MANAGED DEVELOPMENT OF TREE ROOTS. I. ULTRA-DEEP ROOTBALL AND ROOT BARRIER EFFECTS ON EUROPEAN HACKBERRY

by Philip A. Barker

Abstract. Four-year-old seedlings of European hackberry (*Celtis australis*) with rootballs 35 cm (14 in.) and 70 cm (28 in.) deep, were field planted in northern California in April 1986 to compare root development as affected by rootball depth and a casing that fit snugly around the rootball to function as a root barrier. Three growing seasons later, the roots of each tree were excavated to a 32-cm depth in an area within approximately 1 m radius from the trunk and the dry weights of these roots determined. Root weight was significantly different between the two root barrier treatments but not between the two rootball depths.

Key Words. *Celtis australis*, root barrier, root growth, root weight, sidewalk damage, trunk diameter, urban forestry.

In the 1988 California Urban Forest Survey, Bernhardt and Swiecki (3) verified a previously undocumented assumption that root damage to sidewalks and other hardscapes is the main reason California cities remove street trees and discontinue usage of various species. Even so, cities apparently keep most of the offending trees rather than sacrifice valued environmental and aesthetic benefits that these trees provide. In doing so they incur substantial expense to repair damage done by these trees, despite recurrence of such damage in a manner as unrelenting as waves on an ocean beach. Redwood City, California, has spent over a half million dollars annually since 1985, to repair root-damaged sidewalks and prune the roots of offending trees or replace decadent trees. This expenditure is in addition to a budget of $400,000 a year for general tree maintenance (pers. comm., Gordon Mann, September 17, 1993). Nearby Palo Alto's annual budget to repair sidewalks, which includes damage from trees, is $560,000 (9). The amount of this damage due to tree roots *per se* is not specified; however, an estimate of 50 percent, or $280,000, likely is conservative. Across San Francisco Bay, the city of Newark has estimated its annual per tree cost at $50 to $100 to deal with the tree root/sidewalk conflicts on approximately 14,000 street trees (file memo by Rich Langevin, park superintendent, December 19, 1989). At the north end of San Francisco Bay from Newark, the City of Vallejo budgeted $300,000 in 1992 to repair root-damaged sidewalks (pers. comm., Joe Bates, August 3, 1992). The problem is not limited to California. I regularly receive requests from throughout the United States for information on how to deal with a community's "tree - sidewalk dilemma," as expressed by an inquirer from a rural community in Ohio. Cities outside the United States where the same problem exists include Mexico City (2) and Manchester, England (9).

The core of the problem is believed to be growth of tree roots either against or near the underside of sidewalks and eventual displacement of the sidewalks as these roots increase in diameter. Warping, cracking, and creation of "lips" due to differential displacement of adjacent sections of sidewalks frequently result (Fig. 1). These conditions, particularly the lips, cause "trip and fall" accidents which increasingly are the basis for tort claims against cities or responsible parties.

Management efforts that promote exceptionally deep rooting of trees and, consequently, greater separation of roots and overlying sidewalks, are a possible option for reducing the problem. Hypothetically, compared with shallow roots, forces generated by cross-sectional enlargement of deep roots will dissipate throughout a greater volume of soil, consequently delaying the time when sidewalks are adversely affected.

This paper reports the results of an experiment that was part of on-going research on urban tree

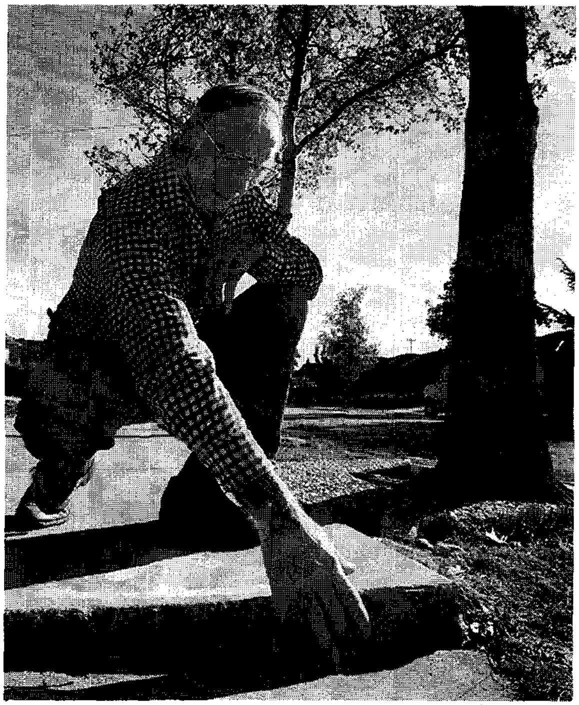

Figure 1. A concerned resident examines a hazardous sidewalk in Gilroy, California, which resulted from uneven displacement of adjacent sections of the sidewalk by roots of a nearby American sweetgum tree (Liquidambar styraciflua) (From Wilson (8), by permission of The Dispatch, Gilroy, California).

root management at the Solano Urban Forestry Research Area (SUFRA), located at Solano Community College, near Fairfield, in northern California. The objective of the experiment was to determine how an ultra-deep rootball and a root barrier would affect the distribution of shallow roots and stem diameter of the test trees.

Materials and Methods

Two-year-old bareroot seedlings of European hackberry (*Celtis australis*) were grown for two more years in 'sleeve' containers to produce trees with rootballs about 18 cm (7 in.) wide and 70 cm (28 in.) deep (1). The containers were custom fabricated from black polyethylene tubing of 0.15 mm (0.006 in. or 6 mils) thickness, as previously described (1). The exceptionally narrow design of the containers served to conserve rootball weight and facilitate manual handling of the trees in the nursery and during their transport and outplanying.

In April 1986, 80 of the randomly selected trees were outplanted at SUFRA in an experiment consisting of single-tree plots with 2 x 2 factorial treatments arranged in a randomized complete block design of 20 blocks. The trees were spaced 4.6 m (15 ft.) apart in and between rows. When the trees were outplanted, the rootballs of 40 trees were sawed off to make rootballs of 35-cm depth. A 2-cm-thick slice of matted roots was sawed off of the bottoms of the rootballs of the other 40 trees. These latter trees had nominally 70-cm or ultra-deep rootballs. Among the 40 trees of each of the two rootball depths, the containers were completely removed from the rootballs of 20 trees. On the other 20 trees the sides of the containers were left intact on the rootballs to function as root barriers. Because of the snug fit around a rootball (Fig. 2), similar to a sausage casing, these barriers also are called casings herein. Once the trees were outplanted, the casings extended 5 cm above the soil surface and 35 cm deep. That is, the below-ground depth of the casings or barriers equaled the depth of the 35-cm rootballs and half the depth of the 70-cm rootballs.

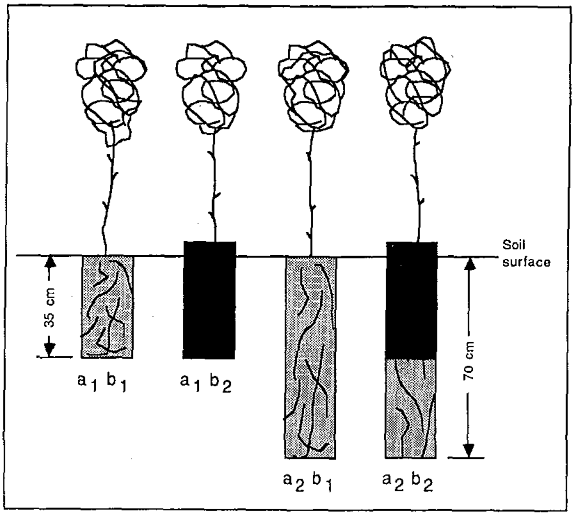

Figure 2. Schematic representation of the treatments on the European hackberry trees, as follows (L to R): 35-cm rootball without casing ($a_1 b_1$), 35-cm rootball with casing (a_1 b_2), 70-cm rootball without casing (a_2 b_1), 70-cm rootball with casing (a_2 b_2).

Soil at the experiment site, which is classified as Class I of the Yolo Series (6), is an alluvial, well-drained dark brown, generally silty clay loam, without mottling. It had 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. The climate at the site has a maritime influence because of its location, approximately 16 km (10 miles) north of the mouth of the Sacramento River and a similar distance inland, across a range of low mountains, from the north end of San Francisco Bay. The site receives about 40 cm (15 in.) of precipitation annually, primarily from October through April, and rarely experiences freezing temperatures in winter.

All treatments were maintained in mowed, irrigated turf and were fertilized in mid spring and late summer with ammonium nitrate at a rate of 90 kg of N per hectare (80 lb per acre) per application.

In May 1989, 3 years after the experiment had been installed and when the trees were 7 years old and approximately 3.6 m (12 ft) tall (Fig. 3), a 1-m^3 round pit was dug around each tree to expose its roots in that part of the soil horizon. The original rootballs remained intact as cores in the center of each pit. Each pit was dug to a depth of 32 cm with radii outward of 125 cm from trunk center or 102 cm from the original rootball. To leave the roots intact, the pits were excavated manually by trenching just outside the perimeter of each pit with a shovel. Soil within the pit area then was raked with a long-handled, 4-tine cultivator into the trench and then piled outside the trench.

The exposed roots within each donut-shaped pit, which was 32 cm deep and had a radius outward from the original rootball of 102 cm, then were harvested for drying and weighing. Log transformations of the dry weight data were analyzed by ANOVA. Treatment means and standard errors (SEM) were derived from descriptive statistics rather than ANOVAs.

Stem diameters at 30 cm (1 ft) above ground level were measured on November 25, 1986, December 18, 1987, and November 30, 1988. ANOVAs were done on each year's data after rejecting a multi-year repeated measures analysis. Log transformation of the data was considered

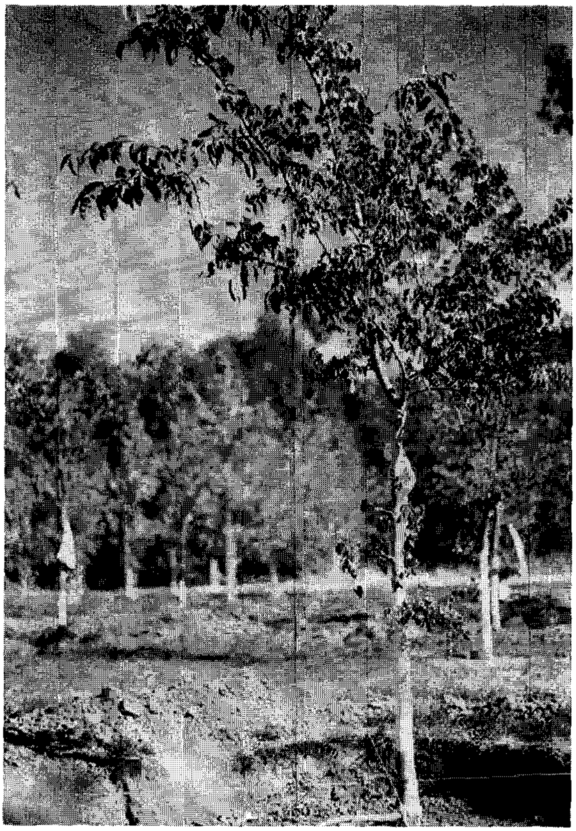

Figure 3. Panoramic view of the experiment with excavation of the roots in progress.

unnecessary because of the small variances and the probability that larger sample sizes (replications) would have dampened the magnitude of the variances. Multiple comparisons were calculated for the 95 percent confidence intervals of the means, using pooled variances and the Bonferroni adjustment (4).

Though the experiment had 20 replications (blocks), data for both root weights and stem diameters were analyzed from only 10 blocks that had been randomly chosen for excavation. Excavation of additional blocks was considered unnecessary because of the apparent similarity of the results with those of a previously excavated experiment of similar design where the test tree was Western black cherry (*Prunus serotina* ssp. *virens* var. *virens*) (Barker, unpublished data). Despite the randomized complete block design of the experiment, an unbalanced analysis of variance procedure was used on all of the data because two of the four trees in one of the blocks inadvertently had received the same factorial treatment when the experiment was installed.

Results

Root growth. Differences in mean root weights (MRW) betweeen the 35- and 70-cm rootballs, regardless of barrier treatment, as well as among blocks, were not significant ($P = 0.70$ and 0.55, respectively). Conversely, MRW was significantly less for trees with root barriers, regardless of rootball depth, than for trees lacking root barriers ($P = 0.0001$). MRW of trees with the 35-cm rootballs and root barriers was, on average, less than one third that for such trees without root barriers (55.6 $\pm$ 12.0 vs. 183.5 $\pm$ 15.7 g). Trees with the 70-cm rootballs had the same pattern of difference in MRW but by a magnitude of about nine times (33.5 $\pm$ 9.1 vs. 296.1 $\pm$ 79.1 g.).

Within the usual limits of significance, there was no interaction between the rootball type and the root barrier treatments ($P = 0.1007$). That is, the MRW for each rootball type did not differ significantly between the barrier and the no-barrier treatments.

For each of the four treatment combinations, representations of the excavated roots of individual trees are shown in Fig. 4 and the MRW of the excavated roots in Fig. 5.

Stem diameter. Mean stem diameter (MSD) was significantly greater for trees with the 70-cm

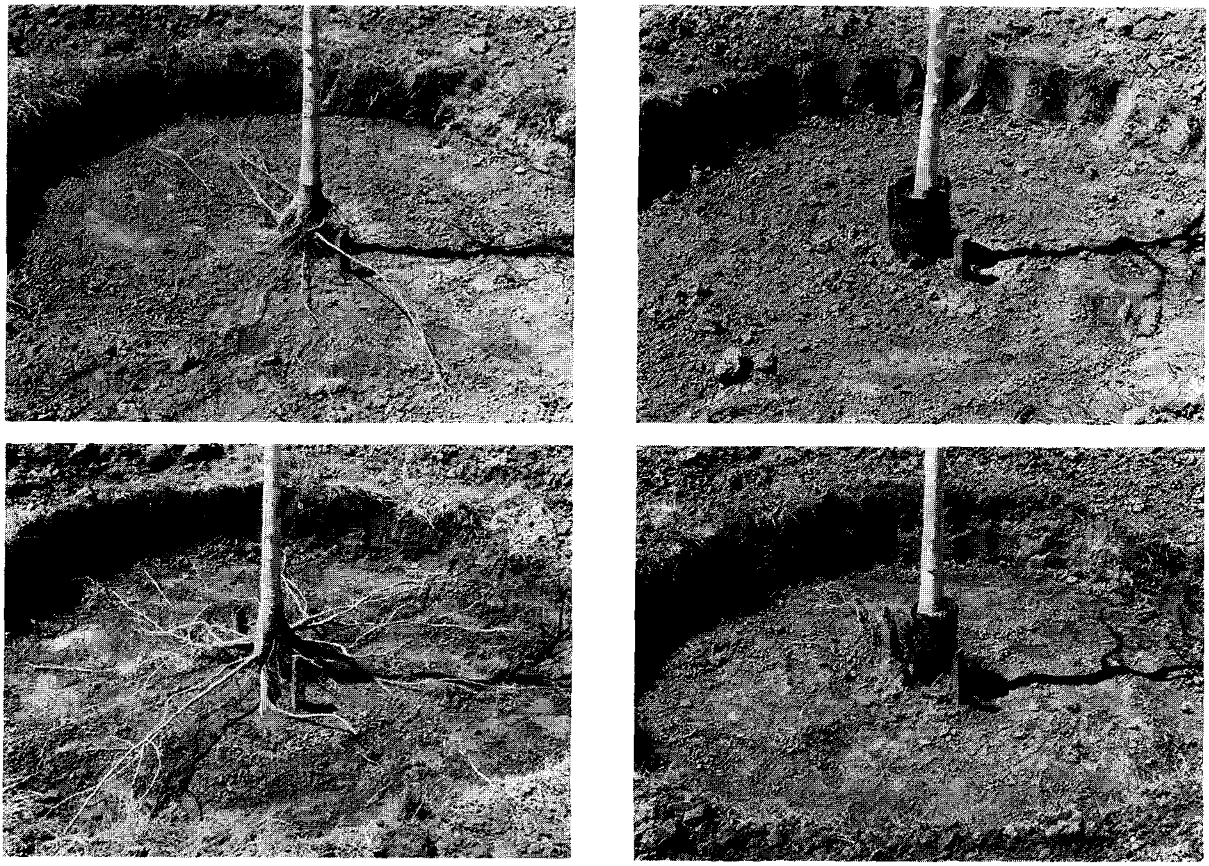

Figure 4. Representative amount of roots of European hackberry exposed in the excavation pit for each of the four treatment combinations, as follows: top row, 35-cm rootball; bottom row, 70-cm rootball; left column, no rootball casing; right column, rootball casing, which functioned as a root barrier.

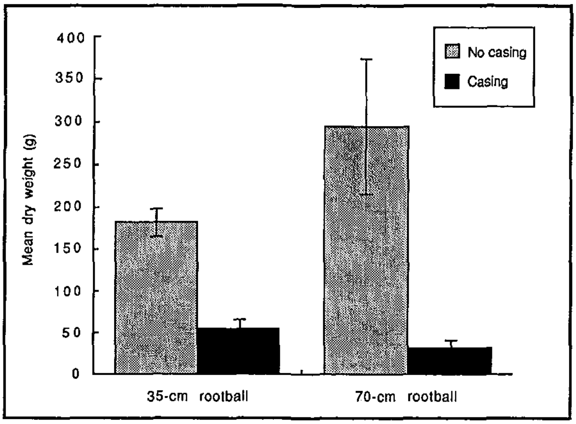

Figure 5. Mean dry weights of European hackberry roots for the four rootball type/barrier treatment combinations, based on 10 replications for both of the 35-cm rootball treatments and 11 and 9 replications for the 70-cm rootballs, without and with the casing treatment, respectively; brackets atop each column represent plus and minus one standard error of that mean (SEM).

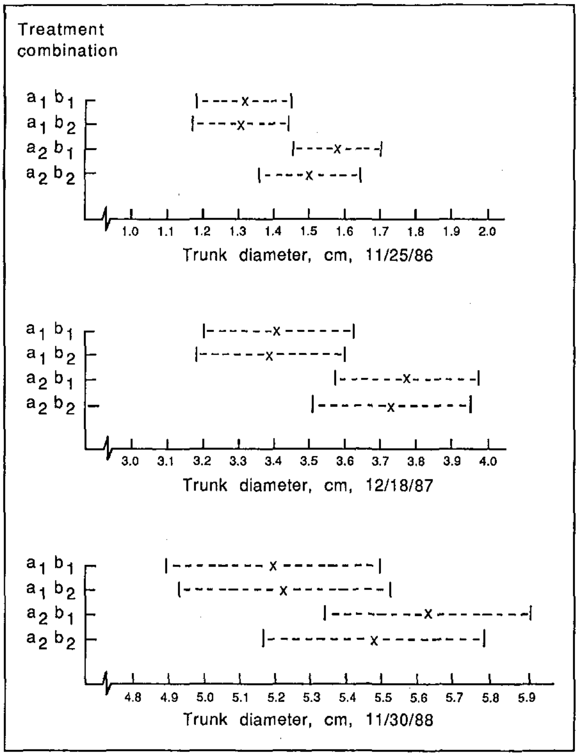

Figure 6. Simultaneous 95 percent confidence intervals (Bonferroni method) for stem diameters of European hackberry trees for each of four rootball/constraint treatment combinations (a_1b_1, 35-cm rootball, without casing; a_1b_2, 35-cm rootball, with casing; a_2b_1, 70-cm rootball, without casing; a_2b_2, 70-cm rootball with casing) at the end of growing seasons 1986, 1987, and 1988.

rootballs, regardless of root barrier treatment, than for trees with 35-cm rootballs ($P = 0.0001$ [1986], 0.0002 [1987], and 0.004 [1988]). Conversely, the MSD was not significantly different between the two root barrier treatments ($P = 0.83$). Block effect was significant for the last two but not the first year of the experiment ($P = 0.83$ [1986], 0.04 [1987], 0.0003 [1988]), which suggests that the trees responded differently to site conditions as they increased in size.

When averaged over the two root barrier treatments, the MSD was 18, 10, and 7% larger in 1986, 1987, and 1988, respectively, for trees with 70-cm rootballs than for trees having 35-cm rootballs. Simultaneous 95% confidence intervals of the MSD (Fig. 6) showed a clustering of the two root barrier treatments for each rootball type in each of the 3 years of the experiment. The wider 95% confidence intervals in successive years suggest increasing within-treatment variability with increasing tree stem diameters. Despite stem diameter differences, there was no apparent difference in overall crown size among the treatments.

Discussion

Although different rootball depths were not found to affect root growth, contrary to what had been expected, significant reduction in root growth due to the casing treatment indicates the potential effectiveness of inhibiting shallow root growth with this type of root barrier. From a practical standpoint, a barrier, regardless of type, primarily affects lateral growth of *root apices* rather than radial growth of existing roots. Even with this relatively thin barrier, rather than puncture and grow through it, root apices that contacted it diverted direction of growth—generally downward. There was no evidence that roots that had grown downward and under the barrier then grew abruptly upward and back to their original depth. Instead, lateral root growth evidently was resumed primarily at the new, lower depth. This finding does not preclude the possibility, however, that continued lateral growth of these deepened roots eventually may be into shallower soil.

Additional studies will have to be done before it is known how this type of root barrier affects root development in various soils and with other tree species, irrespective of soil type. Moreover, it is unknown whether significant differences found in root growth, as affected by the barrier treatment, would 1) apply to trees growing near sidewalks and 2) result in reduced damage to the sidewalks.

Also important for a better understanding of root development of urban trees, but not determined in this study, is the affect of the planting method. In this experiment, no amendments were mixed with the backfill soil, which was tamped with the heel of the foot 5 to 7 times when the space between rootball and boundary of the planting hole was about two-thirds full. Such firm tamping helped anchor the trees in the ground and augmented the benefits of staking the trees. Alternative planting practices, though not used in this experiment, include 1) tamping the backfill soil little if any and 2) watering the tree after about half to two thirds of the backfill soil has been replaced. Further experimentation is needed to test the hypothesis that such planting alternatives promote abrupt upward growth of roots after they have grown under a root barrier.

A similar experiment with Western black cherry produced similar results (Barker, unpublished data), as previously stated. Whether or not these two studies, which corroborate one another, represent a general pattern may depend, among other things, on inherent root system characteristics of each tree species. Three-quarters of a century ago Pulling (5) reported that the root systems of some tree species are shallow and others comparatively deep. Some species may tolerate a wide range of depths, he reported, whereas other species may tolerate a very narrow depth range.

Though the following point is speculative, because the genus Celtis is in the Ulmaceae Family along with shallow-rooted Ulmus or elm species, Celtis species may likewise be shallow rooted. However, coupled with an inherent rooting habit is also the effect of edaphic and other environmental factors, particularly when a species is grown outside its natural range, as typifies any array of urban trees, which, collectively, can be considered to be of global origin. Indeed, environment may so strongly affect the growth of urban trees as to virtually mask any genetic control over their root system development.

As previously mentioned, this experiment was done on a deep alluvial clay loam soil, which is ranked among the best for production of agricultural crops, including tree fruits. This consideration and the fact that the trees were regularly irrigated suggest that their environment was anything but adverse. It is probable that less pronounced treatment differences would be found if the same experiment were carried out in a hostile environment.

The purpose of using trees with unusually narrow rootballs in this experiment was to limit the weights of the rootballs for improved ease in handling the trees. Considerations beyond the scope of this experiment would be required if trees with such narrow rootballs were used elsewhere (1).

Whereas root growth in the top 32 cm of soil was markedly inhibited by the root barrier but not by an exceptionally deep rootball, conversely, stem growth was significantly enhanced by the ultra-deep rootballs, irrespective of the root barrier treatment. Enhancement of stem diameters is a *priori* evidence of the promotion of tree vigor with ultra-deep rootballs.

The significant block effect on trunk diameters in the last 2 years of this 3-year experiment suggests that soil quality or other components of the environment varied within the experiment site. Sensitivity in analysis of the data was enhanced, therefore, by block design of the experiment.

Conclusions

Implicit in the results of this experiment is the possibility of inhibiting shallow root growth with a root barrier of polyethylene tubing of a mere 0.15 mm thickness that fits snugly around the rootballs of outplanted trees. On the other hand, there was no evidence that ultra-deep rootballs would likewise inhibit shallow root growth.

Overall, the results add important information to yet a meager body of knowledge about controlling the depth of tree roots. Further research of this nature, particularly applicable to trees in cities and smaller communities, could be guided by the conclusion of Stout (7) concerning his study of excavated root systems of trees in natural stands of mixed hardwoods. "There is so much variation within species and sites,"he said, "that many more individual trees will have to be excavated and studied before any broad statements can be made."

Acknowledgements. We thank the Orange County Nursery, Inc, Visalia, California, for donating the 2-year-old seedling trees used in this experiment, and the Solano Community College, Sacramento Tree Foundation, California Conservation Corps, statisticians Dr. Chris Drake and Julie Yee, and technicians Dorothy Apodaca, Bruce Bushard, and Al Franklin for help with various components of the experiment. The article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

Literature Cited

1. Barker, Philip A. 1994. *Polyethylene sleeve containers for container-grown trees.* American Nurseryman 179(4):97-98.
2. Benavides Meza, Hector M. 1992. *Current situation of the urban forest in Mexico City.* J. Arboric. 18(1):33-36.
3. Bernhardt, Elizabeth, and Tedmund J. Swiecki. 1989. The state of urban forestry in California. California Department of Forestry and Fire Protection, Urban Forestry Program, The Resources Agency, State of California, Sacramento, California. 67 pp.
4. Neter, John, William Wasserman, and Michael Kutner. 1990. (3rd ed.) Applied Linear Statistical Models, p. 930. Richard D. Irwin, Inc., New York, NY. 1181 pp.
5. Pulling, H.E. 1918. *Root habit and plant distribution in the far North.* Plant World 21:223-233.
6. Soil Conservation Service. 1977. Soil survey of Solano County, California. USDA Soil Conservation Service. 65 pp.
7. Stout, Benjamin B. 1956. Studies of the root systems of deciduous trees. Black Rock Forest Bul. No. 15, Harvard Black Rock Forest, Harvard University, Cambridge, Massachusetts.
8. Wilson, Marshall. 1988. Beauty of trees costs homeowners. The Dispatch, Gilroy, California, November 18, page 1.
9. Wong, T.W., J.E.G. Good, and M.P. Denne. 1988. *Tree root damage to pavements and kerbs in the city of Manchester.* Arboricultural Journal 12:17-34.

Research Horticulturist (retired),
Urban Forestry Research, Pacific Southwest Research Station
USDA Forest Service
Berkeley, California 94701-0245.

Résumé. Des semis de micocoulier de Provence (*Celtis australis*) en mottes de 35 à 70 cm de profondeur ont été plantés en champs dans le nord de la Californie afin de déterminer si le développement des racines était affecté par 1) la profondeur de la motte et par 2) la barrière au développement racinaire qui entourait de façon serrée la motte. Après trois saisons de croissance, les racines de tous les arbres ont été déterrées à une profondeur de 32 cm et jusqu'à une distance de 1 m du tronc; la masse des racines asséchées a été ensuite mesurée. La masse en racines était significativement différente entre les deux types de traitement de barrière racinaire, mais ne l'était pas entre les deux profondeurs de mottes.

Zusammenfassung. Vom Südl. Zürgelbaum (Celtis australis) wurden Jungpflanzen mit 35 cm und 70 cm tiefen Wurzelballen im Norden Californiens ausgepflantzt, um das Wurzelwachstum in Bezug auf 1. Wurzelballentiefe und 2. auf eine Wurzelsperre, die genau um den Wurzelballen passt, zu vergleichen. Nach drei Wachstumsperioden wurden die Wurzeln in einem Abstand von 1m zum Stamm bis zu einer Tiefe von 0.32m ausgegraben und die Trockengewichte bestimmt. Das Wurzelgewicht war deutlich unterschiedlich zwischen den beiden Wurzelbegrenzungsbehandlungen, aber nicht zwischen den zwei Wurelballentiefen.