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Seventeen years' growth of street trees in structural soil compared with a tree lawn in New York City

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ABSTRACT

In 1997, *Quercus bicolor* and *Quercus phellos* in a New York City streetscape were planted in CU-Structural Soil under a concrete sidewalk and in a tree lawn with the intention of observing long term plant response as a comparative study of an early installation of the new designed soil method. The trees have been measured nine times since the second year post-installation. We present the growth of trunk diameter, height and slenderness ratios. To verify root colonization in the structural soil under the sidewalk, tree root presence was measured using ground-penetrating radar in 2009, year 12. In the 17th year, trees in the sidewalk were similar in size with a higher level of survivorship as compared to the trees in the tree lawn. Adjusting for year of replacement in the tree lawn, model predictions for diameter of trees 15 years post-installation were no different for *Q. bicolor* in either the sidewalk (21.38 cm) or the tree lawn (22.05 cm). *Q. phellos* in the tree lawn were predicted to be slightly larger, 34.29 cm versus 31.34 cm in the sidewalk. Roots had colonized the structural soil under the sidewalk to 60 cm, its full depth. This provided evidence that the structural soil medium served as an acceptable rooting environment.

1. Introduction

Developing a strategy to address long-term tree growth in various site and soil systems qualifies as a major challenge confronting practitioners in urban vegetation management. Canopy size expectations can be developed from nursery catalogs, botanic texts, tree selection software, experiential estimates or allometric model estimations. Unfortunately, such observations and expectations normally assume a park-like or relatively good site for the tree species' needs, which does not reflect the field situation in most urban tree installations. While guidance is available, there is limited published data taken directly from urban trees with reference to specific planting limitations common in urban design from which to evaluate or manage urban tree growth expectations (McPherson and Peper, 2012; Quigley, 2004; Grabosky and Gilman, 2004; Sanders and Grabosky, 2014; Lindsey and Bassuk, 1991).

Developing tree growth expectations in balance with resources provided by the soil in a city streetscape underpins any discussion of environmental services expected by the urban canopy. Streetscapes present competing needs between tree roots, pavement support, telecommunications and lighting infrastructure, signage and visual sight lines. Chief amongst these competitors is pavement support from the soil profile held in common with the expected street tree root zone.

To integrate the support needs for pavement and the biotic needs of trees for a healthy urban canopy, designed soil systems have been developed and in many cases established as a design response (Kristofferson, 1998; Bartens et al., 2008; Couenberg, 1994; Arnold, 1993). A chief limiting factor in the adoption of any new tree management technology is the time needed to observe tree growth over an entire design life cycle. To wait for a whole life cycle (spanning decades) is not at all efficient. For hard infrastructure, engineering testing and accelerated aging tests can support risk analyses with new materials or technologies prior to broad integration into use. Urban tree response to new technology presents a challenge in that many years are needed to evaluate tree growth to an envisioned design size. There is a need to track tree response to new design methods which require long-term observation.

We report on a long-term study initiated in 1997 after installation of the project site to compare a designed soil system (CU-Soil or CU-Structural Soil) and a grass-tree lawn with two oak species, *Quercus bicolor* Willd. and *Quercus phellos* L. The designed soil was based on a compactable aggregate skeleton supporting a horticulturally viable interstitial soil component between the compacted aggregates (CU Soil). Early survivorship and early growth

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responses are reported elsewhere (Grabosky et al., 2002; Grabosky and Bassuk, 2008). Of course, as a working landscape, and with a sidewalk installed over the streetscape treatment, it is currently infeasible to argue for excavation and testing of the root zone below the pavement. Additionally, since the paved section covers a designed soil to provide root colonization, there has been on-going interest in verifying root colonization under the pavement rather than escape, to and exclusive colonization of, adjacent soils, given the pavement is bordered by a wall (with footing) then a park soil system supporting a planted landscape.

2. Methods

2.1. Site location and description

The study site was a sidewalk and tree lawn near McCarren Park, located in Brooklyn, NY on Lorimer Street which runs North–South between Driggs and Bayard Streets (40°43′12.85″ N, 73°57′01.27″ W). On the west side of the street, a 0.9 m deep, 2.1 m wide continuous trench of CU-Soil supported a concrete sidewalk along the entire length of the block. The mix design for this particular system was a gravimetric percentage of 80% granitic crushed stone (1.9 cm nominal size), 20% soil with a hydrogel binder (0.025%). The soil used in the stone-soil mixture was a Bridgehampton Loam, 48-19-33 Sand Silt Clay respectively, pH 4.5, organic matter 5.3%. The materials were specified to be compacted to a minimum of 95% AASHTO T-99 peak density. Based on previous studies, our expectation for installed density would range from 1.9–2.1 Mg m^{-3}, with a total porosity estimate of 21–28% v/v and 7% plant available water holding capacity (Grabosky et al., 1998; Grabosky et al., 2009). Trees were installed into 0.9 by 1.5 m openings on the park-side edge of the sidewalk, covered by 10 cm square granite block unit pavers on 8.3 m tree-to-tree spacing. Since the test profile is a working landscape covered in concrete, no recent testing has been conducted after installation acceptance since it would involve coring through the concrete and other associated logistics. The street side of the sidewalk was bordered by a standard poured concrete curb (Fig. 1). The park side of the sidewalk was bordered by a 15 cm masonry wall with a 30–45 cm deep foundation that supported an ironwork fence. The wall defined the back edge of the tree planting openings. The sidewalk width was 2.7 m wide, greater than the trench, which extended from the park side of the sidewalk toward the street.

The East side of the street was a tree-grass lawn vegetation zone (6 m minimum width) with trees placed at least 1.8 m from the sidewalk. Soil for the tree lawn was established at grade, in an

Fig. 1. A Google Earth Street View image of the study site looking north. The sidewalk is on the left side of the image, showing the low wall, fence and benches in the background. The tree lawn is on the right side on the image.

established section of the city. The pre-existing soil was categorized as Laguardia Urban Land Complex (Loamy-skeletal, mixed, superactive, non-acid, mesic Typic Udorthent; Soil Survey Staff, 2015). Soils tests in 2015 taken from the tree lawn confirmed a sandy-loam texture soil with gravel (9–16% grav.) throughout the soil profile. Soil pH ranged from 6.83 to 6.96 and EC ranged from 0.08 to 0.10 mmho/cm throughout the depth of sampling. No deficiencies were reported in any layers, however Potassium (Mehlich 3 extraction) was considered below optimum in the subsoil layer below the rooting colonization zone at 97.5 kg/ha. Organic levels were considered a bit higher than expected at 6% in the rooting zone and 2.8% in the subsoil layer below the root colonization zone (data not shown).

Three tree species, *Q. phellos*, *Q. bicolor* and *Koelreuteria paniculata* Laxm. were planted in a mixed order along the length of the street in 1997. Originally, 12 *Q. phellos* and 14 *Q. bicolor* were planted in the sidewalk. Similarly, 17 *Q. phellos* and 19 *Q. bicolor* were planted in the tree lawn. Data are not reported on *Koelreuteria* due to low replication (originally 9 in the sidewalk and 3 in the tree lawn).

2.2. Observations

Trees were measured 2, 3, 6, 10, 12, 14, 15, 16 and 17 years after installation (most often in late July and early August, with one observation in May and 2 in late June. For this study, only the 7 observations which recorded tree height (by Suunto Clinometer or LaserAce hypsometer) and trunk diameter at 4.5 foot elevation (DBH) by diameter tape are reported. Replacement trees which were installed due to original tree death/failure were added to the data set, adjusting their individual timelines to their replacement installation date. We have tracked growth and dimension to infer bulk tree condition as a less costly comparative method until such time as a visual deficiency or bulk size difference suggested the value in more detailed, and costly, tissue/soil nutrient or leaf physiological response studies.

To better understand whether roots in the sidewalk trees colonized under the pavement or simply escaped below the park wall into the soils in the park, the roots in the designed soil under the sidewalk were mapped using a ground penetrating radar (GPR) calibrated to the designed aggregate-soil system in 2009, the 12th year after planting (Bassuk et al., 2011). Using a single 900 Mhz antenna GPR system, root signals were mapped along three transects running parallel to the street at 0.31, 1.1 and 1.7 m from the trunks of the trees to the sidewalk curb. Transects on the park-side of the boundary wall were not developed due to benches and planting beds against the boundary wall which included numerous trees and shrubs preventing GPR sampling. The 296 m transects were developed from joining 27 radar plot files per transect and then splitting the full length into ten uniform length segments. Root signal occurrences were developed for three depth ranges (0–21 cm, 21–42 cm, 42–63 cm) represented as root signal count per 29.6 m sidewalk length. To describe observed clustering of root signals in the 42–63 cm depth range within 0.31 m of the trunk, a third approach to demonstrate clustering by proximity to the root ball was developed. Signals within 2 m of the tree trunk center were compared to the total count in transect length at that specific depth. The root distribution in all other sections was uniform across the transect lengths at their specific depths. The GPR analysis was developed to map root colonization density by signal density and cannot discern specific root diameter classes or directionality by linking transects. Since we cannot know the specific tree origins for each root, the density of root signal occurrence is independent of specific trees and thus unfit for a species level analysis. Roots in the tree lawn were not mapped due to issues in a multiple-line tree placement, multiple other small trees inter-planted on the site in