Effects of Root Pruning on Container-Grown Maple and Oak[1]

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Abstract

Two experiments were conducted on container-grown plants that were actively growing in spring to evaluate the effects of root pruning prior to repotting or planting in a field plot. In experiment 1, severe root pruning significantly reduced height and trunk diameter growth for both 'Summer Red' maple (*Acer rubrum* L) and overcup oak (*Quercus lyrata* Walt.) after repotting into a larger container. Shoot and root dry weights were less with plants severely root pruned compared to plants that were not root pruned or had been lightly root pruned. Overcup oaks that received no root pruning or were lightly root pruned did not differ in height or trunk growth 24 weeks after study initiation. However, overcup oaks severely root pruned had brown foliage within 10 days of repotting and within 2 months had extensive dieback, which resulted in negative height growth by the end of the study. In experiment 2, 'Autumn Flame' red maple that received no root pruning had similar growth to plants that had light root pruning, but was greater than plants that received moderate or severe root pruning during the first growing season in the field. Autumn Flame red maples severely root pruned prior to field planting had 65% less height growth than plants receiving no root pruning during year 1. After four years, shoot and trunk diameter growth was similar among treatments. The number of circling roots at the soil surface decreased as the amount of root pruning increased.

Index words: root scoring, root circling, tree growth, container production.

Species used in this study: 'Autumn Flame' and 'Summer Red' red maple (*Acer rubrum* L); overcup oak (*Quercus lyrata* Walt.).

Significance to the Horticulture Industry

Root pruning prior to transplanting into larger containers or into field or landscape plantings is often touted as beneficial for subsequent growth. Moderate root pruning did not affect subsequent shoot and trunk growth of overcup oak and red maple during a spring flush but, more importantly, moderate root pruning reduced but did not eliminate circling roots at the soil surface. Severe root pruning reduced the number of circling and girdling roots of overcup oak and red maple trees grown in solid-wall containers, but after one growing season both tree species had less height, trunk diameter, and shoot and root dry weight than plants lightly or moderately root pruned or plants that were not root pruned. Red maples that were severely root pruned had lower shoot and trunk diameter for three years after transplanting compared to trees that were non-root pruned and those that were lightly or moderately root pruned. The plants in this study were root pruned in the spring when trees were in full leaf and growing. Spring is the most popular time for landscaping, however, from a physiological point of view, moderate to severe corrective root pruning may be less stressful if done in the fall or while plants are dormant.

Introduction

Landscape tree mortality from girdling roots has become a major concern to many landscapers and urban foresters. Girdling roots located near the soil surface can reduce the flow of water and nutrients from the root system to the branches as well as prevent carbohydrates produced in the leaves from reaching the roots. Often, girdling roots compress and weaken the trunk of a tree, which results in a slow decline in health and a premature death (Altland 2007). Container production may exacerbate circling, kinked or girdling roots and subsequently affect trees planted in a landscape (Chapin and Stack 2008, Fare 2013, Gilman et al. 2009).

Root quality with container production has been addressed in previous research with copper-treated and air root pruning containers (Arnold 1996, Gilman and Harchick 2008, Gilman et al. 2010, Levinsson 2013). Arnold (1996) reported that circling roots were reduced when root tips reached the inside of the nursery container surface when treated with cupric hydroxide. This potentially reduced or eliminated incidences of girdling roots in the landscape. In contrast, plants grown in copper-treated containers had circling roots on the interior of the root system five years after planting in a landscape (Gilman et al. 2009). Nursery container designs that physically root prune during the production phase have fewer circling roots; however, plants that are left growing in the container for extensive periods often develop circling roots (Gilman et al. 2010, Maynard et al. 2000).

Growers and landscapers seeking to improve root structure of container plants prior to transplanting often choose from three current practices (Watson and Syndor 1987). Current recommendations by Cooperative Extension in Florida, Colorado, and Maine for planting container-grown plants suggest scoring the root ball of container grown trees with vertical slits at least 2.5 cm (1.0 inch) deep into the root ball (Chapin and Berg Stack 2008, Gilman 2006, Whiting et al. 2006). A more intensive method suggested by the University of Florida Extension Service is edge pruning to remove all roots on the outside edge of the root ball (Gilman 2006). Shaving or slicing the exterior of the root system of container-grown plants reduced the number of exterior circling roots (Gilman 2006, Gilman et al. 2010, Gilman and Wiese 2012). The third, and most severe method, one recommended by Chalker-Scott (2005) and Chalker-Scott and Stout (2009), suggests that all bark substrate be removed from container-grown trees prior to planting and using corrective pruning to improve root structure. Scoring or slicing the root ball is the least invasive of the three practices and takes less time than removing all exterior circling roots or removing substrate from the root zone prior to root pruning. The objective of this research

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was to evaluate the short and long term effect of three root pruning methods on container-grown trees that had resumed growth in spring after winter dormancy.

Materials and Methods

Experiment 1. Uniform 'Summer Red' red maple liners grown from cuttings and overcup oak, seed propagated, were grown in solid-wall 11.3 and 14.5 L (#3 and #5) containers (C1200 and C2000, Nursery Supplies, Chambersburg, PA), respectively, for one year in a pine bark substrate amended with 6.5 kg (11.0 lb) Osmocote Pro 19-5-9 (19N-2.2P-7.5K) (O. M. Scotts Co.) controlled-release fertilizer, 0.9 kg (1.5 lb) Micromax (O. M. Scotts Co., Maryville, OH), and 0.6 kg (1.0 lb) Aqua-Gro (Aquatrols, Paulsboro, NJ) per m^3 (per 1.3 $yard^3$). On May 5, 2006, trees were repotted (using substrate described above) into solid wall 50.5 L (#15) nursery containers (C6900, Nursery Supplies, Chambersburg, PA) at the Tennessee State University Nursery Research Center in McMinnville, Tenn. Prior to potting into the 50 L containers, the root systems of the red maples and overcup oaks were subjected to one of the following treatments: 1) root system left intact (non-root pruned), 2) root system was scored latitudinal from top to bottom six times equidistance around the perimeter of the root system with 2.5 cm (1 in) deep slits (lightly root pruned), 3) root system was scored latitudinal from top to bottom six times equidistance around the perimeter with 2.5 cm (1 in) deep slits, and then cut roots were loosened from the root ball to reduce circling (lightly root pruned with root loosening), or 4) the bark substrate was completely removed from the root system by gently blowing the bark with an air compressor; exposed roots were pruned at a point to remove any circling or crossover roots inside the root ball or pruned at the deflected point from contact with the container wall; surface roots that were circling the trunk were also removed (severely root pruned). Plants were placed in a completely randomized design by species and grown on an outdoor gravel pad.

Daily irrigation was applied cyclically with micro spray stakes. As plant water use increased throughout the growing season, leachate was collected bi-weekly to determine the needed increase in irrigation to maintain a 20% leaching fraction. Pest management was maintained with traditional nursery practices during the growing season.

Plant height and trunk diameter [measured at 15 cm (6 in) above the substrate surface] were recorded at the onset of the study (May 9) and at the end of the growing season (October 25). Shoot ratings determined visually were recorded on June 5, June 29, July 13, July 28 and September 6 with the following scale: 1) healthy, 2) leaf wilt and defoliation, 3) tip dieback, 4) severe dieback down stem, and 5) dead. Only June 5, July 13 and September 6 shoot ratings are shown in Table 1. The root systems were rated at the end of the experiment with the following scale: 1) few roots exposed on the periphery of the root ball, 2) up to 25% coverage on the periphery of the root ball with roots, 3) up to 50% coverage on the periphery of the root ball with roots, 4) up to 75% coverage on the periphery of the root ball with roots, and 5) up to 100% coverage on the periphery of the root ball with

Table 1. The short-term effect of root pruning methods on height, trunk diameter, foliar and root ratings and shoot and root dry weights of 'Summer Red' red maple (*Acer rubrum* L.) and overcup oak (*Quercus lyrata* Walt.) grown in #15 nursery containers in experiment 1.

Root pruning treatments[z]	Height growth (cm)[y]	Trunk diameter growth (mm)[y]	Foliar rating[x]			Shoot dry weight (g)	Root rating[w]	Root dry weight (g)
			June 9	July 13	Sept 6			
				'Summer Red' red maple				
Non-root pruned	165a[v]	22.2a	1.0a	1.0a	1.0a	2052a	4.3a	638a
Lightly root pruned	142a	20.6a	1.0a	1.0a	1.0a	2072a	4.8a	660a
Lightly root pruned (cut roots loosened)	162a	21.6a	1.0a	1.0a	1.0a	2103a	4.5a	539a
Severely root pruned	36b	9.0b	4.1b	4.2b	3.2b	699b	2.7b	161b
LSD	44.2	3.1	2.2	2.2	2.2	504	0.7	241
				Overcup oak				
Non-root pruned	94a	12.4a	1.0a	1.0a	1.0a	1178a	2.7b	548a
Lightly root pruned	78a	11.3a	1.0a	1.0a	1.0a	1186a	3.6a	593a
Lightly root pruned (cut roots loosened)	81a	11.5a	1.0a	1.0a	1.0a	1298a	3.2ab	530a
Severely root pruned	–26b	2.4b	3.8b	4.3b	2.8b	381b	0.8c	299b
LSD	37	1.4	2.1	2.1	2.1	213	0.9	159

[z]Root pruning treatments: non-root pruned; lightly root pruned = root system was scored from top to bottom six times equidistance around the perimeter of the root system with one-inch deep slits; lightly root pruned with cut roots loosened = root system was scored from top to bottom six times equidistance around the perimeter with one-inch deep slits then cut roots were straighten to prevent circling; and severely root pruned = the bark substrate was completely removed from the root system by gently blowing the bark with an air compressor, then roots were pruned to remove any circling or crossover roots.

[y]Height and caliper growth determined from substracting initial height and trunk diameter measured on May 9 from measurements made on October 25, 2006.

[x]Foliar rating scale: 1) healthy, 2) leaf wilt and defoliation, 3) tip dieback, 4) severe dieback down stem, and 5) dead.

[w]Root system rating scale: 1 = few roots exposed outside of the rootball surface, 2 = up to 25% coverage of the root ball, 3 = up to 50% coverage of the root ball, 4 = up to 75% coverage of the root ball, and 5 = 100% coverage of the root ball.

[v]Treatments followed by the same letter are not significantly different. Means separated using Fisher's protected LSD, $\alpha \leq 0.05$.

roots. On October 25 to 26, all plants were cut at the substrate surface and shoot and root dry weights were determined. Pine bark substrate was gently blown from the root mass using a compressed air system. Both roots and shoots were dried in a forced-air oven at 56C (133F).

Treatments were replicated five (red maple) or six (overcup oak) times in a completely randomized design by species, with one tree per plot. Plants that died during the experiment was excluded from all subsequent growth data and considered missing data points. All data were subjected to analysis of variance with the GLM procedure of SAS (Version 9.1, SAS Institute, Cary, NC) and differences among treatments were separated by a Fisher's least significant difference, $P \leq 0.05$.

Experiment 2. Uniform plants of 'Autumn Flame' red maple grown in solid-wall 11.3 (#3) containers were purchased in March 2007 from a local propagation nursery in McMinnville, TN, and planted into solid-wall 50.5 L (#15) nursery containers (C6900, Nursery Supplies, Chambersburg, PA). The container substrate and daily irrigation used is described in Experiment 1. Less than one year later, on May 20, 2008, the plants were removed from the #15 container and the root balls were pruned as described above (except the lightly pruned with root loosening treatment was replaced with moderately pruned roots scored at a 5 cm (2 in) depth to adjust for the larger root ball size) then planted in a field with a Waynesboro silt loam soil in a randomized pattern with 3 m (10 ft) between rows and 4.6 m (15 ft) between plants in a row. Plants were immediately hand watered, and throughout the four growing seasons plants were irrigated through a drip line to apply about 2.5 cm (one in) of water in one event if equivalent rainfall had not occurred in the previous week. To simulate a landscape planting, plants were mulched with a coarse pine bark at planting and each spring to maintain a 91 cm (3 ft) circular area around the base of the tree at a depth of 7.6 cm (3 in). Based on soil test recommendations, the soil pH was maintained at 6.0 during the experiment and recommended nutrients were applied annually in March. Pest management was maintained with traditional practices during the growing season.

Plant growth measurements as described above were recorded at the onset of the study [May 21, 2008; average height 312 cm (10.2 ft), average trunk diameter 3.1 cm (1.2 in)] and at the end of each growing season in 2008 (year 1), 2009 (year 2), 2010 (year 3), and 2011 (year 4). Shoot ratings determined visually were recorded on May 27, June 16, July 18, August 21, September 11, and September 29 in 2008 using the following scale: 1) healthy, 2) wilted, 3) defoliation, 4) stem dieback, and 5) plant dead (data not shown). In spring 2009, date of the initial spring growth was recorded (data not shown).

During the four-year study, branches that were removed from the trunk [up to 95 cm (3.1 ft) above the soil line] or canopy during corrective pruning were dried, weighed and added to the final dry weight. In October 2011, plants were harvested from the field. Branches were severed from the trunk at a height of 95 cm (3.1 ft) and the trunk was cut at the soil line then dried in a forced-air oven at 56C (133F).

The root system was dug from the field with a mechanical digging spade that provided a 122 cm (48 in) diameter root ball with a depth of 102 cm (40 in). After soil was removed using a compressed air system, the original 50 L root ball was visible on the non-pruned, and the light and moderate root pruning treatments. When planted in 2008, the average root ball size from the 50 L container was 46.7 cm (18.4 in) wide and 38.4 cm (15.1 in) in height. The number of exposed roots on the soil surface from the original 50 L root ball that were greater than 5.0 cm in diameter which were circling or girdling (embedded) in the trunk were counted. The distance between these roots to the trunk was measured and the length of the root section impacting trunk growth was measured. The root ball was cut in half at a mid-point about 20 cm (7.9 in) deep, which represented an equal distance from the top of the root system to what was the bottom of the original 50 L nursery container. Circling roots in the top and bottom section that were on the root ball perimeter of the original 50 L container were counted and the length measured from an origin where the circling started to a point that the root no longer imposed a risk as a circling root. The diameter and total length of these circling roots were measured at 10 cm (4 in) increments (length data not shown). Also, the number of radiating roots that extended past the original 50 L container into the field soil was counted from the top and bottom half of the root ball and the diameter of the roots measured at the point they grew from the 50 L container perimeter.

Treatments were replicated eight times in a completely randomized design, with one tree per plot. Plants that died during the experiment were excluded from all subsequent growth data and considered missing data points. All data were subjected to analysis of variance with the GLM procedure of SAS (Version 9.1, SAS Institute, Cary, NC) and differences among treatments were separated by a Fisher's least significant difference, $P \leq 0.05$.

Results and Discussion

Experiment 1. Severe root pruning adversely affected height and trunk diameter growth for both red maples and overcup oaks, as well as shoot and root dry weight accumulation (Table 1). Red maples that had been severely root pruned at potting had about 77 and 59% less height and trunk diameter growth, respectively, compared to plants that had no root pruning or were lightly root pruned with loosened roots. Plants that received either of the light root pruning treatments had similar height and trunk diameter growth as those that were not root pruned.

The foliage on plants that had been severely root pruned was turning brown within 2 weeks of repotting, with defoliation and tip dieback on most branches (Table 1). Within 60 days of potting, two of the five plants severely root pruned had died. By early September, the surviving red maples that had been severely root pruned were starting to produce new leaves. Red maples that were non-root pruned, or those that received either of the light root pruning treatments appeared healthy throughout the growing season.

Shoot dry weight was indicative of overall growth performance of the trees (Table 1). The non-root pruned and both of the lightly root pruned red maples had about 66% more shoot biomass than red maples that were severely root pruned.

The root ball of non-pruned red maples in the 50 L container had 75% or more of the root ball periphery covered with roots, compared to the root ball of severely pruned plants, which had less than 50% of the root ball periphery covered with roots (Table 1). Plants that were lightly root pruned had a similar root rating as the non-root pruned plants. Severely root pruned plants had 75% less root weight than

the non-pruned and 77 or 70% less than either of the lightly root pruned plants, respectively.

Overcup oak, though less vigorous than red maple, had a similar growth response to the root pruning treatments (Table 1). The non-root pruned plants and plants that received either of the light root pruning treatments showed no significant differences in height or trunk growth during the test. The author observed overcup oaks that received severe root pruning had brown foliage within 10 days of repotting and within 2 months had extensive dieback, which resulted in negative height growth [–26 cm (–10 in)] by the end of the experiment. Trunk diameter of severely pruned overcup oaks was at least 56% less compared to growth with other root pruning treatments. One plant died in mid-July; however, by early September, plants that had defoliated and had stem dieback were starting to produce new leaves, but shoot regrowth was not vigorous enough for any height increase. Shoot dry weight was at least 68% less with severely root pruned overcup oaks compared to the other root pruned treatments.

Roots that were visible on the periphery of the overcup oak root balls were similar among the non-pruned and the light root pruned with cut roots loosened, but were significantly less than overcup oaks that had been severely root pruned (Table 1). Overcup oaks that were lightly root pruned had the most root coverage, with between 50 to 75% on the periphery whereas overcup oaks that were severely root pruned had less than 25% coverage. Root dry weights showed similar root growth among the non-pruned and both of the lightly root pruned plants. The severely root pruned overcup oaks had 45, 50, and 44% less root dry weight than plants that were non-pruned, the lightly root pruned, and the lightly root pruned with cut roots loosened, respectively.

Experiment 2. Growth of Autumn Flame red maple was affected by the root pruning treatments during the first growing season in the field (Table 2). In year 1, the non-root pruned plants had similar shoot growth to plants that had light root pruning, but greater growth than plants that received moderate or severe root pruning. Red maples that had been severely root pruned prior to field planting had 65% less height growth than plants receiving no root pruning. Trunk diameter growth during year 1 was similar between the non-root pruned plants and plants that were lightly or moderately root pruned. Red maples that were severely root pruned had about 0.2 cm trunk diameter increase during the first growing season, which was 85% less than non-root pruned plants.

Foliar ratings were made monthly during the first year (2008) in the field. The only plants that showed any sign of stress, such as defoliation or stem dieback, were the plants that had been severely root pruned (data not shown). During the first year, three of the eight plants that had been severely root pruned died.

During year 2 (2009), height growth and trunk growth was similar among all treatments with about a 100 cm height growth and an increase of 2.3 cm (~1 in) trunk diameter (Table 2). Bud break in the spring of 2009 was not recorded, but it was obvious that all treatments leafed out similarly, which indicated there was no apparent carryover of stress from the first growing season in the field. During the third growing season (2010), all treatments had more height increase than during the previous 2 growing seasons. The only significant difference in height increase was approximately

Table 2. The long-term effect of root pruning methods on height, trunk diameter and dry weights of 'Autumn Flame' red maple (*Acer rubrum* L.) grown in #15 nursery containers prior to field planting in experiment 2.

	Year 1 (2008)		Year 2 (2009)		Year 3 (2010)		Year 4 (2011)		2011			
Root pruning treatments[z]	Height growth (cm)[y]	Trunk diameter growth (cm)	Height growth (cm)	Trunk diameter growth (cm)	Height growth (cm)	Trunk diameter growth (cm)	Height growth (cm)	Trunk diameter growth (cm)	Final height (cm)	Final trunk diameter (cm)	Trunk dry weight (kg)	Shoot dry weight (kg)
Non-root pruned	41.4a[x]	1.3ab	101.2a	2.4a	158.5a	2.1a	90.0b	2.5a	712.1a	11.7a	4.9a	29.2a
Lightly root pruned	21.7ab	1.4a	102.9a	2.3a	150.1ab	2.1a	64.6b	2.5a	660.1ab	11.7a	5.0a	29.7a
Moderately root pruned	11.3b	1.0b	101.1a	2.4a	144.7ab	2.1a	99.9ab	2.5a	668.3ab	11.4a	4.4a	26.2a
Severely root pruned	–27.6c	0.2c	98.7a	2.0a	126.7b	2.0a	134.3a	2.4a	636.9b	9.9b	3.3b	18.2b
LSD	28.9	0.4	42.7	0.6	30.9	0.3	40.7	0.7	61.5	1.0	0.7	5.0

[z]Root pruning treatments: non-root pruned; lightly root pruned = root system was scored from top to bottom six times equidistance around the perimeter of the root system with one-inch deep slits; moderately root pruned = root system was scored from top to bottom six times equidistance around the perimeter with two-inch deep slits then roots were straighten to prevent circling; and severely root pruned = the bark substrate was completely removed from the root system by gently blowing the bark with an air compressor, then roots were pruned to remove any circling or crossover roots.

[y]Height and caliper growth determined each year by subtracting the height and trunk diameter from the measurements taken at the end of the previous growing season. Initial measurements were made on May 21, 2008.

[x]Treatments followed by the same letter are not significantly different. Means separated using Fisher's protected LSD, $\alpha \leq 0.05$.

a 20% greater increase in non-root pruned plants versus severely root pruned plants. Trunk diameter averaged 2.1 cm among all treatments.

In 2011 (4th growing season), the plants that had been severely root pruned at the onset of the test had the greatest increase in height growth (134 cm) compared to 90 and 65 cm increase in height with red maples that were non-root pruned or had light root pruning, respectively. Trunk diameter grew uniformly among treatments with an average increase of 2.5 cm, which is typical for red maples grown in Zone 6b.

When the final heights were taken in October 2011 (Table 2), non-root pruned plants were taller than plants that had been severely root pruned, 712.1 cm verses 636.9 cm, but similar in height to plants that had received either a light or moderate root pruning, 660.1 or 668.3 cm, respectively. Even though the severely root pruned trees had more shoot growth in year 4 (2011) of the study compared to the other treatments, the growth was not enough to make up for the previous years deficit.

Trunk diameter at the end of the experiment was smallest, 9.9 cm, with plants that had been severely root pruned compared to non-root pruned plants and those that were lightly or moderately root pruned. The trunk dry weight and shoot dry weight was at least 25 and 30%, respectively, lower from plants that had been severely root pruned compared to the other treatments. This research shows that it may take several years for severely root pruned plants to equal the size (height and trunk diameter) of plants that were not root pruned. Levinsson (2013) reported similar results when oaks were root pruned and transplanted then monitored for three years until shoot growth resumed pre-root pruning and transplant growth rates.

The root ball dug by the mechanical digging spade provided a slightly larger root ball than standard nursery practices for this size tree; however, it gave the author an opportunity to observe more of the root development from the original 50 L container into the existing field soil. Once the soil had been removed from the root ball, it was obvious that after 4 years in a field setting, the root system was still visibly intact from the nursery container, especially in the lower half of the root ball of the non-root pruned treatments as well as the light and moderately root pruned treatments. It was also apparent that there were very few roots that extended downward from the original container root system into the existing field soil with all root treatments (data not shown). The root systems were cut in half at a midpoint, 20 cm (7.9 in) from the top of the root system to the bottom of the root system, which represented an equal distance from the top of the root system to what was the bottom of the nursery container. There were a similar number of roots radiating from the original 50 L nursery container perimeter into the field soil from the top half of the root system among treatments (Table 3). However, in the bottom half of the root ball, the plants that were moderately root pruned had a similar number of roots radiating into the field soil as plants that were lightly pruned, 23 and 20.1, respectively, but had a greater number of roots than non-root pruned plants or plants that had been severely pruned, 23 verses 13.7 and 13.7, respectively.

The diameter of the roots radiating into the field soil from the top half of the root system was similar among plants that were light or moderately root pruned; however, the root diameter was larger than with the non-root pruned plants or severely root pruned treatment. In the bottom half, plants lightly pruned had similar root diameters as the moderately root pruned trees, but larger than the non-pruned plants or those severely pruned.

The number of circling roots present in the top half of the original root system with the non-root pruned plants was similar to plants that had been lightly or moderately root pruned, but more than three times greater than those in the severely root pruned plants (Table 3). The number of circling roots in the bottom half showed a similar trend with fewer circling roots in the severely pruned plants. The diameter of the circling roots were larger in the top half of the non-pruned and lightly pruned plants compared to those that were moderately or severely root pruned. In the bottom half of the root system, the plants that were non-root pruned had the greatest number of circling roots compared to the other treatments. Circling roots several inches below the soil surface may ultimately girdle or graft with another part of the root system, but have relatively little effect on water and nutrient support (Altland 2007). It may, however, affect the long term stability of the tree if structural roots do not radiate outward from the tree (Gilman 2006). The outline of the original nursery container was not visible in the severely root pruned plants, but surprisingly there were still circling roots; however, the author believes it was a result of root growth from the original pruned roots.

Plants that received no root pruning had the largest number of roots > 5.0 mm (0.2 in) circling the trunk near the soil surface, followed by plants that had received light or moderate root pruning (Table 3). Though not statistically analyzed, 24 of the 93 roots identified on the non-root pruned plants as circling on the soil surface were girdling the trunk compared to 12 of 70 and 12 of 50 roots with the light or moderately root pruned plants, respectively. Plants that received severe root pruning had the least number of circling roots, with an average of 2.5 per tree; however, 4 of the 14 roots considered circling on the severely root pruned plants were girdling the trunk. This was somewhat surprising from the severely pruned plants considering the root structure had been supposedly corrected 4 years prior when planted in the field. However, roots that originated from the pruned cut grew in all directions. Gilman and Wiese (2012) found that in addition to shaving or slicing the root ball sides, performing the same technique on the top of a container-grown oak reduced the number of circling roots, but did not eliminate circling roots from developing within two years after transplanting.

The diameter of the circling roots near the trunk was similar between the non-pruned, and lightly or moderately root pruned compared to plants that had been severely root pruned (Table 3). The distance of the circling roots from the trunk was greatest with plants lightly root pruned and was significantly more than in plants that had been severely root pruned. There was a lot of variability as to the length of the circling roots at the soil surface in all treatments, thus no significant differences were identified. As trunk diameter increases and diameter of the circling roots increase, the potential for trunk girdling can occur.

Gilman (2006) and Gilman and Wiese (2012) reported that root slicing the outside surface of container-grown maple root balls at planting did not affect growth one and two years after planting. However, root pruning adversely affected growth and fruiting of grapevines (Ferree et al. 1999). An experiment by the author (unpublished data) was conducted with root pruned 'Brandywine' red maple transplanted from

Table 3. The long-term effect of root pruning on the number, diameter and length of girdling or circling roots of 'Autumn Flame' red maple (*Acer rubrum* L.) grown in #15 nursery containers prior to field planting in experiment 2.

	Roots at soil surface				Roots radiating beyond original root ball				Roots circling within original root ball			
Root pruning treatments[z]	Number of circling roots	Diameter of circling root nearest the trunk (mm)	Distance of circling root from the trunk (cm)	Length of circling root (cm)	Number of roots radiating from the top half[y]	Number of roots radiating from the bottom half	Diameter of roots radiating from the top half	Diameter of roots radiating from the bottom half	Number of roots circling in the top half	Number of roots circling in the bottom half	Diameter of roots circling in the top half	Diameter of roots circling in the bottom half
Non-root pruned	11.6a[x]	24.9a	5.4ab	50.6a	23.0a	13.7b	12.9b	18.8bc	10.1a	9.4a	24.8a	19.0a
Lightly root pruned	8.8b	21.5a	7.3a	23.8a	23.6a	20.1ab	16.7a	21.2a	9.0a	8.4a	21.8a	13.4c
Moderately root pruned	6.2c	21.2a	5.1ab	21.2a	27.4a	23.0a	15.4a	20.4ab	7.7a	8.2a	17.3b	16.5b
Severely root pruned	2.5d	11.2b	3.3b	16.9a	26.0a	13.7b	13.1b	18.0c	3.1b	2.4b	13.1c	10.8d
LSD	0.9	7.9	2.6	29	10.4	7.2	1.9	2.4	3.8	4.5	3.4	2.0

[z]Root pruning treatments: non-root pruned; lightly root pruned = root system was scored from top to bottom six times equidistance around the perimeter of the root system with one-inch deep slits; moderately root pruned = root system was scored from top to bottom six times equidistance around the perimeter with two-inch deep slits then roots were straighten to prevent circling; and severely root pruned = the bark substrate was completely removed from the root system by gently blowing the bark with an air compressor, then roots were pruned to remove any circling or crossover roots.

[y]The root system was cut in half about 20 cm (7.9 in) deep, which represented an equal distance from the top of the root system to what was the bottom of the #15 nursery container.

[x]Treatments followed by the same letter are not significantly different. Means separated using Fisher's protected LSD, $\alpha \leq 0.05$.

50.5 L (#15) containers into 95.l L (#25) nursery containers either in late fall 2006 or early spring 2007. These plants were dormant when the root systems were subjected to root pruning treatments. All plants leafed out similarly in the spring of 2007 and after one growing season in container culture, there were no differences in height or trunk diameter growth, foliar ratings, or shoot and root dry weight. The most popular period of time for landscaping is in the spring, often after trees have leafed out, but from a physiological point of view, corrective root pruning may be less stressful if done in the fall or while the plant is dormant.

In these experiments, severe root pruning caused enough stress to container-grown 'Summer Red' red maple, overcup oak, and the field-planted Autumn Flame red maple to cause defoliation, stem dieback, and even mortality (Tables 1, 2, and 3). This is in contrast to another report where radical slicing and shaving off the periphery of the root ball in combination of removal of all roots on the top edge of the root ball had no measureable impact on top growth (Gilman and Wiese 2012). Tree root pruning in their research, however, was conducted during the dormant season. In our experiments, light to moderate root pruning showed little to no negative short term effect of plant growth with red maples, but did not prevent circling or girdling roots. Although water stress was not measured, the plant ratings in this study support prior findings that removal of a large root mass of container-grown Shumard oak (*Quercus shumardii Buckl.*) resulted in increased water stress and decreased field performance (Arnold 1996).

These two experiments were designed to see the effects of root pruning on container-grown plants after trees had leafed out in the spring. In both tests, severe root pruning that should have improved the root structure of the plant adversely affected plant growth during the first year after root pruning. Similar height and trunk growth occurred in subsequent years, but after four years, severely root pruned plants grown in the field were smaller than plants that were non-root pruned, light or moderately root pruned. Severe root pruning may be the best alternative for correcting and reducing the number of circling or girdling roots from trees grown in containers for the long term, but tree vigor may be affected during subsequent years after repotting or transplanting into the ground.

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