soil temperatures in spring in the upper soil profiles (i.e., it is colder with increasing depth) in some cooler temperate climates it is important to have many root tips in the top portion of a liner root ball when planting in spring (24). Roots of other species deflected downward in propagation containers often grew out the bottom of the liner after planting into soil, resulting in artificially deep and deformed root systems close to the trunk (5, 27, 28). This has also been a concern of shade tree growers who purchase whips from other growers. Deflection of mother roots downward in the propagation container forces them to grow parallel to one another directly under the trunk causing constrictions and inclusions which can restrict passage of substances through vascular tissue (20). Distributing the root tips in the lateral (horizontal) position more evenly along the liner root ball sides, instead of at the bottom, allows mother roots to grow in a more natural position (7, 9, 29). Lindstrom and Rune (20) showed that trees became more stable after planting when some roots were able to grow in a more horizontal orientation instead of being deflected downward or around. A reduction in downward and tangential root deflection in propagation containers coated with copper hydroxide also produced root systems similar to naturally regenerated trees resulting in identical anchorage between the two groups (7, 11). Further research is needed to evaluate anchorage for maple from the propagation containers tested in the current study.

Trees growing in all container types made from plastic had similar imprint ratings (Table 7). The imprint from the original liner that resulted from roots deflecting up, down and around as they met the wall of the propagation container was less visible in EPP and EPS than SM containers. Trees propagated in EPP had almost no roots > 2 mm (0.08 in) diameter that grew up (ascended) into the substrate of the 10 liter (3 gal) container and the least number of deflected roots > 2 mm (0.08 in) diameter (Table 7). Trees retained in

EPP propagation containers 26 weeks had fewer roots [> 1 mm (0.04 in) diameter] that ascended as they grew into the 10 liter (3 gal) container substrate than those held only 10 weeks (Table 8) because there were fewer live roots outside the paper container to dislodge and deflect when shifting at 26 weeks (Table 6). Fewer live roots on the outside of the paper could have resulted from drying or the low winter temperatures (–7C, 22F) killing roots growing outside the substrate in January and February 2009 just prior to shifting. Furthermore, many roots were growing into adjacent Ellepots and they were cut leaving a short stiff straight root stub when harvested for shifting into 10 liter (3 gal) containers. The root stubs remained straight and more-or-less horizontal or angled downward only slightly as substrate was filled in around the liner root ball. Combined with the dramatically reduced number of roots deflected by the propagation container wall, roots growing from these cut roots that are close to the substrate surface is likely the source of the shallower root system measured 2.5 cm (1 in) inside 10 liter (3 gal) container wall in the finished trees that were shifted from EPP (Table 7).

Abundant straight roots are considered a desirable attribute on trees because they lead to better anchorage than trees with circling roots (20). Number of roots growing straight from the trunk in 10 liter (3 gal) containers was not impacted by propagation container type when cuttings were retained for 10 weeks before shifting to 10 liter (3 gal) containers (Table 8). However, holding trees for 26 weeks in EPP propagation containers resulted in finished root balls in 10 liter (3 gal) containers with significantly more straight roots than any other container type. Trees from EPS and AC held 26 weeks also produced more straight roots than trees from SM containers. Instead of deflecting at the container wall like trees in plastic containers, many roots had grown through the paper wall into adjacent Ellepots by 26 weeks after sticking cuttings; these were typically among the largest roots (although their diameter was not measured) and they had to be cut to separate them from others prior to shifting into 10 liter (3 gal) containers. Cut roots generate replacement roots near the cut end that grow in a 3 dimensional cone- or fan-like array in the same general orientation as the root segment proximal to the cut (16, 30) resulting in several relatively straight main roots. Because the average orientation of cut roots was only 41 degrees from horizontal in the current study (in top half of liner plug), some new roots grew from these cut roots into the 10 liter (3 gal) container close to the substrate surface. Roots cut close to the substrate surface would have an enhanced opportunity, compared to deeper roots, to remain shallow and grow straight into the substrate of the 10 liter (3 gal) container (7, 28). Presence of at least some roots close to the soil surface has been associated with increased anchorage compared to a root system with only downward oriented roots growing primarily from the bottom of the liner root ball (7). Although not directly measured, rooting into adjacent Ellepots (for EPP and EPS) appeared less common 10 weeks after sticking cuttings so fewer roots may have been cut prior to shifting to the 10 liter (3 gal) container. This might explain why the number of straight roots in the 10 liter (3 gal) containers was not impacted by propagation container type when trees were held for only 10 weeks in propagation containers (Table 8).

Trees in 10 liter (3 gal) containers shifted from all propagation container types except the two with the most deflected root systems (SM and EPSM) generated more straight roots from 26-week than from 10-week-old liners by a factor of 2.5 to 5 (Table 8). Fewer straight roots on SM and EPSM containers could have resulted from the steeper angle of mother roots ($r = 0.34$, $p < 0.01$) at 26 vs. 10 weeks retention time (Table 8); roots steeper than 45 degrees from horizontal were not counted as straight roots. The dominance of these mostly downward-oriented roots may have suppressed growth on those smaller-diameter non-deflected roots closer to the substrate surface that had a greater opportunity to grow into straight roots. Moreover, SM, EPSM, and RM had more roots growing around the propagation container wall at 26 weeks retention time than the other three containers (Table 6) indicating these trees had placed a relatively large amount of wood into those deflected roots. Number and length of roots deflected around the propagation container wall after 26 weeks (Table 6) was more negatively correlated ($r = -0.87$ and -0.85 respectively, $p < 0.03$) with the number of straight roots in the 10 liter (3 gal) container than any other root attribute measured in propagation containers. Gilman et al. (14) showed that roots appear to have a poor capacity

Table 8. Mean separation of interactions of propagation container type and retention time in propagation container on root attributes after 10 months in 10 liter (3 gal) containers with no root pruning.

Propagation container type	Retention time in propagation container (weeks)	No. ascending roots > 1 mm	No. roots > 1 mm tangent to trunk	No. straight roots from trunk	Angle of mother roots at trunk	Diameter of mother roots at trunk (mm)
SM	10	3.8b[z]	1.7ab	2.8d	42.7c	4.5bc
	26	8.4a	3.4a	3.4cd	57.9ab	5.4abc
EPP	10	2.7b	1.8ab	3.3cd	50.2bc	5.1abc
	26	0.4c	0c	18.8a	40.1c	5.7abc
EPS	10	4.5b	1.5b	2.3de	44.1bc	6.8a
	26	2.6b	0.6b	10.8b	44.2bc	4.9abc
EPSM	10	3.0b	1.3b	2.2de	48.1bc	4.0c
	26	4.4b	0.8b	1.0e	67.3a	6.4ab
AC	10	4.8b	1.0b	3.0d	48.7bc	5.2abc
	26	2.6b	1.0b	11.6b	52.3bc	5.6abc
RM	10	4.0b	2.0ab	2.2de	49.6bc	4.4bc
	26	4.8b	1.6ab	5.8c	47.8bc	6.3ab

Note: Trees were not root pruned when shifted into 10 liter containers; root attribute descriptions in Table 3.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 5 trees per container type × retention time in propagation container combination.

for generating new roots on the outside (convex) surface of curved or deflected roots perhaps due to suberization (27). With suberization, the deflected portion of the root system (i.e., the portion of the root system 'imprinted' by the liner) may become progressively less able to generate roots after outplanting certain species, unless roots are pruned or injured. Further research in this area is encouraged. The larger downward angle of the mother [> 2 mm (0.08 in) diameter] roots at the trunk within the dimensions of the EPSM containers compared to the others (except SM) after 26 weeks (Table 8) also corresponded to the least number of straight roots in 10 liter (3 gal) containers. This emphasizes the importance of preventing mother root deflections in propagation containers so roots can develop their more natural, straight horizontal orientation early.

Trees in EPP and EPS containers had less than one-tenth of the deflected root length and number than trees in all other containers (averaged across retention times, Table 4) which also could explain the abundance of straight roots when these rooted into the substrate of the 10 liter (3 gal) containers (Table 8). Trees in AC also had abundant straight roots growing from the trunk to the edge of the 10 liter (3 gal) container. Lack of deflected roots positioned more root tips in the horizontal position and closer to the substrate surface. Another explanation for abundant straight roots could be that some secondary roots [e.g., those growing away from the trunk from downward-angled (mean 41 degrees) mother roots] in EPP and EPS, grew to the periphery of the paper where they branched or ceased growing in response to air-pruning which positioned root tips close to the substrate surface. This was in contrast to trees in plastic containers whose secondary roots were deflected or perhaps failed to develop. Secondary roots may have failed to develop along the plastic container wall because it presented a physical barrier. Finally, mother roots in EPP and EPS had a smaller diameter than those in smooth containers (Table 4) indicating their growth was comparatively suppressed. Suppressed mother roots may have increased branching (although the visual branchiness rating was similar for all container types, data not shown), or may have induced existing smaller mother roots to grow, presenting more non-deflected root tips to the substrate in the 10 liter (3 gal) container. There is some evidence of this in Table 7 which shows that liners from EPP were the only ones to develop more mother roots than SM. Despite the presence of plastic, trees from AC containers held 26 weeks may have developed many straight roots in 10 liter (3 gal) containers because roots were air-pruned (i.e., they stopped elongating because the root tip grew outside the substrate and into the air) as they reached the liner wall at the position of one of the relatively-large 24 holes [mean size = 6 × 10 mm (0.24 × 0.4 in)]. Perhaps the large size of the holes, relative to the other plastic containers, was effective at air pruning.

Straight roots grew primarily from roots that were present in the liners, not from new roots produced from the stem after trees were shifted into 10 liter (3 gal) containers. Straight roots had two origins: 1) short, existing, mother roots within the liner that had not been deflected by the propagation container wall, or 2) less commonly, a secondary root was generated at the point where the mother root made a bend at the propagation container wall. Although not counted as straight, some secondary roots (1.4 to 4.6, depending on container type, Table 7) > 1 mm (0.04 in) diameter that grew more-or-less horizontal to the substrate surface from much larger mother roots that were deflected downward by the propagation container wall might eventually be considered straight roots as trees grow. The fact that number of roots emerging from the trunk was not different between trees retained in propagation containers for 10 weeks and 26 weeks (data not shown) indicated that new roots had ceased forming from the stem by 10 weeks after sticking cuttings. If a sizable number of new roots were generated from the trunk base after shifting into the 10 liter (3 gal) containers, there would not have been a strong interaction between propagation container type and retention time in container on the number of straight roots (Table 8). In other words, trees in all container types would have generated the same amount of new roots into the substrate in 10 liter (3 gal) containers. Therefore, it seems clear that in order to produce straight roots, with few descending, ascending, tangent or circling roots on red maple in 10 liter (3 gal) containers it is best to shift from a propagation container that has few deflected roots. This has been achieved by coating the walls with copper (3, 6), growing in containers that air prune roots (4), growing trees in a stabilized substrate for a short period of time before significant root deflection occurs (22), and propagating in containers that allow roots to grow through the walls and into the adjacent pots (10). The current study shows that growing trees in Ellepots is also effective.

The larger size of certain attributes, such as caliper and root diameter at the trunk, for trees in 10 liter (3 gal) containers retained in propagation containers for 26 weeks compared to 10 weeks (Table 9) could be attributable to 6 to 8 weeks more growing season, not the influence of retention time in container. Trees retained in the propagation containers for 10 weeks were shifted in October and finished part way through the next growing season in August, whereas trees retained 26 weeks were in the 10 liter (3 gal) containers throughout the entire growing season, February through December. Using

Table 9. Root attributes after growing in 10 liter (3 gal) containers for 10 months after retention for either 10 or 26 weeks in 6 different propagation container types.

Retention time in propagation container (weeks)	Trunk caliper (mm)	Diameter of 5 largest roots at trunk (mm)	No. mother (> 2 mm) roots at trunk	Total length straight roots from trunk (mm)	Angle of 5 largest roots at trunk	Root angle 2.5 cm inside 10 L container wall	Difference between mother root angle and main root angle
10	11.3b[z]	5.4b	13.3b	938b	68a	38a	−9b[y]
26	13.3a	7.1a	20.7a	2002a	58b	32b	−20a

Note: Trees were not root pruned when shifted into 10 liter containers; root attribute descriptions in Table 3.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Mean of 30 trees averaged across 6 container types.

[y]Negative number indicates the distal portion of the root (i.e. main root) was at a lesser angle to substrate surface than the angle as mother root emerged from the trunk.

Table 10. Mean separation for root attributes of trees root pruned or not pruned when shifted from 6 propagation containers to 10 liter (3 gal) containers 10 months earlier.

Root pruning	Percent trunk circled by roots > 2 mm (%)	Culls (%)	Original liner imprint rating (1–5)	No. roots > 2 mm deflected by propagation container wall	No. lateral roots > 1 mm from descending roots	Angle of 5 largest roots (degrees)	Angle of mother roots at trunk (degrees)	Difference between mother root angle and main root angle
Yes	1.2b[z]	0b	1.4b	1.9b	0.6b	42.1b	39.6b	–10b
No	21.5a	23a	3.7a	7.3a	2.6a	57.8a	51.6a	–20a

Note: Trees retained 26 weeks in propagation containers; root attribute descriptions in Table 3.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Means of 30 trees averaged across 6 container types.

this difference as a surrogate for additional growth time in the 10 liter container, the root system appeared to be shifting to shallower roots with a greater number of mother [> 2 mm (0.08 in) diameter] roots and more straight-root length with time (Table 9). This was likely a result of more roots growing to a diameter above the measurement threshold [i.e., > 2 mm (0.08 in) diameter].

Liners root pruned vs. not at planting. Root pruning when shifting into 10 liter (3 gal) containers improved root systems by dramatically impacting 8 root attributes across all propagation container types (Table 10). Root pruning liners, regardless of propagation container type, effectively eliminated root wrapping around the trunk resulting in fewer culls and almost no root deflection 10 months later. The imprint from the liner was nearly eliminated by root pruning trees from all container types. Root pruning reduced the number of roots growing from descending roots because pruning eliminated most descending roots. Root pruning also dramatically reduced the angle of departure of the 5 largest roots growing from the trunk from 57.8 to 42.1 degrees and of all mother roots > 2 mm (0.08 in) diameter. The difference between mother root angle at the trunk and main root angle at the 10 liter (3 gal) container periphery was reduced by root pruning resulting in a more horizontally-oriented root system closer to the substrate surface.

Response of trees to root pruning depended on the propagation container type for 4 root attributes (Table 11). Root pruning reduced number of tangent roots in SM containers to a level equivalent with all other container types. Root pruning liners shifted from SM and EPSM propagation containers reduced the number of ascending roots in 10 liter (3 gal) containers, and reduced the number of tangent roots in trees shifted from SM containers (Table 11). Number of ascending roots > 1 (0.04 in) or > 2 mm (0.08 in) and number of tangent roots was not affected by root pruning in EPP, EPS, AC, and RM. Root pruning encouraged mother roots, adventitious roots from cuts, and woody second order roots, to grow closer to the substrate surface as shown by a reduced angle of departure from the trunk (Table 10). This resulted from new roots growing from the cut root segments which typically were close to the substrate surface. By contrast, many roots growing from trees that were not pruned elongated from intact root tips positioned toward the bottom of the propagation root balls.

Presence of main roots of red maple borne at a shallow angle and close to the surface discourages formation of stem girdling roots by reducing the number of roots growing over mother roots and other main roots (13). Root pruning increased dramatically the number of straight roots growing from all propagation containers except EPP which had an extremely high number without pruning (Table 11). By many measures, all container types retained 26 weeks in the propagation container produced nearly equivalent root systems provided root balls were mechanically pruned by removing roots (shaving the root ball) on the periphery when shifting to 10 liter (3 gal) containers. Furthermore, root pruning had no effect on mortality, trunk, or height growth consistent with others (14). There was little correlation between root attributes in propagation containers (measured prior to root pruning) and attributes in 10 liter (3 gal) containers for liners that were root pruned when shifting into 10 liter (3 gal)

Table 11. Mean separation for interactions of propagation container type and root pruning when shifting into 10 liter (3 gal) containers on root attributes after 10 months.

Propagation container type	Root pruning	No. ascending roots > 2 mm diameter	No. ascending roots > 1 mm diameter	No. roots > 1 mm diameter tangent to trunk	No. straight roots from trunk
SM	Yes	0.2c[z]	1.2cd	0.4bc	17.6ab
	No	4.2a	8.4a	3.4a	3.4e
EPP	Yes	0.2c	0.2d	0.2bc	19.8a
	No	0.2c	0.4d	0.0c	18.8a
EPS	Yes	2.0b	3.2b	0.0c	16.4ab
	No	1.4bc	2.6bc	0.6bc	10.8d
EPSM	Yes	0.2c	1.0cd	0.4bc	15.6abc
	No	2.6ab	4.4b	0.8bc	1.0f
AC	Yes	1.0bc	3.0b	0.4bc	18.0a
	No	2.6ab	2.6bc	1.0bc	11.6cd
RM	Yes	1.0bc	3.6b	0.2bc	13.2bcd
	No	2.0b	4.8b	1.6b	5.8e

Note: Trees retained 26 weeks in propagation containers; root attribute descriptions in Table 3.

[z]Means in a column with a different letter are statistically different at $p < 0.05$. Means of 5 trees per container type × root pruning combination for a total of 60 trees.

containers (e.g. compare Table 6, 26 weeks; with Table 11, root pruned). Without root pruning, propagation container had a large influence on root morphology in 10 liter (3 gal) containers with EPP having the most straight roots and few ascending or tangent roots (Table 11).

In conclusion, red maple root system quality reflected by shallow angle of mother roots, shallow depth of main roots, presence of straight roots, and fewer circling, tangent, and ascending roots in a 10 liter (3 gal) container improved as number and length of roots deflected up, down, or around the much smaller propagation container wall diminished. This was accomplished by retaining cuttings in the propagation container for a short period of time in any of the propagation systems tested (10 weeks in this study). When retained in the propagation container for a long period of time (26 weeks), growing in a propagation system such as Ellepots that discourages formation of these roots, or removing deflected roots by pruning away the outside periphery of the liner root ball when shifting to a larger container both resulted in high quality root systems. However, Ellepots should not be used to grow trees as inserts in smooth-sided plastic propagation containers because defects develop comparable to those in other plastic containers.

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