REPLACING SOIL IN THE ROOT ZONE OF MATURE TREES FOR BETTER GROWTH

by Gary W. Watson, Patrick Kelsey, and Klaus Woodtli[1]

Abstract. Soils were replaced in various patterns within the root zone of mature landscape trees as an alternative to surface mulching. Care was taken to minimize the damage to the root systems, through careful positioning of the excavations, or use of hydraulic excavation procedures. Tree roots grew better in the new soil mixes than in the original site soil, exhibiting up to a 320% increase in fine root density and up to a 68% increase in rooting depth. Declining annual growth rate trends were reversed by the treatment in *Tilia* and *Platanus*. Soil replacement has potential as another useful tool for treating declining trees.

The cause of urban tree decline is often found below ground. Urban soils can deteriorate over the decades from a combination of uniquely urban influences and interruption of organic matter recycling. Traffic, even from pedestrians, can increase bulk density. Runoff from many building materials and pavements can increase alkalinity. Leaves and other fallen organic matter are raked and taken away instead of being allowed to decompose and enrich the soil.

Poor soil conditions (in particular, low levels of porosity, aeration, and moisture holding capacity) result in inadequate fine root development. This combination results in restricted availability of moisture to the tree, which in turn leads to stress-related disease and insect problems. Improving soil texture and structure increases porosity and reduces bulk density, and results in better fine root development and a reestablishment of the proper root:crown balance. Traditional methods for improving soil physical properties cause damage to the already limited tree root system. The challenge is to improve the soil, and ultimately, the root system, with minimal damage to the root system during implementation of the chosen process.

Numerous methods have been used by arborists to improve the soil around trees. The benefits of mulching have been demonstrated in many studies. Over a period of years, maintaining a layer of organic mulch on the soil surface produces desirable changes in the soil, such as a reduction in surface bulk density, and increased moisture availability, porosity, and organic matter content. The interface between the highly decomposed lower layer of mulch and the increasingly organic soil is soon obscured. Root development is enhanced in the improved soil environment. Increases in root development of up to 400% have been reported in the soil beneath the mulch, and the mulch layer itself can serve as an additional medium for root development supporting even greater root densities than the improved soil (3,10).

Vertical mulching is the term often used to describe the process of drilling a grid of 1–2 inch (2.5–5.0 cm) diameter holes in the soil around trees to improve aeration. These holes are sometimes filled with a porous material. Vertical mulching has been commonly used in the industry but seldom studied (2). Smith (8) found that open holes stimulated the growth of trees as much as holes filled with fertilizer did. Kalisz et al. (4) found that holes filled with perlite, which should provide excellent aeration, did not increase root mass in the adjacent soils after 3 years. The effect of the treatment on crown development was not reported.

Air injection methods have become more popular in recent years, but their effectiveness is questionable. Rolf (5) showed that the bulk density of sandy soil can be decreased by compressed air injections, but in a loam soil, use of the equipment itself can increase bulk density. Smiley et al. (8) reported no change in bulk density after treatment. Root density was unchanged after these treatments (G. Watson, unpublished data). No increase in top growth resulted from the aeration treatment (7).

1. Woodtli Baumflege, Bern, Switzerland.

Rolf (6) has shown that subsoiling with excavation equipment can relieve compaction. Bulk density was decreased and porosity was increased. Shoot growth of trees planted in subsoiled plots was greater than shoot growth of trees in compacted plots of undisturbed control soil.

Each of these methods of treatment has limitations. Surface mulch is very effective, but considered undesirable at some locations. Vertical mulching is very labor intensive. Air injection may not be effective in fine-textured soils. The large equipment required for subsoiling limits usefulness on smaller sites, and it cannot be used near existing trees without severe damage to the root systems.

A procedure that replaces greater volumes of soil in more concentrated areas around trees could combine many of the advantages of these other methods while overcoming many of the limitations. Zu (13) reported that such a techniques was used to revitalize ancient (at least 300 years old) trees on high traffic sites in China. Areas of soil around the tree were removed by hand without damaging the larger woody roots. The pits were refilled with a high-quality soil mix, and bundles of branches were used for aeration and as a source of organic matter as they decomposed. Root and shoot growth increased after installing the treatments.

Studies of 2 similar "soil replacement" techniques will be reported here; both were intended to provide areas of high-quality soil for root proliferation. Over a longer period, the increased aeration, organic matter, and biological activity in the replaced soil may also help to improve the adjacent site soil and increase root development in areas adjacent to the replacement soil. Both involve replacement of substantial volumes of soil around existing trees to improve root development without the intensive labor required for drilling numerous small holes or for hand-digging.

Methods

Morton Arboretum study. This study focused on the root response to the replaced soils. White oaks (*Quercus alba)* were chosen because this species has been subject to decline in the upper Midwest for decades. Its root system is considered relatively slow growing and sensitive to disturbance. A positive response of white oak roots to the treatment would likely mean that many other species would also respond. The oaks were growing in a naturally slightly acid, high clay content soil with good soil structure, moderate porosity, high water-holding capacity, and perched water table. The oaks were in competition for resources with deep-rooted meadow grasses.

A backhoe was used to dig 4 radially positioned trenches around large (31 inch [79 cm] dbh) trees. Trenches began 10 ft (3 m) from the trunk to minimize damage to the large roots and were 10 ft (3 m) long, 2 ft (60 cm) deep, and 14 inches (35 cm) wide. Each trench held approximately 1 yd^3 (m^3) of new soil.

The 2 types of backfill soil mixes used to refill the trenches were 100% aged mixed hardwood leaf compost and a 50/50 mix (by volume) of the same leaf compost and the higher quality soil from the upper half of the trench. Two trenches around each of 3 trees were filled with each soil mix.

Root density samples were taken 1, 2, and 4 years after installation of the treatments. At each sampling, 1 core (2.7 inches [7 cm] in diameter and 16 inches [40 cm] deep) was removed from each trench (2 samples per treatment) and from 2 control areas per tree at the same distance from the trunk, but removed from any possible influence of the trenches. Two and 4 years after treatment, the undisturbed soil adjacent to the trenches was also sampled to detect any changes in root development that may have resulted from the improved soil. Cores were centered 4 inches (10 cm) and 11 inches (27 cm) from the edge of the trench.

Kruskal-Wallis one-way ANOVA on ranks was used to compare root densities of treatments to the control ($p < 0.05$) using SigmaStat for Windows 95.™ Dunn's Method was used as a multiple comparison procedure.

Switzerland study. Soil replacement treatments had been installed on a commercial basis at various locations in Switzerland from 1987 to 1989. High-pressure water jets washed the soil away from the roots. The water and soil was then vacuumed away. This procedure using specialized equipment is called hydraulic excavation. Very little root damage occurs, and the process can be accomplished quickly in certain kinds of

Table 1. Sites where soil replacement treatments were installed around landscape trees.

Location	Year Treated	Trees at Site	Species	Method
Lehrerseminar	1987	6	*Tilia tomentosa*	holes
Tegimenta Rotdreuz	1987	13	*Platanus* × *acerifolia*	mostly pits
Olten (Klosterplatz)	1987	6	*Tilia platyphylos*	pits
Olten (Amthausquai)	1986	13	*Tilia platyphylos*	pits
Terllering Aarau	1987	13	*Tilia platyphylos*	holes
Lugano	1989	10	*Platanus* × *acerifolia*	mixed pits and holes

soils. The replacement soil was a custom mix of coarse sand, composted organic materials, and fertilizer. The local term used to describe the entire soil replacement process is RADOSAN.

Since the treatments were installed on multiple sites in actual landscapes, uniform treatments could not be achieved on all sites. Locations and descriptions of each site are listed in Table 1. The 39 *Tilia* spp. and 23 *Platanus* × *acerifolia* trees averaged 23 inches (59 cm) and 21 inches (53 cm) dbh respectively. The holes excavated with the equipment described above were 4 inches in (10 cm) diameter, up to 24 inches (60 cm) deep where soil conditions allowed, and spaced from 12 inches (30 cm) apart on confined sites to 30 inches (75 cm) apart on open sites, approximately within the dripline, as the site would permit. Pits were large areas of soil around the trunk excavated up to 24 inches (60 cm) deep and not more than 65 ft^2 (7 m^2) in area.

In September 1991, both the new soil and undisturbed original site soil were sampled by augering around each tree to compare maximum rooting depth in the replaced soil with that in adjacent untreated control sites. One treated area and 1 untreated area were sampled per tree. In the case of trees in planting pits where this was not possible, nearby treated and untreated trees were used. An increment boring was removed from each tree, 4.5 ft (1.4 m) above the ground, to measure annual growth rings. Rooting depth was correlated with treatment depth in the same holes using Pearson's correlation in SigmaStat for Windows 95 ($p < 0.05$).

Results

Morton Arboretum study. After 1 year, root density in the all-compost and in the half-compost replacement soils was 1.4 and 2.3 times greater, respectively, than in the control (Figure 1). These new soils had no roots in them at the time of installation. As is often the case in root samples, the variation among samples was generally high enough to prevent statistical significance between treatments, though differences are very large.

After the second year, root density in the 2 replaced soils was similar to the first year, at 1.6 and 2.2 times greater than the control for the all-compost and the half-compost treatments, respectively (Figure 2). Root density in the soil core centered 4 inches (10 cm) from the all-compost-filled trenches increased by 78%, while the soil adjacent to the half-compost-filled trenches remained similar to the controls.

At the final sampling date, 4 years after treatment, root density in the half-compost soil remained unchanged at 2.1 times greater than the control, while the root density in the all-compost soil rose significantly to 3.2 times the control. Root density in the soil core centered 4 inches (10 cm) from the all-compost trenches remained the same

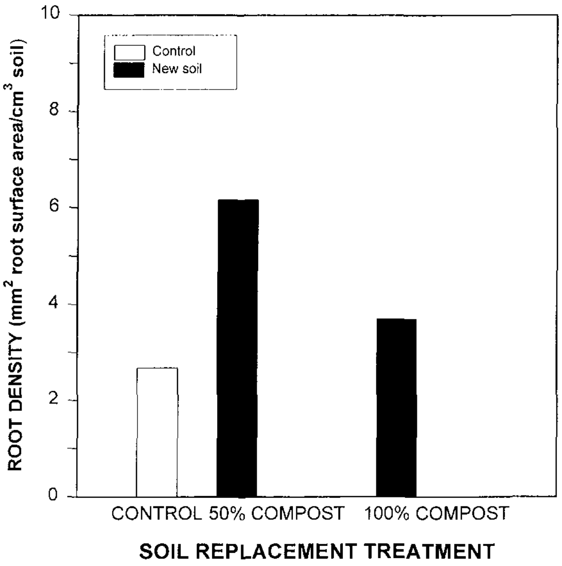

Figure 1. Root density 1 year after soil replacement treatment. Control locations were at least 6 ft (2 m) from the trenches.

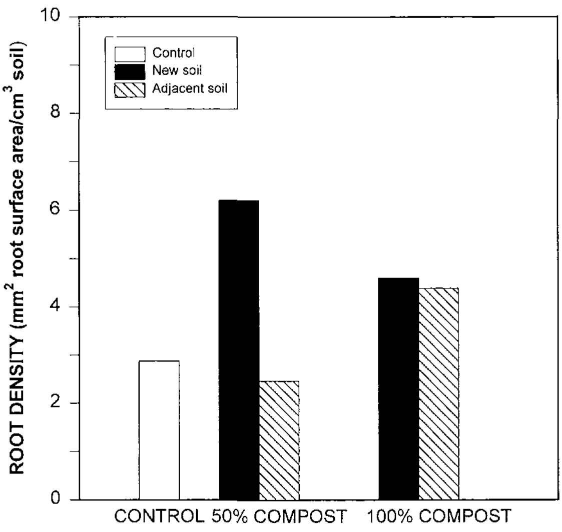

Figure 2. Root density 1 year after soil replacement treatment. Control locations were at least 6 ft (2 m) from the trenches. Adjacent soil samples were within 2 inches (5 cm) of the trench.

as in the second year after treatment, at 1.9 times the control. Root densities in the core samples centered 11 inches (27 cm) away from the all-compost-filled trench were also 50% greater than the control (Figure 3). Root densities in the soils adjacent to the half-compost treatment remained very similar to the controls for the entire study.

Switzerland study. Rooting depth in the replaced soil averaged 7.7 inches (19.5 cm) deep for *Tilia* and 18.7 inches (47.7 cm) for *Platanus,* while in the site soil, tree roots averaged only 4.5 inches (11.6 cm) and 15.3 inches (39.0 cm) deep, respectively. Roots colonized the majority of the depth of the replaced soil (59% for *Tilia* and 90% for *Platanus*). Rooting depth in replaced soil was 68% deeper than the controls for *Tilia* and 37% deeper for *Platanus.* Rooting depth was positively correlated with treatment depth, suggesting that deeper treatments increase overall rooting depth. The rooting depth relationship for *Platanus* was more strongly correlated than for *Tilia.* All correlations were significant at $p < 0.05$.

Increment borings showed that before soil replacement, the trunk growth of the *Platanus* trees had been decreasing for all 6 years measured, and the trunk growth of the *Tilia* trees had been slowing for the last 3 years (Figure 4). In the year following the soil replacement treatment, growth of both species began to increase. The first year after treatment, the *Platanus* trees grew at a rate nearly equal to the highest rate measured before treatment and, in the third and fourth years, surpassed the highest pretreatment growth measured. *Tilia* growth increased after treatment, but not to the same level measured before the onset of decline. The changes in growth rate were not statistically significant, but the trends in the data were supported by visual improvement in tree condition.

Discussion

In the Morton Arboretum study, roots of white oaks grew into the replaced soil from the perimeter, and grew to nearly twice the density of fine roots in the existing site soil after only 1 year. This shows that roots of this species, which is generally considered to be slow growing, can grow quite rapidly in a quality soil medium. This confirmed previ-

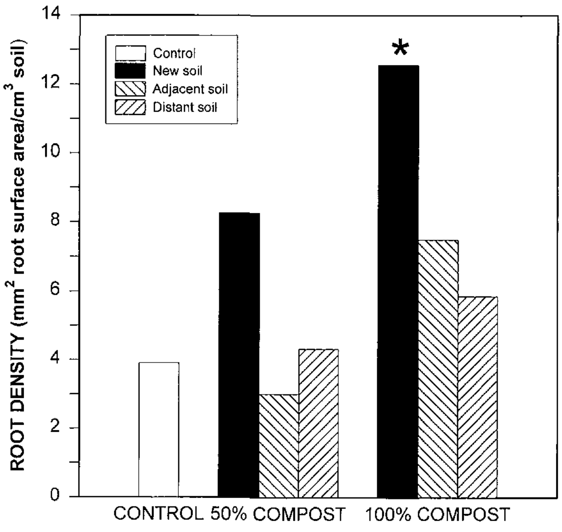

Figure 3. Root density 1 year after soil replacement treatment. Control locations were at least 6 ft (2 m) from the trenches. Adjacent and distant soil samples were within 2 inches (5 cm) and 12 inches (30 cm) from the trenches, respectively. An asterisk indicates that value was significantly higher than control at $p < 0.05$.

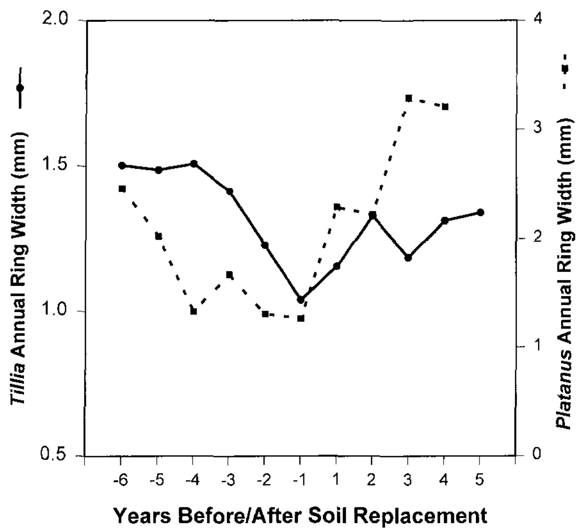

Figure 4. Trunk growth of trees before and after soil replacement treatment.

ous field observations by the authors. Root densities in the half-compost soil reached a maximum level in this first year, while roots in the all-compost replacement soil did not increase as rapidly in the first year, but continued to increase through the fourth year. Only in the fourth year was root development better in the all-compost than the in half-compost mix. Root density in the soils adjacent to the all-compost-filled trenches also showed improvement in the second and fourth years after the treatments were installed. Though the increases were not statistically significant, the trend is consistent and probably indicates that 100% compost replacement soil can have a greater effect on root development in adjacent soils. Why this could be true is unknown. Higher fertility from the 100% compost may be the most likely cause. High nitrogen can increase root growth (12), and the compost may have been rich enough in nitrogen and other nutrients to promote rapid growth in the replacement soil and adjacent soils. RADOSAN replacement soil also has a compost component and is also high in available nitrogen (0.73%).

The highly organic replacement soil in the trenches was excellent for root development, but decomposition of the organic matter will cause some settling over time. On sites where this would be a problem, a sandy mix, similar to Amsterdam Tree Soil, may work well (1).

When mechanical excavation is used for installation of the replaced soil, disturbance should be kept far enough away from the trunk to avoid major root damage and instability. In the Morton Arboretum study, in which trenches were kept at least 1 ft (30 cm) away from the trunk for every 3 inches (7.5 cm) dbh, very few large roots were severed in the excavation of the trenches. A greater distance would be even safer. In just 1 year, the trenches are filled with more roots than were present before the treatments were installed. This rapid root system recovery allows additional trenches to be installed between existing trenches every few years, until ultimately a large percentage of the soil in the root zone is replaced.

The data from the Swiss experiment also show an increase in depth of root development. Previous measurements of root development on trees treated with the RADOSAN process also showed a large increase in fine root mass (Linder and Keist, unpublished data). The hydraulic excavation equipment does not damage woody roots, and any damage to fine roots by the short exposure to air probably is overcome in a single season. Repeated treatments would also be possible with this process.

Any positive influence on soils and root development adjacent to areas of replaced soil will not occur as quickly as it does in soils immediately under a surface mulch layer, but considering this potential for increased root development in soils adjacent to the soil replacement treatments, the optimum soil replacement pattern would have a large interface surface area with the site soil relative to the volume of soil replaced. Instead of a few large concentrated areas of replacement soils, numerous smaller volumes (similar to the 4 inch [10 cm] diameter RADOSAN holes) would provide a reasonable amount of new soil and the greatest potential for improvement of the site soil because of the large interface with the soil. Numerous holes of this size could not be accomplished with a soil auger without risk of serious root injury.

Before soil replacement treatment, the *Tilia* and *Platanus* trees were declining. Annual growth increments were becoming smaller, and typical decline symptoms were apparent in the crown. Partial soil replacement increased root development and stimulated top growth, and the healthy appearance returned.

The soil replacement procedure is flexible enough to use on any site. Many kinds of equipment can be used and soil can be replaced in a variety of patterns around the tree. However, care must be taken to avoid damage to the large woody roots. Hand excavation can be used where site access is restricted and on sites where the soil within 10 feet (somewhat less for small trees) of the base of the tree is to be removed. A small trencher can be used to excavate a radial spoke pattern on medium-sized sites. For large trees on large sites, a backhoe can be used. The hydraulic excavation used in RADOSAN is ideal for any size of site, as long as the soil does not have too high of a clay content (> 27% clay).

Soil replacement has potential as another useful tool for arborists, but is not necessarily the first choice for treating declining trees. Establishing a layer of organic mulch on the soil surface, at least to the dripline, will probably be more effective and faster acting, though response times will still be measured in years. Maintaining proper and even soil moisture though both wet and dry periods will undoubtedly help to stabilize the trees more immediately. Fertilizers should be applied only if testing indicates a nutrient deficiency.

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The Morton Arboretum
Lisle, IL 60532

Résumé. Les sols des arbres en milieu urbain peuvent subir des changements avec le temps qui diminuent leur capacité à soutenir une croissance vigoureuse des racines. L'épandage de paillis sur la surface est une mesure efficace pour en améliorer les conditions mais n'est pas toujours possible. D'autres stratégies d'améliorations des sols, tels l'ameublissement, l'amendement et l'incorporation verticale de paillis, peuvent être destructrices de racines ou très exigeantes en main-d' uvre. Le remplacement stratégique de sol autour d'arbres déjà établis peut être réalisé avec un minimum de dommages au système racinaire et des résultats probants en regard de l'amélioration du développement des racines et de la cime.

Zussammenfassung. Die Böden im Wurzelbereich von Stadtbäumen unterliegen mit der Zeit Veränderungen, die ihre Fähigkeit, gesundes Wurzelwachstum zu unterstützen, reduzieren. Oberflächiges Mulchen kann diese Bedingungen effektiv verbessern, aber es wird nicht überall akzeptiert. Andere effektive Maßnahmen zur Bodenvergesserung, wie Bodenbearbeitung, Einarbeiten von bodenverbessernden Zusätzen und vertikales Abmulchen, sind entweder zu arbeitsintensiv oder sie zerstören die Wurzeln. Strategischer Bodenaustausch um die vorhandenen Bäume kann mit einem minimalen Wurzelschaden durchgeführt werden und führt zu einer Verbesserung der Wurzelentwicklung und des Baumwachstums.