MANAGED DEVELOPMENT OF TREE ROOTS. II. ULTRA-DEEP ROOTBALL AND ROOT BARRIER EFFECTS ON SOUTHWESTERN BLACK CHERRY[1]

by Philip A. Barker

Abstract. Three-year-old seedlings of southwestern black cherry (*Prunus serotina* subsp. *virens* var. *virens* with rootballs 35 and 70 cm deep were field planted in northern California in April 1986 to compare the effects on root development of rootballs of two depths and a root barrier, which was a polyethylene casing around the rootballs of half of the trees of each treatment. Three growing seasons later, the roots were excavated to a depth of 32 cm in an area within a radius of 1 m from the tree trunks and dry weights of the exposed roots of each tree determined. There was no significant difference in root dry weights between the two rootball types. The casing, on the other hand, significantly reduced root dry weights for each rootball type.

Key Words. Arboriculture, root barrier, root development, root growth, root weight, sidewalk damage, trunk diameter, urban forestry.

The conflict between tree roots and sidewalks (2,5,7) is one of the most pervasive problems in urban forestry. Root problems were ranked third in importance out of nine traits of selected street tree species in a study by Sommer et al. (25). Paralleling findings of Wagar and Barker (28) concerning the problem in California, Wong et al. (30) reported that 30% of a sample of more than 2,000 street trees in Manchester, England, were causing pavement damage.

Sidewalk damage by nearby trees results from numerous interrelated factors. Roots that develop immediately below sidewalks or any pavement are of particular concern if, as is intuitively assumed, they displace the overlying pavement sooner than deeper roots. Contributing to the problem is the interaction of various biotic and abiotic elements of the environment. Contrary to common viewpoint, sidewalks and other paved surfaces, among various abiotic factors, apparently promote rather than deter development of shallow tree roots. Kopinga (13), who studied the problem of tree root damage to asphalt pavements in The Netherlands, found that roots of poplar (*Populus* sp.) trees grew immediately beneath the pavement. Soil humidity was constantly high in this location but flucuated markedly in vegetation-covered soil beside the pavement. Roots of these same trees typically were deeper in the soil where there was no pavement.

A concrete sidewalk or other paved surface functions as a barrier against soil moisture loss by either evaporation or transpiration, notwithstanding its counteracting effect of blocking percolation of rainwater into the soil. When a pavement or a sidewalk, in particular, warms, some of the heat radiates to the soil beneath it. Conversely, when a sidewalk cools, its temperature drops more rapidly than that of underlying soil. In this case, moisture from the soil condenses on the underside of the sidewalk, only to evaporate back into the soil whenever heat buildup of the sidewalk again outpaces that of the soil (3,12). Such conditions constitute a favorable environment for growth of shallow tree roots.

Radial growth of shallow tree roots warps and cracks sidewalks in particular, often creating "lips" by uneven displacement of adjoining sections of sidewalks. This type of damage results in pedestrian accidents, commonly classified as "trip and fall," and claims for damages by injured victims.

The objective of our experiment was to determine the feasibility of controlling the depth of tree roots under field conditions. It compared root growth primarily in the top 32 cm of soil and secondarily below 32 cm for treatments designed to control rooting depth. The study, which also examined stem size as a function of top growth, was part of a larger study on managed root development to promote deep rooting of urban trees.

Materials and Methods

The experiment involved 72 southwestern black cherry trees (*Prunus serotina* subsp. *virens* var. *virens* (18) randomly assigned to 4 rootball-barrier treatments as follows: 35-cm rootball without a barrier, 35-cm rootball with barrier, 70-cm rootball without a barrier, 70-cm rootball with a barrier.

The trees had been seed-propagated and container-grown for 3 years (4). For the 3rd year of growth the trees were shifted into containers having diameters of approximately 18 cm (7 in). Containers for the trees randomly picked for the "35-cm rootball without barrier" treatment were commercially available, 40 cm (16 in) deep, and made of semi-rigid, thermoplastic (16). Containers for the other trees were 75 cm (30 in) deep and were custom-made from flexible black polyethylene tubing of 0.15 mm (0.006 in. or 6 mils) thickness (4).

Trees of the 35-cm rootball-casing treatment were derived from trees produced with 70-cm rootballs and the bottom half of these rootballs sawed off when the trees were planted. Correspondingly, approximately 2 cm of roots were sliced off of the bottom of the rootball of each tree in the other three treatments. For all treatments, therefore, there were stubbed-off roots at the bottoms of the rootballs.

The barriers, which fit snugly around the rootballs like a sausage casing and which hereinafter are alternately called casings, were the intact sides of the custom-made containers. The casings were 35 cm deep, which was the entire depth of the 35-cm rootballs and half the depth of the 70-cm rootballs, as schematically shown for equivalent treatments of a companion study (5). Each casing, regardless of rootball depth, extended 5 cm above the soil surface to prevent possible root escape over the top of the barrier.

These 72 trees were planted in April 1986 in a randomized complete block design with one tree per plot and 18 replications. Each tree was planted in a hole dug with a 45-cm (18 in.) tractor-mounted auger to the depth of the rootball. Any auger-induced compaction of the sides of the planting holes was intermittently fractured with a shovel. Because of the favorable soil moisture content, the augering did not otherwise impair soil structure. When planting each tree, the rootball was positioned in the planting hole so its top was at ground level. Native soil without amendments then was backfilled around the rootball to about 2/3 the depth of the planting hole and firmly tamped with the heel of the foot. Following final backfilling and additional tamping, a 5-cm-high circle of soil, or dike, was built outside the perimeter of the filled-in planting hole. The basin within the dike was filled twice with water, which totaled approximately 40 liters (10 gal). Two wood stakes, each 2.4 m (8 ft) long x 5 cm x 5 cm, were driven 60 cm (24 in) into the backfilled soil inside the boundary of the planting hole on either side of the tree and stabilized with a wood cross piece nailed to each stake at about 35 cm (1 ft) above ground. The tree was tied firmly between and near the top of the two stakes with webbing or other flexible banding material, which completed the planting operation. The vitally important wood cross piece nailed to the two stakes kept the tops of the stakes from pulling together and compromising the integrity of the stakes due to severe winds buffeting the tree.

The experiment was done at the Solano Urban Forestry Research Area in northern California, maintained by the USDA Forest Service in cooperation with Solano Community College. The maritime climate, the deep, silty clay loam soil, and other environmental conditions at this site have been previously described (5).

During the first growing season of the experiment, the trees were hand watered with a garden hose and the site otherwise was free of vegetation in the absence of rainfall or supplemental water. Beginning in the second growing season turfgrass was established and thereafter water was applied by sprinkler irrigation to the entire site at 7- to 10-day intervals or whenever the turfgrass showed incipient wilting. Approximately 7 cm of water was applied in each 24-hour irrigation cycle. The trees were fertilized in mid spring and late summer with ammonium nitrate, each application broadcast in a 3-m band around each tree at an actual N rate of 90 kg per hectare (80 lb per acre) White indoor latex paint was applied to the tree trunks annually to prevent heat damage to the bark by solar radiation.

Stem diameters at 33 cm (1 ft) above the soil surface were measured annually near the end of growing seasons, 1986 through 1988. These data, or their log transformations if appropriate, were analyzed by ANOVA. Using pooled variances, 95% simultaneous confidence intervals for the stem diameter means were calculated. Multiple comparison was by the Bonferroni method (20).

In September 1988, when the trees had been in the field three growing seasons and were approximately 4.5 m (15 ft) tall (Fig. 1), the roots of each tree were excavated from 1 m^3 of soil (32 cm depth x 102 cm radius outward from the original rootball). To leave the roots intact, a trench first was dug at the perimeter of the excavation area with a shovel, then, with a 4-tine, long-handled cultivator, soil was scratched from the excavation area or eventual pit into the trench, from where it was piled on the ground outside of the trench. When excavation of the pit was completed, the original rootball (18 cm in diameter) remained as a core in the center of the pit. On average, 1 person excavated the roots of 1 tree per day.

The exposed roots in each of the 32-cm-deep donut-shaped pits then were harvested for drying and weighing. The dry weight data, or their log transformations if indicated by variance magnitude, were analyzed by analysis of variance (ANOVA) and regression analysis as appropriate. Each ANOVA was unbalanced because the datum of a stunted, unhealthy tree was excluded, thus leaving one block incomplete. The effects of rootball depth and rootball casing and any interactions of these two factors were assumed to be the same for all blocks.

Figure 1. Three growing seasons after the experiment was installed, the roots of each southwestern black cherry tree were excavated in 1 m^3 volume of soil, 32 cm deep in an area within 1 m radius of the trunk.

After harvest of the exposed roots, the pits were back-filled with the original soil. Fourteen trees, representing the extremes of observed root weights, were saved on site as sources of germplasm for followup field testing of their tissue cultured progeny. The remaining 58 trees were lifted with a 112 cm (44 in) mechanical tree digger (Vermeer Co, Pella, Iowa, U.S.A.). Each lifted root system was shaken free of soil with a tree shaking machine, customarily used to shake off almonds and walnuts during harvest.

Roots protruding from the original rootballs below a white paint mark that indicated the bottom of the pit, were diameter-measured for those trees in the 7 blocks in which all 4 trees had been lifted. The non random nature of this population of trees precluded statistical analysis of the data.

Results

Shallow root growth. Weights of shallow roots (roots in the top 32-cm soil horizon) were significantly less for rootballs with casings, regardless of rootball depth, than for rootballs without casings (P = 0.0001) (Fig. 2A). For the 35-cm rootballs, those with casings averaged one tenth the weight of roots compared to those without casings (34.1 vs. 347.5 g). For the 70-cm rootballs, barriers reduced roots to one seventh the weights associated with rootballs lacking casings (33.8 vs. 241.2 g). Differences in weights of roots between the two rootball depths, with or without the casing, were not significant (34.1 and 33.8 g; 347.5 and 241.2 g). Interaction between rootball depth and casing also was not significant. An inference to be drawn from these results, particularly with absence of an interaction, is that the different production methods for the trees in each of the two 35-cm

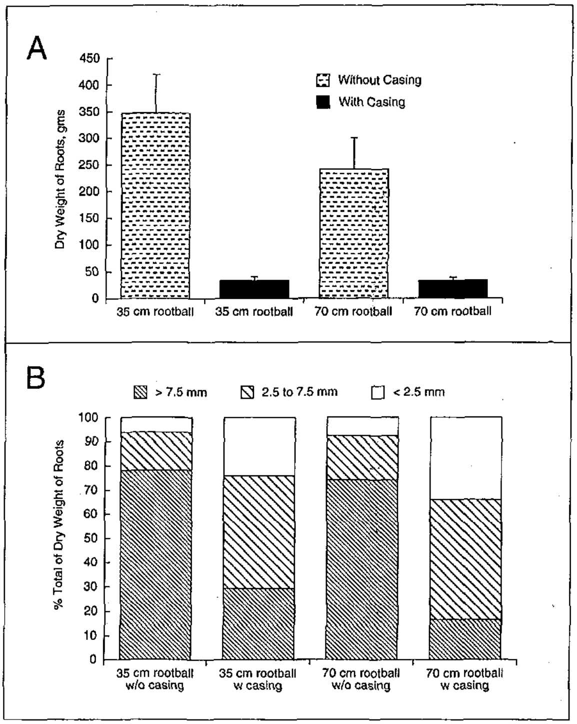

Figure 2. Dry weight of excavated western black cherry roots for each of the four rootball depth-casing combinations: A, means, based on 17 replications for the 35 cm rootballs without casings and 18 replications for each of the other three treatment combinations; brackets above each column represent one standard error of that mean (SEM); B, percentages of the total means for each of three root diameter classes.

rootball treatments did not bias the results.

Representative characteristics of the roots of individual trees for each of the four treatment combinations are shown in Figure 3. The per tree weights of the roots for each of the four treatment combinations are shown graphically in Figure 4.

Where rootballs had no casing, approximately 75% of the weight of the roots was in the largest root diameter-class (> 7.5 mm) (Fig. 2B). Conversely, less than a third of the roots were in the largest diameter class for trees having rootball casing. Hence, not only did we find substantially fewer roots for trees with the casings, but most of the roots with this treatment were in the two smallest diameter classes.

Root growth below 32-cm-depth. The non-random nature of trees that were lifted, as previously stated, precluded drawing statistical inferences from available data on root diameters below 32 cm. Alternatively, therefore, calculated means of the sums of root diameters per tree of the 7-block subset of trees are presented in Table 1 solely to reflect treatment trends. The data suggest what was visually apparent: besides growth of roots from the cut-off roots at the bottoms of all of the rootballs, they also grew out from the sides of 70-cm rootballs.

The roots of one tree were excavated to a depth of 1 m for exploratory purposes. The tree's roots were found the entire depth of the excavation (Fig. 5). Whether or not this pattern typifies all of the trees is unknown.

Stem growth. Stem growth is reflected in trunk diameter measurements. Trunk diameters differed significantly between rootball depths for the second and third years but not the first year ($P = 0.8414$ [1986], 0.0001 [1987], and 0.0003 [1988]). Rootball casing, on the other hand, did not significantly affect trunk diameters in any of the three years. Interaction between rootball depth and casing was not significant any year. Block effects for the respective three years were $P = 0.4711$, 0.0184, and 0.0004, indicating that differences in diameters of the tree trunks among the blocks increased over time and that the block design, therefore, had enhanced the sensitivity of the experiment.

As indicated by the simultaneous 95% confidence intervals of the tree trunk diameters (Fig. 6), there was a clustering of the two casing levels for each rootball type in the second and third years of the experiment but not the first year. Also apparent in Figure 6 is an approximately 25% greater increase in trunk diameter in the second growing season for the 70-cm rootballs compared to the 35-cm rootballs, regardless of the presence or absence of the rootball casing. This differential rate of growth was not sustained in the third growing season.

Just as the variability in trunk diameters among blocks increased with time, with-in treatment variability also increased with time, as reflected by widening 95% confidence intervals (Fig. 6). Trunk diameters were not significantly related to root

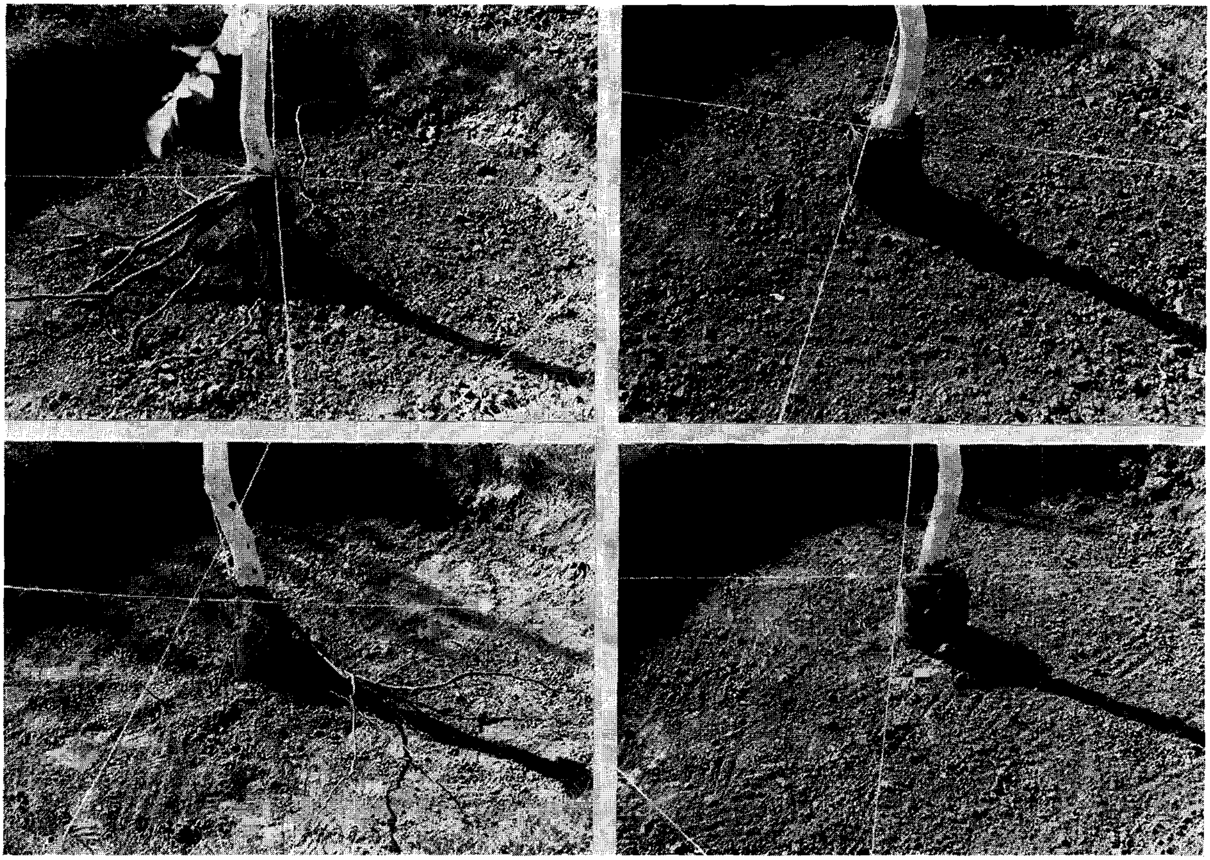

Figure 3. Exposed roots of the western black cherry trees within the excavation pits of Block 8 characterize the general visual differences among the four factorial treatments: top row 35-cm rootballs; bottom row, 70-cm rootballs; left column, rootballs without casing; right column, rootballs with casing.

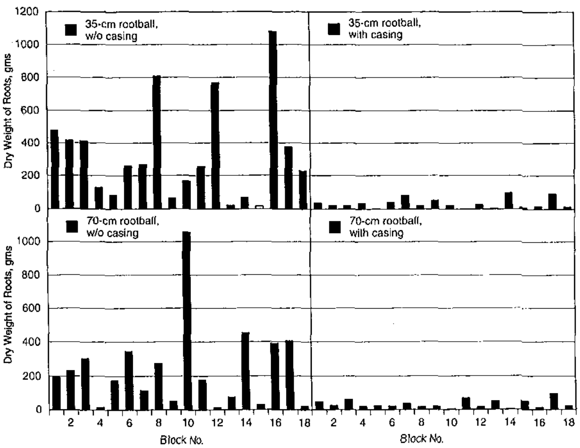

Figure 4. Dry weights of the excavated roots of each western black cherry tree in each of the four rootball-casing combinations in the experiment.

weights, as indicated by regression analysis (t [trunk diameter statistic] = 1.28; df = 1, 66; P = 0.206).

Trunk size differences nothwithstanding, size of the crowns was perceptively uniform for all of the trees except for a stunted tree that was deleted from the experiment as noted above. Because of this crown size uniformity and fiscal constraints as well, other parameters of top growth besides trunk diameter were not measured.

Discussion

Though rootballs of different depths showed no significant difference in root growth, the marked difference due to the casing indicates the potential value of this type of root barrier for controlling the depth of tree roots. Equivalent treatments on

Table 1. Mean sums of diameters of roots emerging from below the 32-cm soil depth (depth of the excavated pits) on rootballs of a 7-block subset of southwestern black cherry trees for each of the four factorial treatments.[1]

Factorial treatment			Mean sums of diameters of roots at depth increments of 10 cm				
Root-ball depth (cm)	Root-ball casing	n	32-42	42-52	52-62	62-72	Total
			(cm)				
35	Without	7	35.7				35.7
35	With	7	50.1				50.1
70	Without	7	17.7	19.7	5.7	6.3	49.4
70	With	7	15.6	20.2	13.2	1.0	49.9

[1] Means for variables have not been statistically analyzed because the data are from non-random trees.

Figure 5. The root system of this tree (70-cm rootball-casing combination) was further excavated to a total depth of 1 m, exposing the numerous roots below the 32-cm depth (indicated by the horizontal white mark near bottom of rootball casing) of the initial excavation pit.

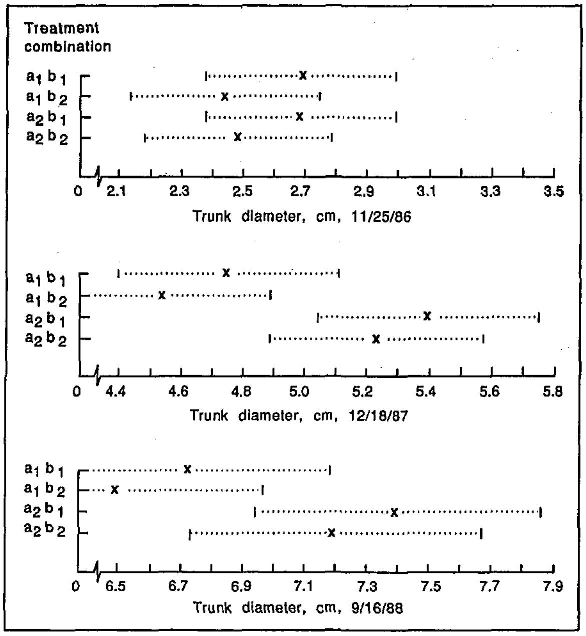

Figure 6. Simultaneous 95% confidence intervals, with Bonferroni adjustment, for trunk diameters based on pooled standard deviations for southwestern black cherry trees for each of four factorial treatment combinations (a_1b_1, 35-cm rootball without casing; a_1b_2, 35-cm rootball with casing; a_2b_1, 70-cm rootball without casing; a_2b_2, 70-cm rootball with casing) at the end of growing seasons 1986, 1987, and 1988.

European hackberry in a companion study had virtually the same effect (5). Despite lack of objective proof, root development below 32-cm appeared to be less for the control trees (35-cm rootball and no casing) than for the trees receiving any of the other three factorial treatments.

The primary function of the casing, as well as other types of root barriers, is not counteraction of forces created by radial enlargement of roots. Instead, when a root apex grows through the soil and encounters a barrier or obstacle of any type, its direction of growth is diverted. Wilson (29) showed that in red maple trees, such diversion of root growth is followed by resumption of growth in the original direction after the root apex has grown beyond the obstacle. If the obstacle is a barrier, continued lateral growth of a root apex may be preceded by downward and, provided the barrier depth is not limiting, eventual below-barrier lateral growth. Once under the barrier, a root apex may continue at the new depth if soil conditions are suitable or it may abruptly turn upward if the soil environment at a shallower depth is more favorable for root growth. On the deep, sod-covered clay loam soils of this experiment, roots showed no pronounced ascent within a radius of approximately 1 m outward from the tree trunk.

Use of unamended backfill soil and firm tamping of the backfill soil around the rootball helped anchor the trees in the ground as well as compacted the soil. We don't know whether exploitation of the backfill soil by new roots depends on how firmly the backfill soil is tamped. Further experimentation is needed to determine if greatest ascendancy of roots to shallower depths after they grow under a barrier occurs in backfill soil that is tamped only lightly or not at all, as is sometimes done. Without concise information about tree root responses to various soils and planting and watering practices, any merits of the planting procedure used in this study are unknown.

The effectiveness of so thin a root barrier of 0.15 mm, versus 1.5-mm thickness of most commercial root barriers, is noteworthy. It brings into question the necessity of commerical barriers being thicker than 0.15 mm. Pragmatically, barriers of the latter thickness may better withstand rough handling and unintentional impacts of tools during installation of the barriers and planting of the trees. Important, also, may be the need for sufficient barrier thickness to enable attachment of internal, vertical ribs that would divert downward any roots otherwise tending to grow horizontally along the internal surface of the barrier (Barker, unpublished data).

How durable were these exceptionally thin, 0.15-mm barriers? Within the 3-year timeframe of this experiment, some of them already had ruptured, apparently because of forces generated by radial enlargement of roots within the barriers. There was no evidence that barrier rupturing affected the amount of shallow roots. By the time they had ruptured, growth that was occurring at the root tips, well beyond the root crown, would have inhibited proliferation of new roots at the root crown, barring absence of any trauma to the root system. Nor was there any evidence that the root barriers impeded radial growth of the roots. Intuitively, it seems likely that, with radial enlargement of the roots, all of the barriers eventually would rupture and be displaced in a manner similar to that of surrounding soil.

An important consideration, which is not apparent in the numerical data, was the marked difference in anchorage of the trees in the two rootball-casing treatments. Trees with the 70-cm rootballs were stable whereas many with the 35-cm rootballs readily wobbled in the ground when the tree trunks were shaken by hand. Roots emerging from the sides of the 70-cm rootballs, as previously mentioned, apparently stabilized the rootballs better than roots emerging only from the bottoms of the rootballs. Such pronounced wobbling of the rootball during storms or other severe load stresses could seriously compromise a tree's stability.

The root weights among the 36 trees planted without rootball casings, regardless of rootball type, ranged between 17 and 1,080 g (Fig. 6). Was this variability due to genetic or environmental effects? Though genotypic differences within tree species exist (6,8,9,10,11,19), investigators routinely have shown tremendous and often overriding environmental effects on root growth (15). Yet, implicit in the variation of root weight among trees of this experiment, or any other population of trees of a single species that show such variability, is the possibility that progeny (ramets) micropropagated from selections of these trees (ortets) will develop corresponding root systems. Though mere speculation pending appropriate experimentation, such micropropagated trees, planted along urban streets, might be particularly compatible with sidewalks. This compatibility may be further enhanced if the trees are planted with a polyethylene casing around their rootballs. But, would there be unacceptable tradeoffs? Such trees may lack desired vigor and survival potential, as observed by Kormanik (14) for American sweetgum (*Liquidambar styraciflua*) and Beineke (6) for loblolly pine (*Pinus taeda*).

Variation in root growth among the trees of this experiment represents an opportunity to investigate genetic and environmental control of root formation and activity within this species. The long-term goal of such research would be to develop selections having the least amount of shallow root growth without compromising the tree's anchorage in the soil. Indeed, micropropagated progeny of selected trees from this experiment now are in production for this purpose.

An abundance of literature describes the morphology of tree roots of various species and selections, particularly forest trees (17,24,26) and fruit trees (1,21,22,27). Little if any literature, however, deals with controlling the *in situ* destiny of root growth by use of physical constraints.

The results of this study, therefore, like those of a companion study (5), ratchet forward an increment of scientific evidence needed by urban tree managers in their efforts to ameliorate tree root-sidewalk conflicts. Followup investigations need to include an array of tree species and within-species selections, numerous types of root barriers, planting practices, soils, sidewalks, and possibly other street improvements as treatment parameters.

Pertinent to considering followup studies is the method, among many possibilities (23), of determining the results. In this study, availability of non-reimbursable labor facilitated labor-intensive manual excavation of the roots as an initial step in determining their weight. Hydraulic excavation of the roots by water jetting would have been faster and less labor-intensive. On the other hand, water jetting would destroy the soil structure and render a site unacceptable for subsequent studies.

Conclusions

Contrary to expectations, this study found that root growth in the upper 32-cm soil horizon was no less for trees with 70-cm rootballs than for trees with 35-cm rootballs. Marked reduction in the weight of roots in this soil zone was achieved, however, with a relatively thin polyethylene tubing surrounding the rootball that functioned as a barrier against lateral root growth.

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