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Root Growth of Accolade™ Elm in Structural Soil Under Porous and Nonporous Asphalt After Twelve Years

By Nina Bassuk, Gary Raffel, and Miles Schwartz Sax

Abstract. Accolade™ Elm trees were planted in CU Structural Soil® overlaid with porous or nonporous asphalt in 2005. At three separate points (2012, 2015, and 2016) over the last twelve years, root densities were measured with Ground Penetrating Radar to a depth of 30 inches (76.2 cm) beneath the asphalt. Roots under the porous asphalt were more numerous and tended to grow deeper in the structural soil profile. Shoot growth was reduced in trees that grew under the nonporous asphalt beginning in the eighth year after planting. CU Structural Soil® is a viable medium for tree growth and stormwater capture when paved with porous asphalt.

Keywords. Ground Penetrating Radar; Porous Asphalt; Root Growth; Shoot Growth; Structural Soil; Urban Trees.

INTRODUCTION

In the conterminous United States, there are approximately 40,000 square miles (103,500 km^2) of impervious surface, with 300 square miles (777 km^2) added each year due to wide-scale development and urbanization (Xian et al. 2011). Increases in nonporous surfaces such as roads, parking lots, roofs, and sidewalks cause a corresponding increase in stormwater runoff (Shuster et al. 2005). The effects of stormwater runoff may include hydrocarbon and bacterial pollution, pesticide and chloride contamination, excess nutrient loads, stream bank erosion, sedimentation, and terrestrial trash collecting in aquatic systems (NYS Stormwater Design Manual 2010). Stormwater concerns are receiving an increasing amount of attention from the general public, and there is currently growing interest in storing and infiltrating stormwater on site (US EPA 2017). Traditionally, solutions to this problem involved retention and detention ponds and the use of bioswales. However, these solutions require a dedicated space, which is rarely available in densely developed urban areas. Another method for storing and infiltrating stormwater on site involves using porous paving with a gravel base course that has enough void space to serve as a reservoir for captured rainwater.

Traditional porous pavement technology approaches the problem only from a water quantity standpoint and usually calls for the use of uniformly sized stones in the reservoir underneath the pavement. As an alternative, CU-Structural Soil® can also be used as a base for porous pavements. Such a system has two major benefits. The first is that CU-Structural Soil® is a mix of narrowly graded (1.0 to 3.0 cm) crushed gravel blended with a clay loam (80% gravel: 20% soil ratio measured by dry weight) and a small amount of a poly-acrylamide hydrogel tackifier that can be compacted to create a load-bearing base for pavement while simultaneously providing a growing medium for adjacent trees (Grabosky and Bassuk 1996). Secondly, CU-Structural Soil® is engineered to support tree growth, resulting in better stormwater abatement since trees slow runoff through canopy interception and take up water with their roots (Armson et al. 2013).

CU-Structural Soil® is a viable growing medium that can be used to support tree growth underneath pavement, in break-out zones, and has a twenty-year track record of installation across North America (Grabosky et al. 2001; Grabosky and Bassuk 2017). Given its high porosity, water infiltration is very rapid through porous pavement and structural soil. Twenty-four inches (61 cm) of CU-Structural Soil® has the capacity to capture 6 inches (15.24 cm) of rainfall in 24 hours. Combined with porous pavement, CU-Structural Soil® can provide a reservoir for stormwater capture under pavement (Table 1)(Grabosky et al. 2009).

Table 1. Reservoir depths and the corresponding levels of mitigated rain events over 24 hours based on the 26% void space within CU-Structural Soil® mix.

Size of rain event		Depth of CU-Structural Soil® reservoir needed to mitigate rain event	
inches	**cm**	**inches**	**cm**
1.56	3.96	6	15.24
3.12	7.92	12	30.48
4.68	11.89	18	45.72
6.25	15.87	24	60.96
7.8	19.81	30	76.2
9.36	23.77	36	91.44

The objective of this research was to measure the shoot and root growth of trees planted in structural soil under porous and nonporous asphalt over the course of a twelve-year time period.

When using CU-Structural Soil® and porous asphalt, there are a few things that are important to keep in mind:

- Porous asphalt has mix specifications that are individually designed for specific projects. All porous asphalt instillations must accommodate rapid water infiltration and be deep enough to provide structural stability (Ferguson 2005).
- The depth of the CU-Structural Soil® reservoir underneath the porous asphalt is designed and scaled to mitigate precipitation events of a specific size (Table 1).
- Infiltration rates for ground water recharge vary greatly and depend on the type of soil underneath the CU-Structural Soil® reservoir. Because of this, it is necessary to perform a soil test to find out the soil type and its drainage characteristics underneath the reservoir.
- Conventional stormwater drainage may be required by regulation. If this is the case, French drains or a traditional PVC drainage system may be installed below the structural soil layer to ensure that water does not back up through the pavement profile.
- Porous asphalt needs maintenance. It should never be sealed. To keep porous asphalt porous, it should be vacuumed once every two years to remove silt and dirt particles. While this is a best practice, it rarely occurs.
- Proper sediment control measures such as silt fencing should be used during construction to keep surrounding sediment off of the porous asphalt. If not, pores in the asphalt may clog and become less effective.
- Tree planting areas should not have raised curbs in the design, as this prevents surface water from flowing into the soil.
- The asphalt should be cut for the tree pits in the later stages of construction. Trees and other landscape elements should be planted last to ensure there is no damage to them during construction.

MATERIALS AND METHODS

In 2005, a 12-car parking lot was designed and constructed in partnership with the Department of Public Works for the City of Ithaca, NY, U.S.A. This new 150 ft × 18 ft (45.72 m × 5.49 m) parking lot was divided in half, with the southern half of the lot paved with a 3-in (7.62-cm) porous asphalt surface, while the northern half used a 3-in (7.62-cm) layer of medium-duty traditional impervious asphalt surface (Figure 1). Prior to paving, the entire lot was excavated to a depth of 2 feet (0.61 m) and CU-Structural Soil® (structural soil) was added and compacted to 95% proctor density in 6-in (15.24-cm) lifts (Proctor 1933). This was used as the new growing medium for the entire lot. There was no additional gravel base course placed over the structural soil since it was designed to act like a base.

In the middle of each pavement profile type (porous or nonporous asphalt), 3-ft (0.914-m) wide tree pits were cut, running the entire 18-ft (5.49-m) width of the lot to the shoulder of the adjacent roadway. Within each tree pit, two bare-root 1.5-in (3.81-cm) caliper Accolade™ Elms (*Ulmus davidiana var. japonica* 'Morton,' ACCOLADE™ Elm) were installed (Figure 2). Eight other Accolade™ Elms of the same size were planted within a 2-ft (0.46-m) adjacency surrounding the parking lot with four of these adjacent to the porous asphalt profile and four of these adjacent to the traditional asphalt profile (Figure 3). Due to the constraints of installing these contrasting pavement

Figure 1. Interface between the nonporous (left) and porous (right) pavement in the parking lot instillation.

Figure 2. Parking lot design showing Accolade™ Elms planted in asphalt cutouts four years after installation. Trees are growing in a CU-Structural Soil® base with either nonporous or porous pavement on top.

treatments within a municipal urban site, a randomized design was not possible for this study. The trees received no irrigation after establishment. Bark mulch was applied annually in the spring of each year. The City of Ithaca averages 37.3 inches (94.74 cm) of rainfall yearly with approximately 3 inches (7.62 cm) of precipitation falling every month. The yearly temperature ranges from 15.4° F to 79.9° F (-9.22° C to 26.61° C) with an average of 46.65° F (8.14° C)(US Climate Data 2018). In this climate, trees are generally not irrigated other than during their first year of establishment.

In 2012, 2015, and 2016, root growth of the trees under porous and nonporous asphalt was measured using Ground Penetrating Radar (GPR)(Mucciardi 2018). Previously, the authors examined the accuracy of using GPR for locating trees' roots under pavement. In that study they discovered through ground truth assessment that the GPR method accurately predicted roots equal to or greater than 1 cm in diameter (Bassuk et al. 2011).

Twelve GPR scans were performed on the set of two trees growing under porous and nonporous asphalt. Each scan covered 24 inches (60.96 cm) wide × 18 feet (5.49 m) long × 30 inches (76.2 cm) deep. Root density was measured at three depth layers, 0 to 8 inches (0 to 20.32 cm), 8 to 16 inches (20.32 to 40.62 cm), and 16 to 30 inches (40.62 to 76.2 cm), and expressed as roots per linear foot. Shoot length of three terminal shoots in full sun in the upper half of the tree crown at the edge of the canopy were measured in September between 2012 and 2018 in trees growing under porous and nonporous asphalt.

Statistics

Roots in the 12 scans adjacent to the trees growing in porous and nonporous asphalt were analyzed as well as shoot growth**.** Measurements were analyzed using JMP Pro v.14 statistical software. Comparison of shoot length by year and root density by treatment and depth were conducted using a two-way ANOVA with a 0.05 alpha level for statistical significance. Tukey-HSD test was used for post-hoc comparison of mean values and to determine matching letters. Matching letters indicate differences between treatments (porous vs. nonporous) and soil depth categories within individual years.

RESULTS

Shoot growth for Accolade™ Elms was equal under porous or nonporous asphalt until 2013, at which time growth of trees in nonporous pavement began to slow down. During 2012 to 2018, shoot growth for trees in porous asphalt was equal between years, while shoot growth for trees in nonporous asphalt declined (Figure 4; Table 2). Root density during year 2012 was nearly equal under porous and nonporous pavement except for roots in the deepest layer of structural soil (16 to 30 in) which grew deeper and showed a density 70% greater than roots under nonporous pavement (Figure 5). In 2015 and 2016, roots were consistently more numerous under porous asphalt than those under nonporous asphalt, especially in the middle and deep layers of the profile (8 to 16 in and 16 to 30 in respectively), showing about 50% greater root density on the 8 to 16 inch profile and 70% greater root density in the lowest profile (Figure 5). For all three years (2012, 2015, 2016) that root density measurements were taken, statistically significant differences were observed for pavement (A. porous vs. nonporous), sampling depth (B. 0 to 8 in, 8 to 16 in, 16 to 30 in), and their interaction (A × B) below a 0.05 alpha

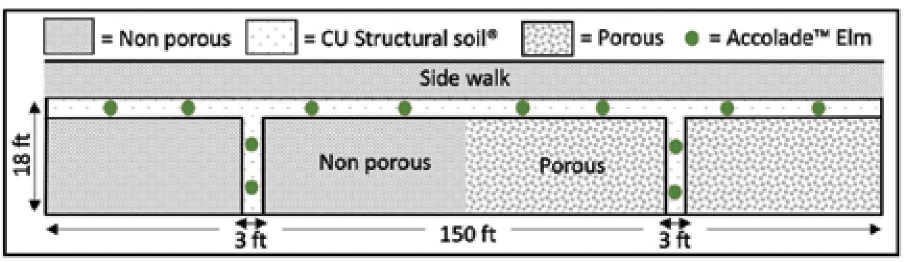

Figure 3. Diagram of the parking lot design showing nonporous and porous pavement over CU-Structural Soil®. Structural soil functioned as a base for pavement and as a planting substrate for Accolade™ Elms. Elms were planted directly into structural soil in pavement cutouts and mulched in after installation.

Table 2. Two-way ANOVA showing effect of year, paving treatment (porous vs. nonporous), and their interaction (A × B) on shoot growth of Accolade™ Elms in Figure 4.

Effect test	Prob > *F*
Year (A)	0.8191
Treatment (B)	< 0.0001
A × B	0.0787

level threshold. This indicated that within each year, pavement type, depth, and their interaction all significantly affected root density.

DISCUSSION AND CONCLUSION

The use of GPR to measure roots underground and beneath pavement has become more accurate as the method has developed (Bassuk et al. 2011). Although the use of GPR to locate utilities and archeological artifacts is not new, its use to locate roots is a relatively recent application of the technology. The GPR system interprets and analyzes roots as narrow tubes of water in the soil profile. The urban soil profile can be very heterogeneous, with buried rubble and urban fill making it difficult to locate roots. Despite these challenges, GPR has been validated and proven to accurately locate roots growing in structural soil and agricultural field soil (Bassuk et al. 2011). That study provided statistically accurate predictions of roots of 1 cm or greater in diameter in these two homogeneous soils.

The great advantage of using GPR is its ability to measure roots nondestructively and iteratively over time. In this study, root growth was measured in structural soil during the summers of 2012, 2015, and 2016, six, nine, and ten years after tree planting. It is clear that root growth changed during each growing season, presumably through the natural processes of root turnover. Root density (roots per linear foot) was significantly greater at lower depths under porous pavement compared to nonporous pavement (Figure 5). The highly porous nature of structural soil captured the precipitation coming though the porous asphalt deeper into the soil profile where roots could access it. This contrasts with the findings of Morgenroth (2010) where root growth was found to be close to the surface of the pavement, which is probably due to the fact that soil underlying the pavement was a fine sandy loam with less macroporosity than structural soil when compacted. He found that roots could take advantage of the deeper soil under porous asphalt as long as the soil was not compacted. Even though CU-Structural Soil® was compacted, its lattice-like structure provided ample macropores and space for root growth.

Terminal shoot length began to decline after the sixth year of trees growing under nonporous asphalt compared to those growing under porous asphalt (Figure 4). Although

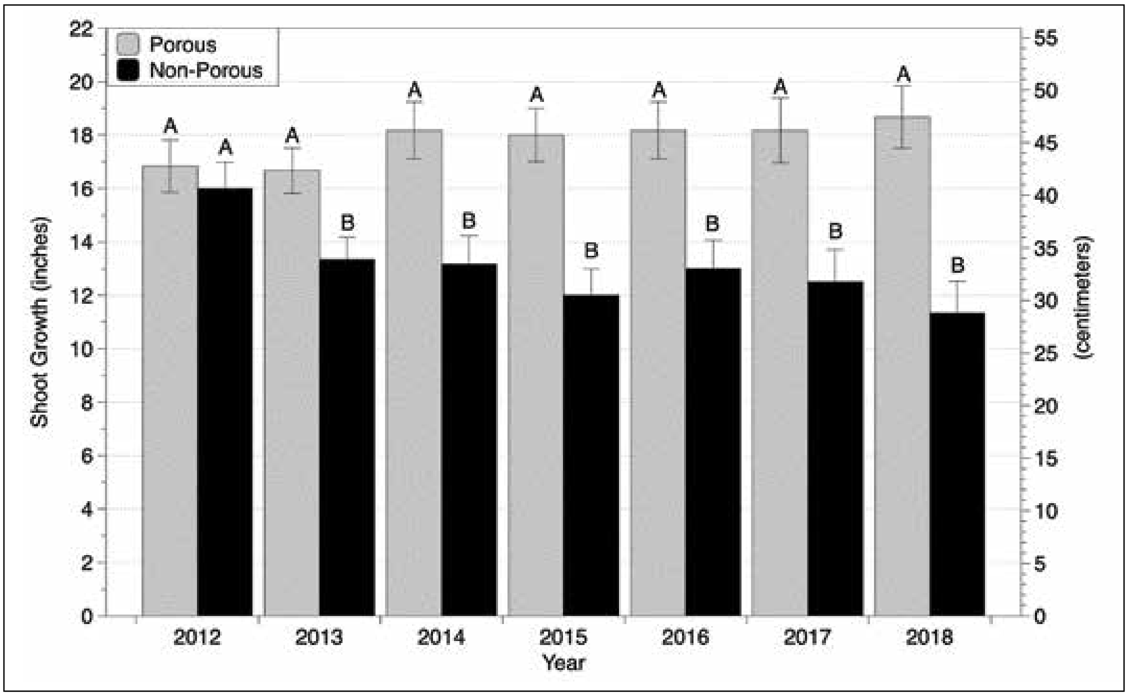

Figure 4. Yearly shoot growth (inches) of Accolade™ Elms grown in porous and nonporous paving between 2012 and 2018 (*n* = 6 per treatment). Matching letters indicate difference by treatment (porous vs. nonporous) for individual years.

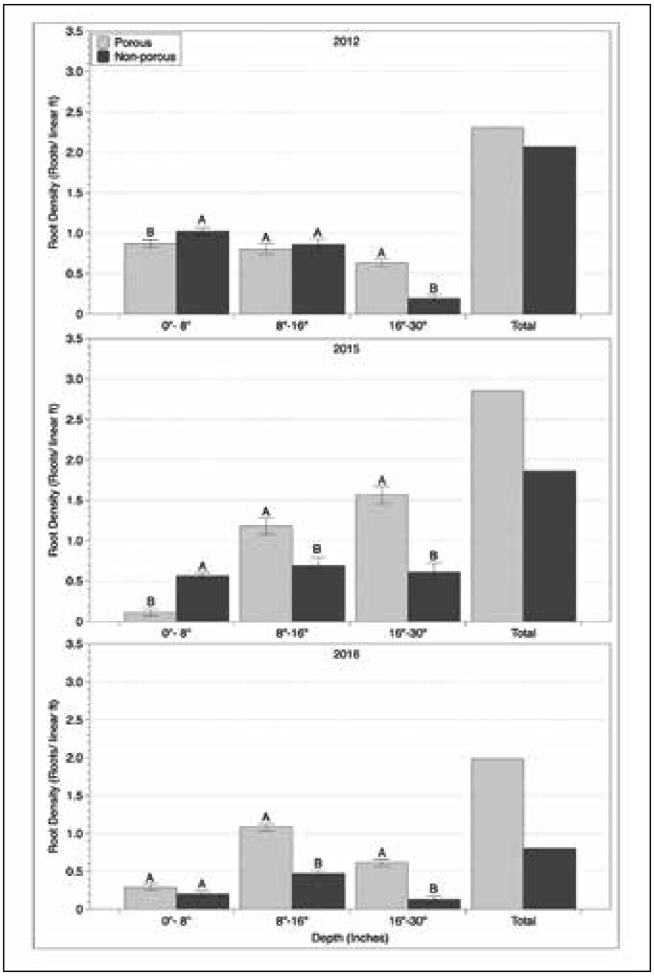

Figure 5. Root density per linear foot of Accolade™ Elm (*Ulmus davidiana var. japonica* 'Morton') at three depths in porous and nonporous pavement in 2012, 2015, and 2016. Matching letters indicate difference by treatment (porous vs. nonporous) for each depth category.

it was not possible to measure soil moisture under the two pavements, root growth density per linear foot was greater in trees under porous asphalt, likely allowing for greater water uptake and shoot growth. It is possible that, had the opening around the trees in nonporous asphalt been greater, adequate water might have been available. Both growing media were identical in this study, with similar available water-holding capacity ranges suggesting that the quantity of water entering the system was the likely limiting factor.

This study offers meaningful insights into how Accolade™ Elms respond to growing under varying pavement types in an authentic urban environment. While the technical replicates per treatment in this study (*n* = 2) were relatively low, the results show clear differences by pavement treatments.

In this installation, roots were more numerous for trees grown under porous asphalt than under nonporous asphalt at certain depths. Greater root density and shoot growth were found for trees in porous asphalt. Future studies including more replicates, a randomized design, and a greater diversity of tree species will be helpful in adding to this body of knowledge. For practitioners, it is essential that when trees are planted in conventional, nonporous pavement openings, adequate access to precipitation must be designed into the system if irrigation is not used.

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Nina Bassuk
Horticulture Section
School of Integrative Plant Science
Cornell University
Ithaca, NY, U.S.A.
nlb2@cornell.edu

Gary Raffel
Dynamic Tree Systems
Bloomfield, NY, U.S.A.
dynamictreesystems@gmail.com

Miles Schwartz Sax (corresponding author)
Horticulture Section
School of Integrative Plant Science
Cornell University
Ithaca, NY, U.S.A.
ms2785@cornell.edu

Résumé. En 2005, des ormes Accolade™ furent plantés dans du sol CU-Structural Soil® recouvert par la suite avec de l'asphalte poreuse pour certains et non-poreuse pour d'autres. À trois moments distincts au cours des douze dernières années (2012, 2015, et 2016), la densité des racines fut mesurée avec un géoradar jusqu'à une profondeur de 30 pouces (76.2 cm) sous l'asphalte. Les racines situées sous l'asphalte poreuse furent plus nombreuses et avaient tendance à croître plus profondément dans le profil du sol structurel. À partir de la huitième année suivant la plantation, la croissance des pousses était moindre chez les arbres plantés sous l'asphalte non-poreuse. Le sol structurel CU-Structural Soil® est un substrat viable pour la croissance des arbres et la collecte des eaux pluviales lorsqu'il est recouvert avec de l'asphalte poreuse.

Zusammenfassung. In 2005 wurden Accolade™ Ulmen in CU-Structural Soil®, bedeckt mit porösem oder nicht-porösem Asphalt, gepflanzt. An drei verschiedenen Punkten (2012, 2015, und 2016) über die letzten zwölf Jahre wurde die Wurzeldichte mit einem Bodenradar bis zu einer Tiefe von 72.6 cm unter dem Asphalt gemessen. Die Anzahl der Wurzeln unter dem porösen Asphalt waren höher und tendierten zu tieferem Wachstum in das Srtrukturierte Bodenprofil. Bei Bäumen, die unter nicht-porösem Asphalt wuchsen, war das Triebwachstum ab dem ersten Jahr nach der Pflanzung reduziert. CU-Structural Soil® ist ein geeignetes Medium für Baumwachstum und Regenwasserspeicherung, wenn poröser Asphalt verwendet wird.

Resumen. En 2005 se plantaron olmos Accolade™ en CU-Structural Soil® sobrepuesto con asfalto poroso o no poroso. En tres puntos separados (2012, 2015, y 2016) durante los últimos doce años, se midieron las densidades de las raíces con el radar de penetración terrestre para una profundidad de 30 pulgadas (76.2 cm) debajo del asfalto. Las raíces debajo del asfalto poroso eran más numerosas y tendían a crecer más en el perfil estructural del suelo. El crecimiento de brotes se redujo en los árboles que crecieron bajo el asfalto no poroso a partir del octavo año después de la plantación. CU-Structural Soil® es un medio viable para el crecimiento de los árboles y la captura de aguas pluviales cuando está pavimentado con asfalto poroso.