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Comparison of Root Barriers Installed at Two Depths For Reduction of White Mulberry Roots in the Soil Surface

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Abstract

Three circling root barrier products, DeepRoot, Tree Root Planter, and Vespro were installed at 30 and 60 cm depths and evaluated to determine whether 1) internal vertical ribs prevented circling roots and 2) installation at 30 and 60 cm significantly reduced root biomass and diameter in the top 33 cm of soil. After three growing seasons, 56 white mulberry (*Morus alba* L.) were excavated and data collected on surface root dry mass, root diameters and locations.
Barriers installed to 30 cm depths did not significantly reduce diameters of roots growing outside the barriers. They did, however, significantly reduce outside surface root dry mass by 31 to 59%. Barriers installed to 60 cm depths reduced surface root dry mass by 85 to 89% and significantly reduced root diameters. Regardless of barrier depth, internal vertical ribs effectively diverted circling roots downward, but more j-rooting was associated with the deeper barriers. Tree growth estimated by measurements of stem diameter, total height and mean crown width, remained unaffected by treatments.

Introduction

Damage to urban hardscapes (sidewalks, curbs, gutters, road surfaces, etc) by tree roots costs California residents at least $62 million dollars annually, either in direct out-of-pocket repair expenses or through tax dollars spent by public works agencies (McPherson and Peper, unpublished data). An average 10% of street tree budgets is spent on removing trees that repeatedly cause damage. When these trees are removed, their quantifiable benefits (air pollution removal, carbon sequestration, temperature modification, energy savings) are lost (McPherson *et al*., 1996; Simpson and McPherson, 1996).

Damage prevention efforts have led some cities and counties to install root barriers in new or refurbished landscapes. Although initial research suggested that such methods might divert roots to grow to deeper levels beneath the hardscape, subsequent research has questioned the efficacy of barriers for reducing roots in locations with less than ideal soil environments. Gilman (1996) found that chemical barriers forced live oak (*Quercus virginiana* Mill.) and sycamore (*Platanus occidentalis* L.) roots deeper in soil, but that many returned to the soil surface within 1.2 m of the barrier due to the high water table at the site. High soil bulk densities at deeper soil levels were related to the return of poplar (*Populus nigra* var. *italica* Muenchh.) and ash roots (*Fraxinus oxycarpa* var. *Raywood*) to surface root levels (Costello *et al*. 1997). A deeper distribution of roots in the soil profile was found when the soil was cultivated to a 46 cm depth, lowering the soil bulk density. Barker (1995a,b) also reported that European hackberry (*Celtis australis* L.) and southwestern black cherry roots (*Prunus serotina* var. *virens* Ehrh.) did not return to soil surfaces within a meter of trees planted in deep, well-drained alluvial soils.

A tree's genetic make-up and the soil environment in which it is grown determine where roots grow and develop. Urban street trees typically grow in poor soil environments and imposing additional restrictions by installing a 60 cm deep root barrier (a standard depth) may further limit soil volume necessary and accessible to root growth. Little research has been conducted to begin determining optimum barrier depths given varying soil conditions although Barker's (1995a,b) studies at the Solano Urban Forest Research Area (SUFRA) found significant reduction in surface root dry mass for barriers that were only 35 cm deep. This study was established after earlier root barrier experiments using polyethylene rootball casings (35 cm deep) reduced surface root dry mass three- to eleven-fold, but appeared to encourage circling root growth (Barker, 1995 a, b). As a result, the objectives of this study were to: 1) determine if barriers designed with internal vertical ribs would prevent circling roots within barriers and 2) compare root growth responses to barriers installed at two depths, 30 and 60 cm for significant reduction of surface root dry mass.

Materials and Methods

The study plot was located at SUFRA, on the Solano Community College campus near Fairfield, California. The soil, Class I of the Yolo Series (Soil Conservation Service, 1977), is an alluvial, well-drained dark brown, generally silty clay loam without mottling. It has a pH range of 6.5-7.5 and an electrical conductivity for soluble salts of 300-500 micro-mhos/cm on a dry soil basis. Soil bulk densities are uniform throughout the site, averaging 1.39 g/cm^3 and 1.45 g/cm^3 at 14 and 34 cm depths, respectively (Peper and Mori, submitted).

Two-year old bareroot seedlings of white mulberry (*Morus alba* L.) were installed in a randomized complete block design comprised of a control and 3 treatments with 2 subtreatments (3 barrier types installed at 2 different depths).

The three barrier products tested were DeepRoot (DeepRoot Partners, LP, Burlingame, CA), Tree Root Planter, (Bumble Bee Products, Inc., Signal Hill, CA) and Vespro (Vespro, Inc., San Rafael, CA). The barriers, constructed of either polyethylene or polypropylene plastic, consisted of three 60 cm x 60 cm interlocking panels connected by plastic lock strips to form circular barriers with 58.2 cm diameters. Standard 60 cm barriers were cut in half to produce the 30 cm depth subtreatment. Internal vertical rib design and spacing constituted the primary difference between barriers. Rib height for DeepRoot and Tree Root Planter measured 1.5 cm with ribs attached at 90E degree angles to the barrier walls. Vespro ribs extended 0.5 to 1.5 cm from the barrier wall in a 90E arc. Ribs were evenly spaced on each barrier but spacing distances ranged from 12 to 17.5 cm among the three barriers.

During field preparation the site was disced, ripped to a depth of 60 cm, disced again, ring-rollered, and lastly dragged and leveled with a length of chain link fence connected to a tractor. Planting holes were drilled 70 cm deep using a 60 cm diameter tractor-mounted auger. Holes were then backfilled by hand to 60 and 30 cm depths and root barriers installed with top edges extending 3 cm above ground to deter roots from growing over the tops of the barriers. Ninety-eight trees comprising 14 replications were planted and staked in May, 1993. All treatments were maintained in mowed turf, receiving 24 hours of irrigation every 10 to 14 days from April through mid-October.

In Spring 1995, squirrels severely damaged tree branches in six of the fourteen blocks while foraging for mulberries; therefore, only the eight unaffected blocks were excavated in 1996. However, two of these blocks were incomplete because three trees died shortly after planting. This reduced 30 cm DeepRoot replications from eight to six and 60 cm Tree Root Planters to seven. Excavation procedures followed those delineated in a previous study (Peper and Mori, submitted), removing the same volume of soil from around each tree (1 m radius by 33 cm deep). Soil outside of the barrier was removed first, roots measured, then cut, bagged and labeled for further processing at the lab. Barriers were removed and inner excavation completed. Inside roots were cut, bagged and labeled. At the lab, roots were washed, dried at 65EC for 72 hours and weighed.

Data collected included 1) total dry mass of roots inside barriers, 2) depth of roots at 18 cm from tree bole center 3) total dry mass of roots outside barriers, 4) diameters of roots growing outside barriers and 5) the distance from the barriers that roots emerged from the floor of the excavation pit. Tree height, crown width and stem diameters were measured in November of 1994 and 1995.

Analyses of variances (ANOVA) were performed using the following model:

$response_{i\,j} = treatment_i + block_j + error_{i\,j}$

Block effect was assumed to be random. Bonferroni’s multiple t-tests were conducted, testing the control against the each of the six treatments (" = 0.05). The 30 cm versus 60 cm barrier subtreatments were also tested at " = 0.05.

Results

Inside root growth

Measurements of root depth at a location 18 cm from tree bole centers were taken on control trees to determine typical depths at which mulberry roots were growing in the soil horizon. Control root mean depth in the top 33 cm of soil was 12.3 cm (±3.6 cm). Although barrier treatment roots were not measured for mean depth, they appeared to grow at the same depth as control trees before being diverted by barriers. Interior barrier excavation revealed surface root growth radiating outward from the tree boles, similar to control trees (at approximately 12 cm depth) until being diverted down by the barriers (Fig.1). Roots rarely came in direct contact with the barriers, maintaining approximately a half- centimeter thick "cushion" of soil between themselves and the barriers. Roots appeared to "sense" the presence of the barrier and begin turning downward, forming a 90E arc rather than an abrupt angle, before actually reaching the barrier.

As shown in Table 1, inside root dry mass (IDM) and inside root diameters (IRDIAM) for the DeepRoot 60 subtreatment were not significantly different from control (P = 0.11). Only the Tree Root Planter 60 and Vespro 60 subtreatments had significantly less IDM (P = <0.01 and 0.02, respectively) and smaller IRDIAM

(P = <0.01 and 0.02, respectively). None of IDMs or IRDIAMs for the 30 cm subtreatments were significantly different from control.

Treatment	Inside Root Dry mass (kg)	Inside Root Diam. (cm)	Outside Root Dry mass (kg)	Outside Root Diam. (cm)	Distance from barrier (cm)	Stem Diameter (cm)	Tree Height (m)	Crown Diameter (m)
Control	0.392a* (0.082)	2.60a (0.292)	0.928a (0.079)	2.38a (0.242)	0.01a (2.092)	5.94a (0.372)	4.29a (0.199)	2.70a (0.206)
DeepRoot 30	0.448a (0.095)	2.39a (0.337)	0.643b (0.091)	2.27a (0.279)	1.90a (2.378)	5.92a (0.422)	3.61a (0.230)	2.88a (0.228)
DeepRoot 60	0.282a (0.082)	2.61a (0.292)	0.127b (0.079)	0.80b (0.242)	17.01b (2.092)	5.82a (0.372)	4.37a (0.199)	2.59a (0.206)
Tree Root Planter 30	0.447a (0.088)	2.23a (0.312)	0.398b (0.084)	2.09a (0.258)	0.85a (2.219)	5.89a (0.395)	4.14a (0.213)	2.72a (0.215)
Tree Root Planter 60	0.137b (0.082)	1.53b (0.292)	0.107b (0.079)	0.72b (0.242)	18.38b (2.092)	5.14a (0.372)	3.82a (0.199)	2.33a (0.206)
Vespro 30	0.302a (0.082)	2.38a (0.292)	0.380b (0.079)	1.98a (0.242)	0.73a (2.092)	5.21a (0.372)	4.14a (0.199)	2.26a (0.206)
Vespro 60	0.201b (0.082)	1.98b (0.292)	0.141b (0.079)	0.88b (0.242)	13.81b (2.092)	5.36a (0.372)	4.35a (0.199)	2.33a (0.206)
30 cm vs. 60 cm	s	ns	s	s	s	ns	ns	ns

* = treatments followed by the same letter are not significant at " = 0.05. s = significant and ns = not significant at " = 0.05. Table 1. Means, standard errors (in parentheses) and Bonferroni multiple t-test results for all treatments against the control. The 30 versus 60 cm barriers were also tested for significance.

Nearly half of the barrier-treated trees (21 of 46) exhibited one or more roots that began to circle but were diverted downward by the internal vertical ribs. The distance the roots ran horizontally along barrier edges before ribs deflected them downward was determined by the spacing between ribs. This was 12, 15 and 17.5 cm for Tree Root Planter, DeepRoot and Vespro respectively. Only four of the forty-six barrier-treated trees exhibited circling roots that extended beyond one rib. This occurred twice with the Tree Root Planter and once each with DeepRoot and Vespro. In all cases, the roots were diverted down upon encountering the second rib (Fig. 1). The presence of circling roots on no more than two trees per treatment type was not significant since circling roots also were found on two control trees.

Outside root growth

For 30 cm subtreatments compared to controls, diameter of roots growing outside the barriers (ORDIAM) and the distance from the barrier (RDIST) at which roots emerged from the floor of the excavation pit were not significant (Table 1).

All 30 cm subtreatments significantly reduced mean outside root dry mass (ODM); however, the three subtreatments responded differently. Root dry mass for the Tree Root Planter and Vespro treatments were 43 and 41% of the control ODM, whereas DeepRoot was 70% of control ODM. Additional t-tests (alpha-level = 0.05) contrasting these treatments confirm that the DeepRoot treatments reduced significantly less dry mass than the Tree Root Planter (P = 0.037) and Vespro (P = 0.042).In contrast, there was no difference in root responses between the three 60 cm subtreatments which reduced ODM from 85 to 88% (Table 1). All three barriers significantly reduced more outside surface root dry mass than the shallower barriers. Similarly, the ORDIAMs were significantly smaller than control and shallower barrier treatments (Table 1). When compared to controls, the deeper barriers reduced ORDIAM 63 to 69%. Additionally, the distance from barriers at which roots of the 60 cm subtreatments grew back up into the top 30 cm of soil were measured. Roots returned to this soil horizon a minimum mean distance of 14 cm outside the barriers (Fig. 2). With the shallower 30 cm subtreatments, roots typically emerged directly from the bottom of the barriers at a 27 cm depth (Fig. 3). Root depths at fixed distances from barriers were not measured, but roots appeared to be growing back toward the surface soil horizon (Fig. 2). The 60 cm barriers exhibited more j-rooting, roots growing under the barriers and abruptly upward. This occurred in one to two roots per tree for approximately 25% of the excavated 60 cm barrier treatments. No one barrier type was more prone to producing j-roots than the next. Barriers tended to be imbedded in the larger-diameter j-roots ($2.0 cm), making removal for interior excavations difficult. J-rooting seldom occured in the 30 cm subtreatments.

Tree growth

Differences in measures of stem diameter, tree height and crown diameter between treatment and control trees were not significant (Table 1). The t-tests contrasting 30 versus 60 cm subtreatments also showed no significant difference. Reduction in root biomass in the surface soil horizon did not affect above-ground growth of the trees.

Discussion

Of particular importance are the significant differences in ODM, ORDIAM and ORDIST between the 30 and 60 cm subtreatments. The exact relationship between increase in root diameter and degree of sidewalk displacement is unknown, but typically, as surface roots grow larger in diameter, more damage is associated with them. Costello *et al.* (1997) suggest that if root diameter and depth are the same for trees with and without barriers, it seems reasonable that trees with fewer roots are less likely to cause damage. Considering that street tree managers describe multiple incidents of sidewalks being uplifted by a single, aggressive root (Dunn, 1997; Fitch 1995), it may be more reasonable to associate less damage with a reduction both in number of roots or total root biomass *and* diameter of existing roots in the soil surface layer. In this study, the Tree Root Planter and Vespro 30 cm subtreatments reduced the dry mass of roots growing outside the barriers in the surface 33 cm of soil by nearly 60% (Fig. 4a). The DeepRoot 30 cm barriers reduced ODM by about 30%. In this case, a reduction in biomass also equates with a reduction in actual number of roots since root diameters were not significantly reduced. Depending upon barrier type, from 40 to 70% of the mulberry root biomass remained in the surface soil horizon with root diameters not significantly different from control root diameters (Fig. 4b). No reduction in root diameter decreases the likelihood that 30 cm barriers will delay the damage caused by roots growing next to sidewalks.

Conversely, the deeper 60 cm subtreatments produced significant reductions in both outside root dry mass and root diameter while also increasing the distance from the barriers at which diverted roots re-emerge into the surface soil horizon. The 60 cm outside root dry mass was 11 to 15% of control ODM and roots in the top 33 cm of soil were roughly one-third the diameter of control roots. Because there are fewer roots and they are of smaller diameter, it is reasonable to assume that the onset of hardscape damage will be delayed.

How much time can be gained before hardscape damage occurs will probably depend upon root growth characteristics of individual tree species and soil conditions. Previous research has demonstrated that different species growing for equivalent times produce substantially different-sized root systems (Costello, *et al*., 1997; Schroth, 1995). Field observations support this:

damage has been associated with sweetgums (*Liquidambar styraciflua* L.) within 15 years of planting, but not associated with other species until 30 or more years of age (Fitch, 1995). The 60 cm subtreatments in this study may delay the onset of hardscape damage but additional research is necessary to determine the relationships between root system rates of development (both normally distributed and barrier-diverted) and damage potential.

The j-rooting occurring on one to two roots for one-quarter of the trees planted in the deeper barriers continues to be of concern, though the long term effects of barriers on the structural stability of trees is unknown. It appears that some mulberry roots are more intolerant to diversion than others, growing beneath the barriers and then returning swiftly returning to a more hospitable environment in the top 30 cm of the soil surface. The level of the roots' intolerance is at some point between 30 (no j-rooting) and 60 cm depths in the well-drained alluvial soils at SUFRA . This effect may also help to explain the smaller root diameters and reduced biomass associated with the interiors of the Tree Root Planter and Vespro 60 cm barriers. The reduced mass and diameters may be a result of the roots' physiological response to being diverted to deeper levels. Growth may be going into the length necessary to extend beneath and beyond the barriers instead of into girth (larger inside diameters were associated with 30 cm barriers).

While it is doubtful that the minimal j-rooting occurring in this study jeopardizes future tree stability, relationships between soil environment, depth of barriers, reduction of interior biomass and incidents of j-rooting also require further investigation.

Roots diverted by the 60 cm barriers re-emerged into the surface zone significantly farther (averaging 14 to 18 cm) from tree boles than control trees, but whether this has any significance in the urban landscape is debatable. Typical street tree planting strip and sidewalk widths in California are each 1.2 m (McPherson and Peper, unpublished data) and roots would still be emerging within the planting strip if barriers were installed in a circular configuration around individual trees. However, as previously stated, the high reduction of surface root biomass and root diameter associated with these deeper barriers indicates potential for delaying initial occurrences of sidewalk damage. It also appears that the mulberry roots are being diverted to deeper levels (below 33 cm) since above-ground growth was not significantly impacted by the barrier treatments. Interestingly, ODM reductions for the DeepRoot 30 cm barrier were significantly less compared to the other two 30 cm barrier subtreatments. Variables that could have affected this treatment's responses in comparison to the other two 30 cm subtreatments include differing sample sizes, soil environment, and barrier materials. The DeepRoot 30 cm treatment had a smaller sample size (n = 6 instead of n = 8) because two bareroot saplings in the treatment died shortly after planting. However, the variability between samples for this and all treatments was very small and, as indicated by the sample mean, root mass was generally higher per tree compared to the other two treatments. It is doubtful that sample size influenced the response. Similarly, the uniformity of soil type, bulk densities and irrigation across the site negate soil environment as the cause. The DeepRoot barrier is made of a different material, polypropylene, whereas Vespro and Tree Root Planter are polyethylene. However, if something in the plastic materials were accountable, a discrepancy in responses between the DeepRoot 60 cm subtreatments and the Vespro and Tree Root Planter 60 cm barriers would be expected. There was no such discrepancy. The 30 cm DeepRoot response may be an anomaly, but it may also indicate that the outcome of installing barriers at this depth, even in ideal soil conditions and for the same species, is unpredictable. A previous study at SUFRA on Chinese hackberries (*Celtis sinensis*) using 30 cm deep Tree Root Planter and DeepRoot barriers reduced neither root biomass nor root diameter. In addition, roots returned halfway to the level of control surface roots within 33 cm of the barriers.

Conclusions

Reductions of surface root biomass and root diameters were significantly different between barriers installed at 30 and 60 cm depths. There was no reduction in outside root diameters by the 30 cm subtreatments. They did significantly reduce surface root dry mass, but not to the extent of the 60 cm treatments. This result, in combination with results of previous studies, indicates that root response to barriers installed to a 30 cm depth is unpredictable, even when tested in excellent soil conditions. In contrast, the barriers installed to 60 cm depths significantly reduced outside root biomass and root diameter without compromising tree growth. However, noticeable j-rooting was associated with these deeper barriers, indicating that some roots were intolerant of soil conditions at the 60 cm depth. Internal vertical ribs diverted all circling roots within the barriers, regardless of installation depth.

While it could be said that the 60 cm barriers produced more significant reductions in surface root biomass and diameters, increasing evidence indicates that barrier effectiveness depends upon tree species' genetic tolerances to soil environment. In this study, roots of white mulberries (*Morus alba*) in cultivated soil were diverted to at least 60 cm depths and approximately 60% remained at that depth for at least a meter radius from the tree bole without affecting tree growth. This is similar to Barker's observation (1995a, b) that barrier-diverted European hackberry (*Celtis australis*) and southwestern black cherry (*Prunus serotina*) roots did not return to soil surface levels. However, barrier-diverted Chinese hackberry roots returned toward surface levels within 0.66 m of tree boles (Peper and Mori, submitted). At the same research location, different species have exhibited different responses to barrier treatments installed in the same soil environment. Further investigation on optimum barrier depths in these soils is necessary to develop baseline data on the efficacy of installing barriers in landscapes where soil conditions are less desirable. If barriers installed at a given depth are not effective in good soil conditions, there is little value to installing them in poorer soils. Conversely, if barriers installed at a range of depths in good soils effectively reduce surface root biomass, testing should continue to determine the relationship between root systems and hardscape damage potential in a variety of soils. Such research must address the long-term effects of barriers on tree health and stability, as well as analyses of the benefits and costs associated with barrier installations to determine whether they are a cost-effective tool for tree management programs.

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