Tree Root Response to Circling Root Barriers

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Abstract. Root system size and distribution were measured for Raywood ash (*Fraxinus oxycarpa* 'Raywood') and Lombardy poplar (*Populus nigra* 'Italica') planted with and without circling root barriers. Trees with circling barriers had fewer numbers of roots than controls (no barriers), but mean root diameters were similar. Root depth 30 cm outside barriers was greater for trees with barriers, but at 90 and 150 cm away, depth was equivalent to controls. Roots tended to grow toward the soil surface after growing under the barriers. No consistent differences in root response to any of the four types of barriers tested were found for either species. Soil cultivation during the installation of a subsurface barrier (used to simulate a hardpan) resulted in lower soil bulk densities and a deeper distribution of roots in the soil profile than in plots which were not cultivated. Reducing soil bulk densities that are limiting to root growth may be an important consideration when using circling root barriers.

Introduction

Damage to urban infrastructure elements (sidewalks, curbs, gutters, etc.) from tree roots is a significant problem worldwide (4,8,17,18). Virtually wherever trees exist in close proximity to hardscapes there are cases of damage. In the United States, it is conservatively estimated that tree-related infrastructure repairs cost cities more than $135 million annually (13, 14). In addition to repair costs, tree losses result: hardscape damage is the second most common reason for tree removal in California (5).

In an effort to prevent hardscape damage and protect urban tree resources, many cities have installed barriers (of various types) which encircle the root system of newly planted trees (circling root barriers, Figure 1). These barriers are designed to deflect roots deep in the soil profile and thereby avoid conflict with infrastructure. It is unclear, however, whether roots remain deep in the soil profile after growing under a barrier. In a well-drained, alluvial soil, Barker (1, 2) found that European hackberry (*Celtis australis*) and southwestern black cherry (*Prunus serotina* 'Virens') trees generated deeper root systems with barriers. Wagar (16) reported fewer number of roots of fruitless mulberry (*Morus alba*) and zelkova (*Zelkova serrata*) trees in the surface 8 inches with barriers in a clay loam soil, but noted substantial surface rooting for some trees with barriers and suggested this resulted from soil compaction/poor aeration at some locations within the study site. Urban (19) excavated a planting of thornless honeylocust (*Gleditsia triacanthos var. inermis*) and observed roots growing down one side of an 18-inch deep brick barrier and up the other side.

Aside from not finding a consistent root response to barriers, these reports suggest that rooting depth on the outside of barriers may be related to soil conditions underneath and to the outside of the barrier. In soils favorable for root growth, roots may remain deeper in the profile; in unfavorable soils, roots may tend to develop near the surface. This study was initiated to further evaluate tree root response to circling barriers. Specifically, our objectives were four-fold: 1) to quantify root growth and root distribution of Lombardy poplar (*Populus nigra* 'Italica') and Raywood ash (*Fraxinus oxycarpa* 'Raywood') trees planted with and without circling barriers, 2) to assess root response to different types of barriers, 3) to evaluate the influence of a subsurface barrier on root distribution, and 4)

Figure 1. Circling barriers are used to protect hardscape elements from damage by deflecting tree roots vertically to the bottom of the barrier. In this study, four commercially available root barriers were used to examine root development inside and outside barriers.

Table 1. Product specifications for circling root barriers.

Barrier	Material	Thickness	Special features
Biobarrier	Spun polypropylene	3 oz.	Fabric with trifluralin.
Typar fabric	Spun polypropylene	3 oz.	Fabric without trifluralin.
Deep root	Polypropylene	80 mil	Plastic with ribs on inside walls to direct roots vertically.
Root Block	Polyethylene	80 mil	Plastic without ribs on inside walls.

to quantify treatment effects on trunk diameter growth.

Materials and Methods

Study plots were located at the University of California's Bay Area Research and Extension Center in Santa Clara, CA. Santa Clara has a Mediterranean climate with mean summer high temperature of 20C and annual rainfall of 33 cm. Soil in the study area is classified as a Zamora gravelly, clay loam with neutral pH.

Prior to tree and circling barrier installation, a subsurface, horizontal barrier was installed across one-half of the experimental plot. Pits were excavated (bulldozer) to a depth of 46 cm for the length (15 m) and half the width (3.6 m) of a circling barrier treatment block. Typar landscape fabric (3 oz.) was rolled onto this exposed surface. Soil was replaced to original grade, watered, and allowed to settle. The subsurface barrier was used to simulate a hardpan which blocks the downward growth of roots, but does not substantially restrict air or water movement.

Four circling barrier products were evaluated: Biobarrier® (Reemay, Inc., Old Hickory, TN) Typar® fabric (Reemay, Inc.), Deep Root® (Deep Root Partners, LP, Burlingame, CA), and Root Block® (Mann Made Products, Redwood City, CA). Product specifications for each barrier are given in Table 1. All barriers were of equivalent dimensions after installation: 60 cm diameter and 42 cm high, open-ended cylinders (buried 38 cm deep with a 4 cm exposed collar above ground to prevent roots from growing over the barrier). Holes (80 cm wide and 45 cm deep) were hand-dug, barriers installed, and the original soil was carefully backfilled on the inside and outside of barriers. Circling barrier treatments in plots with the subsurface barrier were installed to allow an 8 cm gap between the bottom of the barrier and the surface of the buried Typar fabric. Holes for control treatments (no barrier) were dug to an equivalent size as those of the circling barrier treatments and similarly backfilled. All soil was subsequently watered and allowed to settle before planting.

Ash trees (*Fraxinus oxycarpa* 'Raywood' scion on *F. pennsylvanica* rootstock) grown in 5-gallon containers were installed in the center of circling barriers in January, 1991. In January, 1992, bareroot Lombardy poplar (*Populus nigra* 'Italica') were installed in an adjacent plot with an identical layout to that of the ash plot. In both plots, trees were spaced 2.4 m apart in rows and 3.6 m between rows.

Following planting, all trees were thoroughly irrigated by hand. A microsprinkler irrigation system was subsequently installed with emitters spaced so as to provide uniform water distribution across the plots. Irrigations were scheduled using Watermark soil moisture sensors (Irrometer Co., Inc., Riverside, CA) placed at three locations within each plot and at 15 cm and 45 cm depths. Plots were irrigated when mean soil moisture tensions reached 50 to 60 centibars.

At planting, ash mean trunk diameter was 2 cm, whereas poplar diameter was 2.8 cm. Trunk diameter was measured 30 cm above ground each year for the three-year duration of the study.

Prior to tree harvest and root measurements, soil samples were collected with a field core-sampling tool (AMS, American Falls, ID) for bulk density analysis. Samples were taken at distances of 7.6 and 61 cm outside barriers and at 7.6 and 38 cm depths. Three samples at each depth and distance location were taken in plots with and without subsurface barriers.

In October 1993, all ash trees were cut at ground level, while poplars were harvested the following year in August and September. Following harvest, root systems were excavated in place using a hydroexcavation technique (11). Soil was dislodged from roots using high-pressure water hoses, with the slurry of water and soil being removed with a high capacity vacuum system (Figure 2). This equipment is typically used to clean sewer lines and storm drains, but here it proved very useful for nondestructively exposing complete root systems.

The experimental design constituted a randomized complete block design with the subsurface factor (main) split to accomodate the barrier factor (subplots). Five treatment replicates (circling barriers and controls) were underlain by subsurface barrier, and five replicates had no subsurface barrier. Root diameter and depth were measured for each root (>2mm diameter) at 30, 60, 90, 120, 150, and 180 cm distances (straight line distances from the trunk). The 30 cm measurements were made immediately to the outside of the barrier in each barrier treatment. Root number, diameter, and depth data were statistically analyzed using two-way split plot analysis of variance and Fischer's Protected LSD (p=0.05).

Results

Roots Inside Barriers. Although roots within barriers were not measured for size or depth,

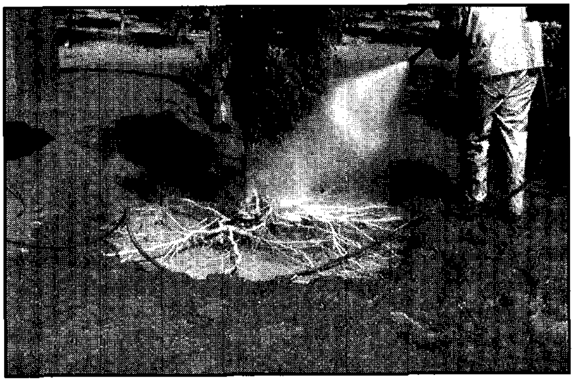

Figure 2. Full root systems were excavated in-place using a hydroexcavation technique. Soil is washed from the roots and the soil-water slurry vacuumed into a large holding tank.

root growth appeared to be most substantial near the bottom of the barriers. The largest roots were found underneath the barrier. Only two trees (out of 80 with barriers) were found to have roots circling the inside walls of barriers. Generally, soil was dislodged easily from roots inside the barrier, indicative of limited root development. This observation differs from findings of Barker (3) who reported substantial circling root development on the inside wall of plastic and fabric barriers.

Roots Outside Barriers. Measurements of root number, diameter and depth for distances of 30, 90, and 150 cm from the *outside of barriers* are reported here (values averaged across both subsurface barrier treatments). Measurements for controls (no circling barriers) are reported at equivalent distances as for circling barrier treatments.

Poplar controls were found to have significantly greater number of roots than circling barrier treatments at equivalent distances outside barriers (Table 2). On average, from 35 to 55% fewer roots were found for circling barrier treatments. The effects of circling barrier treatments did not differ substantially from one another. Fewer roots were found for all treatments at increasing distances from barriers.

With the exception of the Biobarrier treatment, ash controls had significantly greater numbers of roots at 30 and 90 cm than the circling barrier treatments. At 150 cm, there were no significant differences in root number for ash treatments. Ash produced fewer roots per tree than poplar.

There were no significant differences in mean root diameter among the poplar treatments at 30 cm (average diameter 15.1 mm) and 90 cm (average diameter 10.7 mm). At 150 cm, mean root diameter for both the control and Typar treatments (10 mm average) were significantly larger than other barriers (6.5 mm average). Ash root diameters were not significantly different for treatments at 90 cm (7.7 mm average) and 150 cm (5.6 mm average). At 30 cm, mean root diameter of controls (10.7 mm) was not significantly different than barrier treatments (10.3 mm average), but the Root Block treatment produced significantly larger diameter roots (12.7 mm) than Deep Root or Typar treatments (8.1 mm average).

At 30 cm outside barriers (and equivalent distance for controls), poplar in circling barriers produced significantly deeper roots (ranging from 24 to 29 cm deep) than controls (16 cm deep), but no significant differences were found at 90 and 150 cm. Roots of all treatments became increasingly shallow from 90 to 150 cm: 12-16 cm deep at 90 cm and 8-13 cm deep at 150 cm (Figures 3 & 4).

Differences in root depth between ash controls and circling barrier treatments were not significant at any distance. Root systems of all treatments became increasingly shallow from 30 to 150 cm: 15 to 25 cm deep at 30 cm, 9 to 17 cm deep at 90 cm, and 8 to 10 cm deep at 150 cm. No significant differences in root depth were found among circling barrier treatments.

Subsurface Barrier Effects. For both species, trees with subsurface barrier were found to have significantly deeper roots (values averaged across all circling barrier treatments and controls). Root depth differences were significant at all three distances for ash and at 30 and 90 cm for poplar (Table 3). This result was surprising as it suggested that the subsurface barrier promoted deeper-rooted trees. Most roots did not encounter the subsurface barrier, however. Rather than grow down and then horizontally on the surface of the barrier, roots grew downward to just below the circling barrier and then up

Table 2. Circling barrier effects on mean root number (>2mm diameter) for ash and poplar at 30, 90, and 150 cm outside the barrier and at equivalent distances for controls.

	Poplar			Ash		
	Distance from barrier (cm)			Distance from barrier (cm)		
Treatment	30	90	150	30	90	150
	Root number			Root number		
Biobarrier	13.3 b	13.3 b	8.4 b	10.1 ab	8.3 ab	3.0
Deep Root	10.6 b	9.2 b	6.7 b	5.6 c	4.1 c	1.7
Root Block	12.0 b	9.6 b	6.2 b	5.8 c	4.5 bc	1.4
Typar	11.4 b	11.4 b	6.6 b	6.4 bc	4.9 bc	1.4
Control	19.4 a	20.5 a	13.9 a	11.1 a	9.7 a	3.1
						n.s.

Means within columns followed by same letter are not significantly different using Fisher's Protected LSD (p=0.05). n.s. = no significant difference. Each mean is calculated across main plot treatments (10 trees). No significant interactions for main x subplots were found.

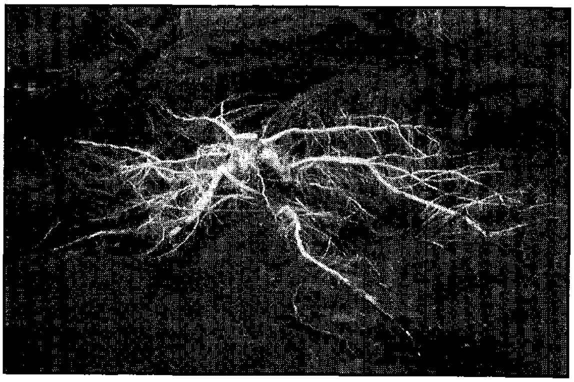

Figure 3. Control trees (no barriers) developed shallow, lateral root systems with most roots found in the surface 15 cm (6 in.) of soil.

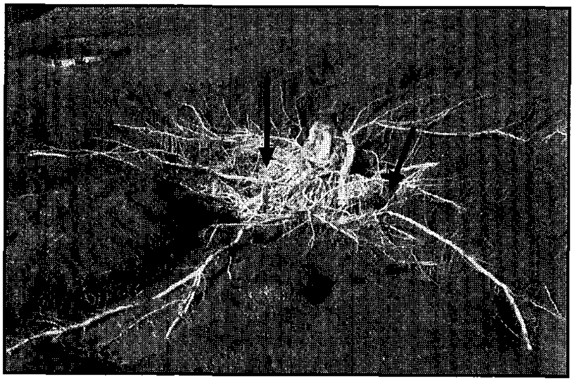

Figure 4. Roots of trees with circling root barriers tended to grow towards the soil surface after growing under the barrier. Barrier wall was 30 cm (12 in.) from trunk and 38 cm (15 in.) deep. Arrows identify location of barrier wall.

Table 3. Subsurface barrier effects on mean root depth (cm) at 30, 90, and 150 cm outside barriers.

Treatment	Poplar			Ash		
	Distance from barrier (cm)			Distance from barrier (cm)		
	30	90	150	30	90	150
	Root depth (cm)			Root depth (cm)		
With subsurface barrier	28.3 a	17.9 a	12.1	24.3 a	16.4 a	11.7 a
Without subsurface barrier	20.3 b	10.8 b	9.5	16.1 b	8.3 b	6.0 b
			n.s.			

Means within columns followed by the same letter are not significantly different using Fisher's Protected LSD (p=0.05). n.s = not significantly different. Means calculated across subtreatments and block (25 trees). There were no significant main x subplot interactions.

towards the soil surface, suggesting that the subsurface barrier did not have a direct effect on root depth. It was proposed that a change in soil bulk density resulting from soil cultivation during subsurface barrier installation may be the principal cause of root depth differences between main plots (with and without subsurface barriers). Bulk density measurements taken at 7.6 and 61 cm from outside the circling barriers and at 7.6 and 38 cm depths in plots with and without subsurface barriers provide evidence for a cultivation effect (Table 4). In the upper 7.6 cm of soil where soil was cultivated during initial field preparation, little difference in bulk density was found for the two main plot treatments (ranging from 1.46 to 1.51 g/cc). Similarly, deeper in the profile (38 cm) and near to the circling barriers (7.6 cm) where cultivation occurred in both main plots during circling barrier installation, bulk densities were higher than at 7.6 cm, but similar to each other (1.60 and 1.64 g/cc). However, at the same depth (38 cm) but 61 cm from the outside of the circling barriers where no cultivation occurred for plots without the subsurface barrier, bulk density was higher (1.72 g/cc) than that at the same distance and depth for plots with the subsurface barrier (1.58 g/cc). Bulk densities greater than 1.55 g/cc in a clay loam soil are reported to be limiting to root growth and function (15). This suggests that the higher density in uncultivated zones may have limited deeper root development in plots without the subsurface barrier.

An evaluation of root number relative to depth (to 30 cm) found that although the total number of roots was similar in cultivated (with subsurface barrier) and uncultivated plots (without subsurface barrier), root number in just the surface 15 cm was significantly greater where the plots were uncultivated for both ash and poplar (Table 5). At 30, 90, and 150 cm there were 2 to 2.7 times more poplar roots near the surface in uncultivated plots, and 1.6 to 2.8 times more at 30 and 90 cm for ash. This effect was similar for both controls and circling barriers. Thus, although total numbers of roots through the soil profile were equivalent, trees in uncultivated plots produced greater numbers of roots in the surface 15 cm than in cultivated plots. This result suggests that soil cultivation during subsurface barrier installation resulted in a greater distribution of roots through the soil profile. Conversely, greater numbers of roots in the surface soil in uncultivated plots may have resulted from root-growth-limiting soil bulk densities deeper in the profile. This result is similar to that found by Gilman (9) for live oak and sycamore trees planted in a soil restricted by a shallow water table. Trees with linear barriers installed 75 cm from trunks were found to develop roots under the barrier and then up towards the soil surface, reportedly because the water table prevented deeper root development.

Trunk Diameter Growth. Poplar trunk diameter growth was approximately twice that of ash. Comparing controls with circling barrier treatments, no significant differences in trunk growth were found for either species. Trunk growth for poplar ranged from 81 to 88 cm, while that for ash ranged from 43 to 52 cm. Mean trunk diameter for poplar was 92 cm in cultivated plots and 78 cm in uncultivated plots, while ash diameters were 54 cm in cultivated and 38 cm in uncultivated plots. Positive effects of cultivation on trunk diameter growth are thought to result from differences in root distribution associated with soil bulk density differences in main plots.

Table 4. Mean bulk density (g/cc) of soil samples taken at 7.6 and 61 cm distances from outside of bariers and at 7.6 and 38 cm depths in plots with and without cultivation (subsurface barriers). Al bulk densities were corrected for gravel content (30% by volume).

Distance (cm)	Depth (cm)	Cultivation (with subsurface barrier)	No Cultivation (without subsurface barrier)
		bulk density (g/cc)	bulk density (g/cc)
7.6	7.6	1.49 (.19)	1.51 (.10)
61.0	7.6	1.46 (.20)	1.49 (.03)
7.6	38.0	1.60 (.05)	1.64 (.03)
61.0	38.0	1.58 (.05)	1.72 (.10)

Standard deviation of samples (n=3) in parentheses after each mean.
Standard error of means = 0.086.

Discussion

The principal difference between the control and circling barrier root systems was found in root number. Circling barrier treatments produced fewer roots than controls for both species at all distances. This difference in root number has implications regarding infrastructure damage potential. If root diameter and depth are equivalent for trees with and without barriers, then it seems reasonable that trees with fewer roots are less likely to cause damage. By simply having more or less roots, the potential for damage changes. It may be, however, that the number of roots is less important than diameter and depth when it comes to potential to cause damage. For instance, a tree with a few roots achieving a critical diameter and depth may be equally damaging as a tree with several roots at the same depth with equivalent or smaller diameter. Further work will be needed to partition the relative contributions of root numbers, diameter, and depth to infrastructure damage.

Unlike previous work in alluvial soil (1,2), but similar to Gilman (1996), circling barrier treatments did not produce root systems which remained deep in the soil profile (at or below the barrier depth). Upon growing past the lower rim of the barriers, roots of both species tended to grow toward the soil surface. At 90 cm (3 ft) from the outside of barriers, average root depth was between 12.5 and 15 cm for each species, respectively, and equivalent to controls. They were even shallower at 150 cm. These findings suggest (and are supported by Gilman, 1996, and Wagar, 1985) that after roots grow under barriers, the barriers have little influence on root placement. Root distribution on the outside of barriers is controlled by plant genetics and the soil environment (physical and chemical). In soils with qualities favorable for deep root development, genetics will likely be the greater influence and some species will generate root systems that are distributed throughout the soil profile. Other species may continue to produce substantial surface rooting regardless of soil quality factors. In poor quality soils, root development will likely occur only where conditions are most favorable, *i.e.*, where air, water, and mineral resources are in greatest abundance (often near the soil surface in urban landscapes).

In this study, differences in soil bulk density apparently resulted in differences in root distribution. In plots which were not cultivated, a high bulk density was found and a large proportion of roots were found in the upper 15 cm of soil. A greater distribution of roots through the soil profile was found in cultivated plots where bulk density was lower. Other studies have reported similar root distribution responses to limiting soil conditions (6, 7, 10). This result strongly suggests that cultivation may be a useful method of developing well-distributed root systems in soils with bulk densities sufficiently

Table 5. Cultivation effects (subsurface barrier treatments) on mean root number in 0-15 cm depth at 30, 90, and 150 cm from outside of barriers for circling barrier treatments and controls combined.

	Poplar			Ash		
	30	90	150	30	90	150
Cultivation (with subsurface barrier)	2.0 a	4.6 a	4.3 a	1.8 a	3.3 a	1.6
No cultivation (without subsurface barrier)	5.4 b	11.3 b	8.2 b	5.3 b	5.5 b	1.3 n.s.

Means within columns followed by the same letter are not significantly different using Fisher's Protected LSD (p=0.05). n.s. = not significantly different. Means calculated from all treatments and replicates combined over each main plot (25 trees) and there were no significant interactions.

high to limit root function. When using circling barriers, it may be an important first step to reduce bulk density in high-density soils in order to achieve a desired root distribution.

Generally, the barrier type did not substantially affect root distribution or size: all four circling barriers generated root systems with similar root numbers, diameters, and depths. Where differences were found, they were not consistent for both ash and poplar. Differences in root number for the ash Biobarrier treatments were not found for poplar. Differences in root diameter for Typar treatment in poplar were not found in ash.

Species did differ in the overall size of root systems. Poplar produced greater root number and larger root diameters in both controls and barrier treatments than ash. Trunk diameter was also greater for poplar. Essentially, poplars grew faster and larger above and below ground than ash. This finding underscores the importance of species selection as a key element in strategies to reduce infrastructure damage potential. Here, two species growing for equivalent periods of time produced substantially different-sized root systems. As noted by others (3, 12), a tree with a larger, faster growing root system is likely to have a higher damage potential than a tree with a smaller, slower growing system. Further work will be needed to link root system size, distribution, and rate of development with damage potential. In addition, the long term effects of circling barriers on tree health and structural stability need to be assessed to fully evaluate the utility of circling barriers in tree management programs.

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Résumé. La dimension du système racinaire et sa distribution ont été mesurés pour le frêne Raymond (Fraxinus oxycarpa <Raymond=>) et le peuplier de Lombardie (populus nigra <Italica=>) plantés avec et sans barrière racinaire autour d=eux. Il a été découvert que les arbres avec des barrières racinaires avaient un plus petit nombre de racines que les témoins (sans barrière), mais les diamètres moyen des racines étaient similaires. La profondeur d=enracinement 30 cm au-delà des barrières était supérieure pour les arbres avec des barrières, mais à 90 et 150 cm, la profondeur était équivalente aux témoins. Les racines ont cherché à croître préférablement vers la surface du sol après être passées sous les barrières. Aucune différence significative n=a été découverte, chez ces deux espèces, dans la réponse des racines à chacun des quatre types de barrières qui ont été testées. Le remaniement du sol effectué durant l=installation d=une barrière sous la surface a produit une diminution de la densité du sol et une plus grande distribution des racines au travers du profil de sol. Un prérequis important à l=emploi des barrières qui entourent un arbre pourrait être la réduction de la densité du sol qui limite la croissance des racines.

Zussammenfassung. Von der 'Raywood'-Esche (*Fraxinus oxycarpa* 'Raywood') und der Lombardpappel (*Populus nigra* 'Italica'), die mit und ohne einer umgehenden Wurzelbarriere gepflanzt wurden, wurde die Größe und die Verbreitung des Wurzelsystems gemessen. Die Bäume mit Wurzelbarriere zeigten bei der Untersuchung eine geringere Anzahl von wurzeln als die Kontrollpflanzen (ohne Barriere), aber die Wurzeldurchmesser waren gleich. Die Durchwurzelungstiefe 30 cm außerhalb der Barriere war bei Bäumen mit Barriere größer, aber bei einem Abstand von 90 cm und 150 cm war die Tiefe vergleichbar mit den Kontrollbäumen. Die Wurzeln wachsen bevorzugtweise zur Bodenoberfläche nachdem sie unter der Barriere durchgewachsen waren. Für keine Baumart wurden übereinstimmende Unterschiede im Wurzelwachstum bei den vier getesteten Typen von Wurzelbarrieren gefunden. Während der Installation der unterirdischen Barriere ausgeführte Bodenbearbeitungen führte zu einer Abnahme der Bodenkörperdichte und einer größeren Verteilung der Wurzeln in ganzen Bodenprofil. Eine Reduktion der Bodendichte, die das Wurzelwachstum einschränkt, kann eine wichtige Vorbereitung bei dem Einbau von umgehenden Wurzelbarrieren sein.