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Species Variation in Root Tolerance of Soil Compaction and Poor Drainage

By Angela Hewitt, Frank Balestri, Marvin Lo, and Gary Watson

Abstract. Loam-over-compacted-clay and loam soil profiles were created in 10 cm × 10 cm × 25 cm containers. Containers were placed in trays of water to simulate poor subsoil drainage in the landscape. Four urban tolerant species, *Acer negundo*, *Catalpa speciosa*, *Gleditsia triacanthos*, *Ulmus americana*, and two less tolerant species, *Quercus rubra* and *Acer saccharum*, were direct seeded in the containers. Soil volumetric water content and oxygen diffusion rate were monitored. At the conclusion of the study, length of fine roots (< 2 mm diameter) was measured throughout the soil profile. Oxygen decreased and moisture increased with soil depth. Fine root density of all species decreased with depth except *Ulmus Americana*. *Catalpa speciosa* was the only species showing a difference in root growth between soil types throughout the profile and had up to seven times the root density of other species at the surface and up to four times at the bottom. Root growth of most species seemed to be reduced more by high soil moisture and reduced aeration than soil texture and compaction.

Keywords. Root Growth; Oxygen; Waterlogging.

INTRODUCTION

Urban soils can be very compacted, poorly drained, and challenging for tree roots. Conditions become less favorable for root growth with increasing depth (Craul 1992). The situation for tree root systems may be even more challenging when tap root pruning during nursery field propagation replaces the natural root flare with a deeper adventitious root flare at the end of the primary root that is pruned as a seedling (Hewitt and Watson 2009). Tolerance of species to difficult soil conditions varies. This contributes to their tolerance of poor soils on urban planting sites (Roloff et al. 2009). Greater knowledge of species ability to cope with difficult soil conditions is needed to determine how critical it is to position the adventitious root flare as shallowly as possible.

METHODS

Two soil profiles were created in 10 cm × 10 cm × 25 cm containers (Figure 1). Loam-over-compacted-clay profiles were created by adding clay in 100-ml lifts and compacted by dropping a 1.33 kg weight 16 times (four times at each edge); the corners were compacted with square wooden rods placed in the corners and hammered flat to a final height of 12.5 cm (+/- 0.5 cm). The upper half of the pot was loosely filled with sifted (2 mm screen) loam soil. The loam profiles were filled only with sifted loam soil.

Containers were placed in trays to hold water to simulate poor subsoil drainage in the landscape (10 pots per tray, 14 trays). Each tray had holes drilled 2.5 cm from the bottom to maintain a consistent water level. Containers were also watered from the top.

Four species considered to be urban tolerant, *Acer negundo*, *Catalpa speciosa*, *Gleditsia triacanthos*, *Ulmus americana*, and two less tolerant species, *Quercus rubra* and *Acer saccharum*, were direct seeded in the containers. There were ten containers with loam profiles and ten containers with loam-over-compacted-clay profiles for each species.

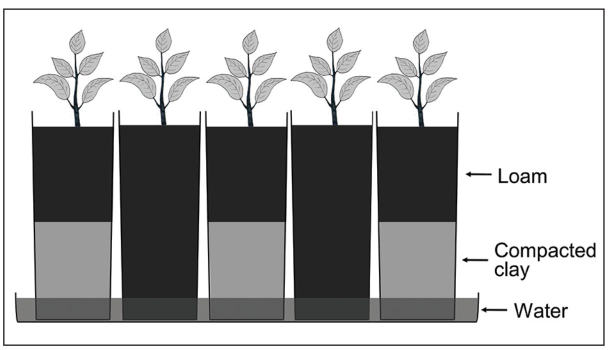

Figure 1. Containers with the two soil profiles were placed in trays of water to simulate the poor drainage common in urban soils.

An additional ten unplanted containers of each soil profile were used to monitor moisture levels and oxygen levels. Volumetric water content was measured through holes in the side of the container using a time domain reflectometer (TDR). Between measurements, holes were covered to prevent soil and moisture loss. In loam-over-compacted-clay profiles, measurements at 5 cm from the bottom were in clay, at 13 cm were just above the clay, and at 19 cm were in loam. Measurements taken in loam profiles were in the same positions.

Oxygen diffusion rate (ODR) was measured in the same ten unplanted containers of each soil profile. The ODR instrument is designed to average the measurements of ten probes taken at the same depth simultaneously, since conditions in the small pockets of soil around the 2 mm platinum needles can be so variable. It was not possible to get multiple sets of probes into each small container for measurements at different depths at the same time, so measurements were taken at 2.5 cm intervals as the probes were inserted progressively deeper. This could only be done once, and had to be done after the soil moisture measurements were complete, since it created holes for air and moisture to penetrate.

At the conclusion of the study, the soil and roots were removed from each container and divided into six equal parts from top to bottom. The soil was washed from the roots. Length of fine roots (< 2 mm diameter) was measured and converted to fine-root volume density with a WinRhizo system (Regent Instruments, Quebec, Canada).

One-way ANOVA ($P \leq 0.05$) with separation of means by the Tukey HSD method was used to compare soil moisture, soil oxygen, and fine-root density across soil depths. T-tests were used to compare fine root density between the two soil profiles at the same depth (JMP®, Version 14. SAS Institute Inc., Cary, NC, 1989-2017).

RESULTS AND DISCUSSION

Soil Conditions

The soil conditions created in the containers were similar to the compacted poorly drained soils that exist on many urban sites. Soil moisture was greater deeper in the container, as would be expected with them standing in water (Figure 2). Moisture increased consistently with soil depth in the loam profile. Moisture at the deepest position in the container was at, or near, the saturation point, where all pore spaces are filled with water. In the loam-over-compacted-clay profile, moisture was highest in the loam just above the compacted clay layer, also very near the saturation point, and likely due to poor infiltration into the compacted clay. The moisture level in the compacted clay was somewhat lower, but also at or near saturation, given the reduced pore space resulting from the compaction (Brady and Weil 1996).

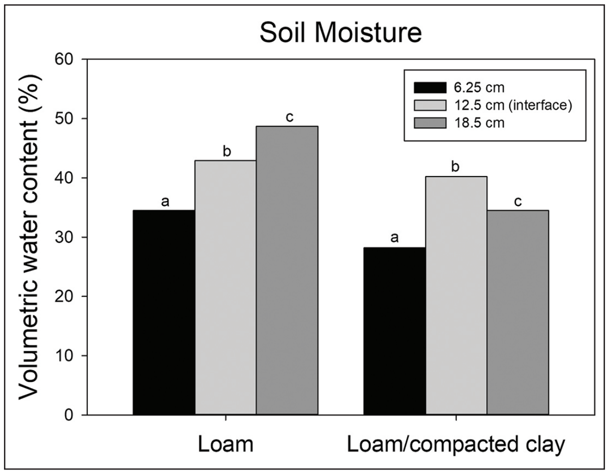

Figure 2. Soil moisture increased with depth and above the loam/compacted clay soil interface.

ODR decreased with soil depth and increasing moisture levels in both soil profiles, as would be expected with fewer air-filled pores (Figure 3). The only significant difference between the two soil profiles was higher ODR in the loam soil at 7.5 to 12.5 cm depth. The lower ODR in the loam-over-compacted-clay profile at this level may have been due to a perched water table over the loam/compacted clay interface.

Root Growth Response

Root growth generally decreased with soil depth (Figure 4). The increased moisture and reduced aeration conditions deeper in the container soil profiles are the factors most likely responsible. In the loam profile, there was a gradual reduction in root density with depth in *Acer negundo*, *Catalpa speciosa*, *Gledetsia triacanthos*, and *Quercus*

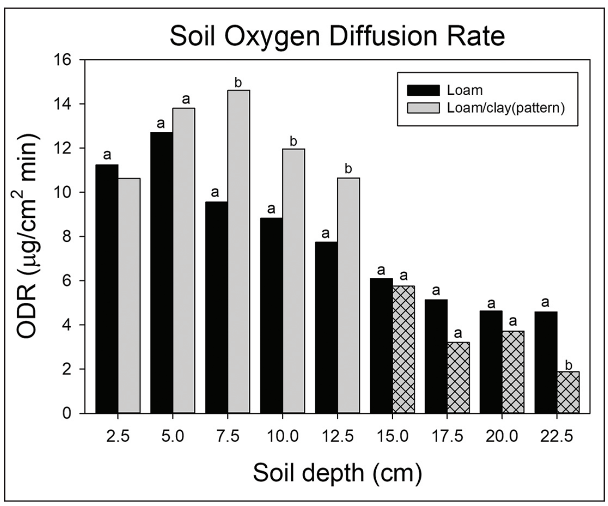

Figure 3. Oxygen in the soil atmosphere decreased with soil depth and increasing moisture levels.

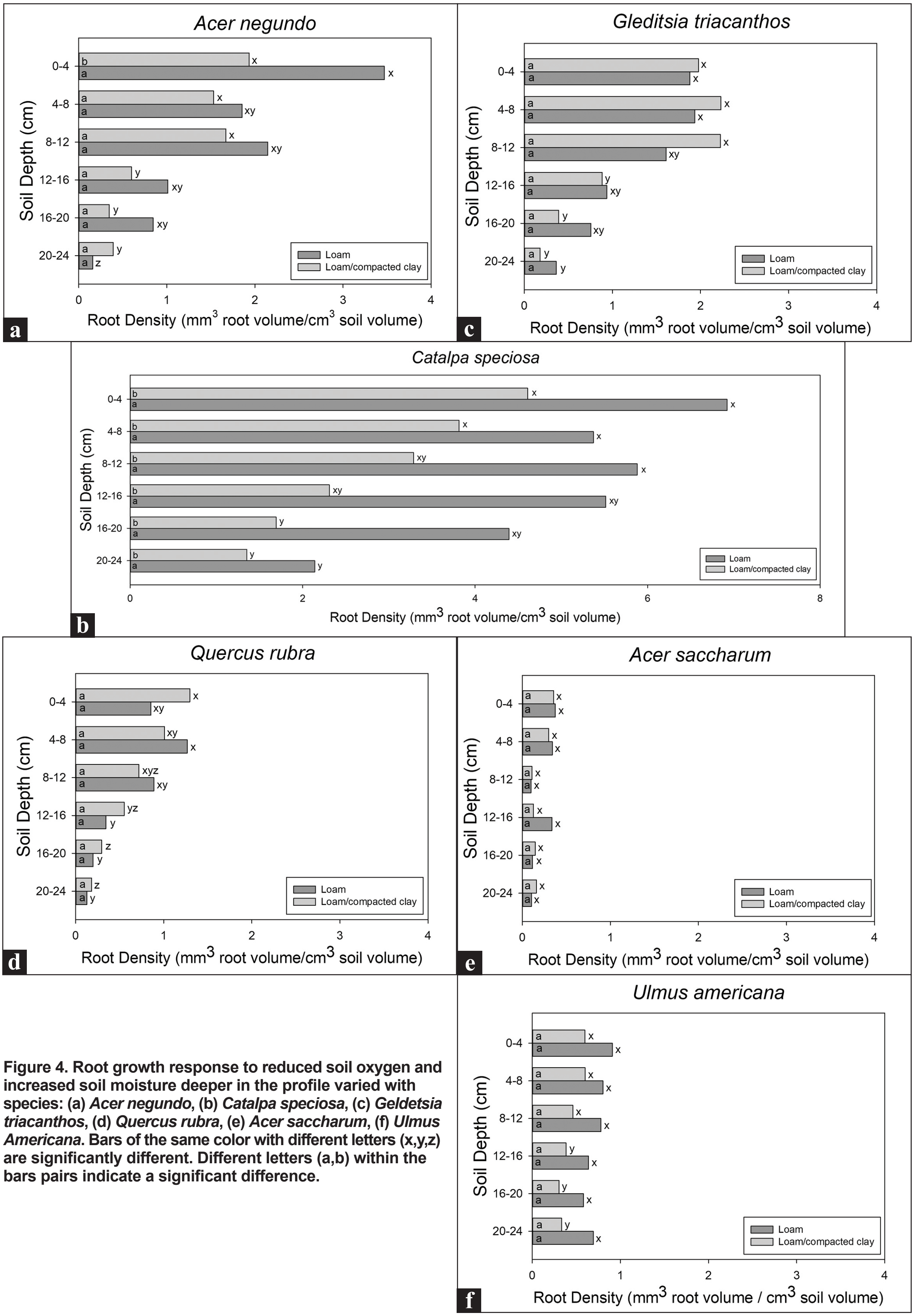

Figure 4. Root growth response to reduced soil oxygen and increased soil moisture deeper in the profile varied with species: (a) *Acer negundo*, (b) *Catalpa speciosa*, (c) *Geldetsia triacanthos*, (d) *Quercus rubra*, (e) *Acer saccharum*, (f) *Ulmus Americana*. Bars of the same color with different letters (x,y,z) are significantly different. Different letters (a,b) within the bars pairs indicate a significant difference.

rubra (Figure 4a-d). A similar trend was apparent in *Acer saccharum* (Figure 4e), but the very low level of root growth throughout the profile impeded the development of significant differences. Root growth of *Ulmus Americana* (Figure 4f) was consistent throughout the profile with no significant differences.

In the loam-over-compacted-clay profile, there was a gradual reduction in root density with depth in *Catalpa speciosa* (Figure 4b) and *Quercus rubra* (Figure 4d), and an abrupt reduction at the loam/clay interface in *Acer negundo* (Figure 4a) and *Gleditsia triacanthos* (Figure 4c). Root density did seem to decrease with depth in *Acer saccharum* (Figure 4e) as well, but again the very low level of root growth impeded the development of significant differences. *Ulmus americana* (Figure 4f) root density was consistent throughout the profile, similar to the loam soil.

Catalpa speciosa (Figure 4b) was the only species showing a difference in root growth between soil types throughout the profile. The other species showed no difference at any level, with the one exception of the uppermost layer of *Acer negundo* (Figure 4f).

Root growth seemed to be reduced more by high soil moisture and reduced aeration than soil texture and compaction. Seasonally high moisture levels have been associated with reduced root development throughout the year (Watson 2012). Day et al. (2000) found that the underlying mechanism of tolerance of some species to compacted soil was that their roots are able to grow under conditions of high soil moisture when soil strength is reduced.

Implications for Urban Tree Growth and Longevity

Three of the four urban soil tolerant species showed a significant reduction in root growth with increased depth and reduced aeration. Though generally considered "tough" species, they do still seem to be affected by challenging urban soil conditions. *Ulmus americana* showed no decrease and may be the most truly urban soil tolerant.

The very low densities of *Acer saccharum* roots may be a characteristic of the species, since growth in the upper well-drained layers of the loam soil was also low. Slower growth may explain this species difficulty in adapting to urban soils.

Catalpa speciosa had up to seven times the root density of other species at the surface and up to four times at the bottom. This species may be a good prospect for more frequent use in urban landscapes, despite concerns over fruit production.

With perhaps the exception of *Ulmus americana*, all of the species tested showed reduced root growth deeper in the soil profile and would likely be affected if the adventitious root flare was too deep. It supports pruning the seedling taproot no more than 10 cm deep when preparing them for replanting in liner production.

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Résumé. Deux profils de sols (loam sur argile compactée puis loam seul) furent créés dans des pots de culture de 10 cm × 10 cm × 25 cm. Ces pots furent placés dans des plateaux d'eau afin de simuler une situation de mauvais drainage souterrain. Quatre espèces tolérantes en milieu urbain (*Acer negundo*, *Catalpa speciosa*, *Gleditsia triacanthos et Ulmus americana*) et deux espèces moins tolérantes de ce milieu (*Quercus rubra* et *Acer saccharum)* furent directement semées dans les pots. Le contenu volumétrique du sol en eau et le taux de diffusion de l'oxygène furent contrôlés. À la fin de la recherche, la longueur des radicelles (diamètre < 2mm) fut mesurée partout dans les profils de sol. Avec la profondeur, le taux d'oxygène diminuait et l'humidité augmentait. La densité des radicelles de toutes les espèces s'amoindrissait avec la profondeur à l'exception de *Ulmus americana*. *Catalpa* *speciosa* fut la seule espèce montrant une différence dans la croissance des racines selon les deux types de sol et possédait jusqu'à sept fois la densité racinaire des autres espèces à la surface et jusqu'à quatre fois leur densité dans le fond des pots. La croissance des racines de la plupart des espèces semble être restreinte davantage par le taux élevé d'humidité du sol et l'aération moindre que par la texture et la compaction du sol.

Zusammenfassung. In 10 cm × 10 cm × 25 cm großen Pflanzcontainern wurden Bodenprofile mit Lehm über verdichtetem Ton mit Lehmanteilen hergestellt. Die Container wurden in Wasserschalen gesetzt, um eine schlechte Unterbodendrainage in der Landschaft zu simulieren. Vier urban tolerante Arten: *Acer negundo*, *Catalpa speciosa*, *Gleditsia triacanthos*, *Ulmus Americana* und zwei weniger tolerante Arten: *Quercus rubra* und *Acer saccharum* wurden direkt in diese Container gesät. Der Bodenvolumenanteil des Wassergehalts und die Sauerstoffaustauschrate wurden überwacht. Am Ende dieser Studie wurde die Länge der Feinwurzeln (< 2 mm diameter) im gesamten Bodenprofil gemessen. Mit der Bodentiefe sank der Sauerstoffanteil und die Feuchtigkeit stieg an. Die Dichte der Feinwurzeln nahm bei allen Arten mit der Tiefe ab, außer bei *Ulmus Americana*. *Catalpa speciosa* war die einzige Art, die Unterschiede im Wurzelwachstum in den verschiedenen Bodentypen innerhalb des Profils hatten sowie die siebenfache Wurzeldichte aller anderen Baumarten an der Oberfläche und vierfach soviel am Boden. Das Wurzelwachstum der meisten Arten schien bei höherer Bodenfeuchte und verminderter Belüftung sich mehr zu reduzieren als durch Bodentextur und Verdichtung.

Resumen. Se crearon perfiles de suelo franco y arcilla compactada en contenedores de 10 cm × 10 cm × 25 cm. Luego se colocaron en bandejas de agua para simular un drenaje deficiente del subsuelo en el paisaje. Cuatro especies tolerantes urbanas, *Acer negundo, Catalpa speciosa, Gleditsia triacanthos, Ulmus americana*, y dos especies menos tolerantes *Quercus rubra y Acer saccharum* fueron instaladas directamente en los contenedores. Se monitoreó el contenido de agua volumétrica del suelo y la tasa de difusión de oxígeno. Al finalizar el estudio, se midió la longitud de las raíces finas (< 2 mm de diámetro) en todo el perfil del suelo. El oxígeno disminuyó y la humedad aumentó con la profundidad del suelo. La densidad de raíces finas de todas las especies disminuyó con la profundidad, excepto *Ulmus Americana*. *Catalpa speciosa* fue la única especie que mostró una diferencia en el crecimiento de las raíces entre los tipos de suelo en todo el perfil y tenía hasta siete veces la densidad de la raíz de otras especies en la superficie y hasta cuatro veces en el fondo. El crecimiento de la raíz de la mayoría de las especies pareció reducirse más por la humedad alta y la aireación reducida que por la textura y compactación del suelo.