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# The impact of soil compaction on soil aeration and fine root density of *Quercus palustris*

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## Abstract

The soil around *Quercus palustris* trees, 30 cm (11.8 in) average diameter breast height (DBH) were treated by compaction (C) or C plus clay slurry (CS) treatments in November 1994 and repeated in May 1996. Soil oxygen diffusion rate (ODR), fine root density (FRD), DBH, twig growth, leaf area and dieback were monitored for 4 years beginning in 1996. Both compaction treatments significantly reduced ODR at 15 cm. Early each season, ODR was below the 0.20 g/cm$^2$/min threshold level reported to inhibit root growth in several species [Stolzy, L.H., Letey, J., 1964. Correlation of plant response to soil oxygen diffusion rates. Hilgardia 35, 567–576] for all treatments and depths. In summer each year, ODR was adequate in the shallow soils of all treatments, though often still significantly lower in compacted soils. At 30 cm, there were no consistent differences in ODR between compacted and uncompacted soil. Significant differences in FRD due to compaction treatments were inconsistent and limited to the upper 9 cm of soil in years 2 and 3. Reduced FRD in compacted soils may be a response to the reduced ODR in spring. There were no differences in DBH, twig growth, leaf area or dieback rating. Given the minimal difference in root growth, the lack of differences in top growth are understandable. This controlled study, and others preceding it, have failed to clearly show the underlying causes of tree decline and death commonly associated with soil compaction and addition of fill soil in real landscapes.


***Keywords:*** Oxygen diffusion rate; Bulk density; Root growth

## Introduction

Soil compaction (C) is common on construction sites (Lichter and Lindsey, 1994; Randrup, 1997). Decline and death of trees on construction sites is commonly attributed to soil compaction, and a resulting deterioration of the root environment. Compaction reduces total air-filled (noncapillary) pore space and reduces average pore size, increases mechanical resistance to root penetration, and can increase or decrease waterholding capacity, depending on the amount of compaction, and initial bulk density and pore size distribution. With the loss of macropore space, water infiltration and gas diffusion is reduced, soil oxygen concentration is decreased and carbon dioxide concentration can increase, possibly to toxic levels. This deterioration in quality of the soil environment renders the soil less favorable for root growth (Craul, 1992).

Studies with tree seedlings in containers have shown that soil compaction reduces vertical root penetration (Zisa et al., 1980; Halverson and Zisa, 1982), but not total root weight of the seedlings (Halverson and Zisa, 1982). For newly planted *Gleditsia triacanthos* seedlings,

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compaction of field soils reduced vertical penetration and overall root development, but increased root length in the upper 2.5 cm of soil (Gilman et al., 1987). Root dry weight of *Forsythia ovata* was decreased by field soil compaction, but not root dry weight of *Cornus sericea* (Alberty et al., 1984). All of these studies used small, recently planted trees and shrubs and measured root growth into new soil. There have been no studies of the effects of soil compaction on the roots of existing large trees with already established root systems in urban landscapes.

Addition of compacted fill could produce some of the same effects as compaction. The fill layer would reduce air and water movement into the soil beneath. The equipment used to place the fill, as well as the weight of the fill itself, would result in some soil compaction, even if the existing soil was not deliberately compacted prior to adding the fill soil.

In a study of a limited number of sites in actual landscapes, Yelenosky (1963) reported that after 9 months, oxygen content decreased and carbon dioxide content increased as depth of clay fill increased from 1 to 3 ft, but no measurements of root development were attempted. In controlled studies, reported effects of soil fill have generally been much less severe. Twenty centimeters of clayey subsoil fill over the root system of *Pinus strobus* for 2 years altered soil gas concentrations slightly, but not enough to damage root systems (Smith et al., 1995). Fill depth of 30 cm lowered oxygen diffusion rate (ODR) in the root zone of *Prunus mahaleb*, but effects were inconsistent, and no plant injury resulted (Tusler et al., 1998). Overlying compacted or uncompacted sandy loam construction fill 20 cm deep had no negative impact on *Quercus alba* and *Liquidambar stryraciflua* root density over 3 years (Day et al., 2001). Compacted fill 30 cm deep had no effect on 3-year-old *Prunus × yedoensis* 'Afterglow' trees after 1 year (MacDonald et al., 2004).

Experimental results seem to conflict with experience in the landscape. More research is needed to understand the relationship between alterations to the soil environment, such as compaction and fill, and fine root development and tree health. Fine roots are responsible for the majority of absorption of water and nutrients supplied to the crown. The purpose of this study is to determine if soil compaction can reduce fine root development of existing large trees with already established root systems in urban landscapes to the point of causing crown decline often associated with compaction after construction around existing trees.

## Materials and methods

An existing plantation of *Quercus palustris*, 30 cm (11.8 in) average diameter breast height (DBH) was available for the experiment. This species naturally occurs in moist soils of floodplains and edges of streams and ponds (Mohlenbrock, 1986), the type of habitat from which many of the best urban trees in the Midwest United States originate. *Q. palustris* is commonly used in urban landscapes that do not have alkaline soils and is probably more tolerant of low soil oxygen than other species. A second, less tolerant species was not available for comparison. The trees were growing in closely spaced linear groups of 2–5 trees, with less than 2 m between trees, and 15 m between groups of trees.

The soil was a Beecher silt loam. This is a nearly level, somewhat poorly drained soil. The surface layer is a very dark gray silt loam about 18 cm thick, with a dark grayish brown silty loam subsurface layer about 10 cm thick. The subsoil is about 70 cm thick transitioning from dark grayish brown firm silty clay to light olive brown silty clay loam. The water table is at a depth of 30–90 cm during wet seasons. Root development is restricted below 86 cm by the compact, moderately fine glacial till. Reaction in the surface layer is slightly acid. Reaction in the subsurface layer ranges from midly acid in the upper part to mildly alkaline in the lower part (Mapes, 1979).

Compaction treatments were applied around the groups of trees because of the intermingled root systems of each group of trees, and the need for access by the large equipment used to compact the soil. Uncompacted space between individual trees was less than 0.5% of the total plot area. Each treatment was applied to two groups of trees, with the end trees of each linear group used for sampling (four trees per treatment). The size of the compacted area was based on industry consensus for construction root protection zone (Harris, 1992). It was equivalent to the surface area of a circle 12 cm radius for each 1 cm (1 ft/in) of DBH, converted to a large rectangle around each group of trees.

Two types of compaction treatments were implemented. The simple compaction (C) treatment was implemented by driving a Ford F800, 15,000 kg (33,000 pound) gross vehicle weight, single axle dump truck with 11R22.5 tires at 105 psi, loaded to capacity, back and forth across each plot multiple times when soil moisture was near field capacity, until there was visible evidence of compaction in the soil structure of sample soil cores. An additional clay slurry (CS) treatment was applied to half of the compacted plots to simulate the type of CS that is sometimes pumped out of flooded foundation excavations and over the surrounding, already compacted, soil. The clay particles could fill the pore space that has already been reduced by compaction, further reducing movement of oxygen. A hole was dug 2 m deep, filled with 1 m of water and agitated with the backhoe bucket for several minutes, creating a slurry with the light olive brown calcareous clay loam underlying soil. The slurry was pumped onto half of the