Pilot Field Study of Structural Soil Materials in Pavement Profiles

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A rhizotron pilot study was conducted to evaluate plant responses in a standard sidewalk installation in comparison to a test profile of skeletal soil material (SSM) and a field control. Chlorosis was detected in the standard sidewalk trees, whereas the SSM profile was comparable to the agricultural control. Roots were observed at the rhizotron wall in 1996. Root counts and distribution by depth suggested an increase in roots for *Acer campestre* and *Tilia cordata*, with roots in the SSM profile occurring predominately in the lower regions of the pavement profile. Trees in the standard sidewalk profile were relegated to the shallow base course layer typical in northeastern sidewalk construction. Roots of *Malus* 'Adirondack' followed the same pattern of rooting depth, but there were more roots observed in the standard sidewalk profile. Several parameters were investigated to account for the preferential root growth deeper into the SSM profile. After ascertaining the consistency with depth of moisture, density, and oxygen levels in the SSM profiles, it is suggested that temperature fluctuations may be a contributing factor for the root distribution phenomenon.

The Urban Horticulture Institute at Cornell University (UHI) has been designing and testing sub-base materials that can be compacted with typical construction equipment, meet normal engineering expectations for materials under pavement, and encourage root growth.

So-called "structural soil materials" under consideration are extremely gap-graded materials lacking medium and large sands. The mixes tested thus far consist of a narrowly graded stone fraction (1.5 to 0.5 in. [3.8 to 1.3 cm]), a clay loam soil, and a small amount of hydrogel. The system works by producing a rigid stone matrix, to bear loading, and partially filling the stone matrix voids with soil. The hydrogel is added as a stabilizing agent, holding the soil in place during the mixing, placement, and compaction phases of construction.

Structural soil materials have performed to our satisfaction in planted studies lasting one and two growing seasons and in laboratory testing for bearing strength (5, 6). Verifying the benefit of using such materials outside of the lab is limited by the financial and logistical difficulties of planting in pavement situations and the destructive harvesting and analysis of the tree root system. While above-ground measurements can provide useful information, more information is needed on the condition of the rhizosphere and of root growth patterns below the pavement. The experimental pilot study described here attempted to provide rhizosphere and root growth data by constructing sidewalks around trees in an instrumented root-viewing chamber (rhizotron). The study translated mixing our test materials to a commercial scale and allowed observation of plant responses and material behavior in a controlled experiment that approximated a working sidewalk.

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Materials and Methods

Two pre-existing rhizotrons located in Ithaca, New York (8), were used in this study. Each chamber was 4 ft (1.2 m) wide, 24 ft (7.3 m) long, and 3 ft (0.9 m) deep, fitted with 0.25-in. (6.35-mm) Lexan® windows along their length, with a viewing area from the bottom of the pavement wearing surface to a depth of 2 ft (0.6 m). Two additional viewing windows were installed on one end of the chamber to bring two additional trees into the study (Figure 1*). Two pavement profiles were used. Each profile ran the length of the rhizotron on opposing sides, so a side-by-side comparison was available for on-site demonstrations (Figure 2). Each profile was installed into an excavated trench equaling the dimensions of the chamber pit. In this study, the excavation was made to a common depth of 2 ft. The trench bottom was compacted to 1.5 Mg/m^3, 97% of its AASHTO T-99 peak density (2).

The first pavement profile simulated a typical sidewalk installation in central New York State, in which there is minimal excavation and then compaction of the existent material, upon which a base material is added, followed by the wearing surface (Figure 2). The subgrade was rebuilt and compacted to 1.7 Mg/m^3, 98% AASHTO T-99, in 6-in. (15-cm) lifts to a plane approximately 8 in. (20 cm) from the top of the viewing chamber window. A base material of well-graded gravel was then placed and compacted to 2.1 Mg/m^3 in two lifts. The wearing surface for both profiles consisted of 6,000 psi concrete 4 in. (10 cm) in depth. All materials were compacted with a Wacker B5 45Y ram tamper (Wacker Corp. Menomonee, Wisconsin). Bulk density was monitored during installation and demolition by the sand cone replacement method, undisturbed soil coring, and the balloon volume replacement method (soil test equipment).

The test profile was a 2-ft (0.6-m) structural soil material base compacted in 6-in. (15-cm) lifts to 1.8 Mg/m^3, an estimated 95% AASHTO T-99 (Figure 2). The structural soil resembled materials being tested in the laboratory at the time, which displayed a high bearing strength (5). The structural soil material consisted of 80% by weight NYSDOT §702-02 #2 gravel, 20% clay loam, and 0.025% of a polyacrylamide stabilizing hydrogel (Gelscape, Amereq Corp. New City, New York) (9). The material was mixed in a 7 yd^3 (5.4 m^3) concrete mixer mounted on a stationary frame with an external power unit. The material was stockpiled on site and covered with

*All figures are located at the end of this chapter.

tarps until installation. Density was monitored during installation and destruction by the sand cone replacement method.

Agricultural controls were installed around the perimeter of the test area without viewing chambers (Figure 1). The control soil was not compacted because it was meant to simulate a nonconfined field-growing condition in the existing Niagara silt loam. As such, the controls were covered with 4 in. (10 cm) of hardwood mulch. The control consisted of pre-existing soil excavated to loosen the soil volume and to eliminate any plow pans in the profile, then replaced. Three trenches for three trees were positioned around the paved treatments. All soils used in the project were excavated within 660 ft (200 m) of the test site.

Bare root *Tilia cordata* 'Olympic' (6 ft [1.8 m]), *Acer campestre* (7 ft [2.1 m]), and *Malus* spp. 'Adirondack' (4 ft [1.2 m]) were established for five months on the Cornell campus in #10 nursery containers filled with the same clay loam used at the interstitial material in the structural soil material and existent on the rhizotron site. Due to the expense of installing the system and the lack of any prior use of the structural soil system, the plants were selected so as to observe responses over a range of species. This allowed for three plant replicates per treatment in this pilot study. Due to the limited number of replicates, the plants were assigned locations in the test profiles and control to spatially distribute them uniformly. Each tree was allotted a 4 × 6 × 2 ft (1.2 × 1.8 × 0.6 m) volume of the profile. Trees were planted into holes held open in the pavement profile by gravel-filled containers of equal size. This allowed a planting space to be opened without destroying the compactive effort applied to the surrounding profile. A 25-cm (9.8-in.) diameter opening in the concrete was left around each tree. The trees were installed into the test profiles on June 20, 1995, and irrigated each day for one week. No additional irrigation was used after that time. The pavement was installed on July 1, 1995.

Rhizosphere oxygen content was monitored at five levels. The first depth was at 3.2 in. (8 cm), with increments every 5 in. (12.5) cm down to 28 in. (71.5 cm). The collection ports were patterned after those used by Yelenosky, constructed of 4-in. (10-cm) lengths of 0.75-in. (1.9-cm) i.d. PVC tubing connected to the surface with 0.25 in. (0.64 cm) i.d. Nalgene tubing capped by a rubber septum (10). Clusters of tubes were placed 36 in. (90 cm) from the viewing window at 6-ft (1.8-m) intervals beginning 12 in. (30.5 cm) from the south end of the pavement pad. Samples were collected by removing 20 mL of air from the system with a syringe and drawing a 20-mL sample. Many of the samples collected in the subgrade were drawn as water, in which case a 0.00 value was entered into the data set, assuming anaerobic conditions in sections where pore-water pressure filled the voids in the sampling port. Samples were analyzed in a Servomix 574 Oxygen Analyzer (Servomix, Norwood, Massachusetts). Samples were drawn weekly from the paved profiles from June 11, 1996, though July 23,1996.

Temperature was monitored with copper constantan thermocouples (Omega type T) at depths of 6, 12, and 24 in. (15.25, 30.5, and 61 cm). Clusters were placed 24 in. from the viewing window at intervals of 6 ft (1.8 m) from the south edge of the pavement pad. Weekly measurements were made in 1996 for treatment and blocking effects. Hourly data were collected July 30 and 31, 1997, to track diurnal temperature fluctuations. This was compared to the Northeast Regional Climate Center field station data collected 1 mile (1.6 km) from the site.

Root distribution data were collected off of the viewing windows within one week of first root contact (August 5, 1996). The data were collected a second time on October 4, 1996.

Each tree was assigned a rooting window length of 6 ft (1.8 m), centered on the tree trunk. A wire mesh grid 2 × 4 in. (5 × 10 cm) was affixed to the window. Root intersections with the wire were counted at five depth increments and recorded, resulting in a relative root distribution.

Relative moisture content and bulk density were monitored with high-speed neutron and gamma radiation via a CPN 501 DR Hydroprobe moisture depth gauge. Access tubes were placed 24 in. (61 cm) from the viewing window at intervals of 6 ft (1.8 m) from the north edge of the pavement pads. Data collection was based on 32-second readings with the neutron/gamma source positioned 12 and 20 in. (30.5 and 50.8 cm) from the pavement surface. Calibration was conducted by destructive sampling and repetitive 256-second testing against sand cone and balloon methods during the duration and harvest of the field study, as well as testing within samples of known density and moisture. The final calibrations are not fully completed at this writing, but the raw particle-count data were used to demonstrate consistency within treatments between pavement sections.

Relative chlorophyll content was measured August 18, 1996, with a SPAD meter (Minolta SPAD 502) to verifiy visual signs of chlorosis in the trees in the standard pavement profile. SPAD meters have been successfully used to measure leaf transmittance as a field diagnostic tool to gauge chorophyll content and/or nutrient status in leaf tissue (1, 4). Ten leaves, the first of the current year's shoot extension on ten separate shoots, were measured three times and averaged for ten measurements per tree. 1997 data from repetitive harvests coincided with matched leaf tissue analysis but are not fully available as of this writing.

Statistical analysis was conducted by dropping the two single tree-viewing pit replicates and one set of control replicates and creating a split-plot layout, with repeated measures in most cases. Preplanned contrasts were conducted with Bonferroni protection. All rhizosphere data were collected in the paved systems only.

Results

No significant within-treatment differences in rhizosphere oxygen content profiles were detected ($P = 0.83$), although the low replication of this pilot study could have prevented small differences from being detected. During the first three weeks, there were the expected significant differences between the two treatments at depths where the standard sidewalk subgrade was compared to the test profile. This effect was masked during the last three weeks, from low replication and increased data variability in the standard sidewalk subgrade. Figures 3 and 4 demonstrate this effect from the collection ports at depths of 18.2 and 23.2 in. (46.1 and 58.8 cm). Oxygen levels at 18.2 in. were adequate in both pavement profiles and depressed in the standard sidewalk profiles. Mean rhizosphere oxygen levels at a depth of 23.2 in. fell below 5% in the compacted subgrade of the standard sidewalk treatment in the few weeks where isolated ports were not filled with water.

The weekly temperature data from the 1996 season yielded no differences within or between treatments ($P = 0.52$ and 0.71, respectively). There was a significant difference between measurement depths ($P < .001$). The lower thermocouple layers were very consistent across the entire test area over the entire observation period (Figure 5). The near-surface temperatures had a larger spread, presumably due to changing shade patterns on the wearing surface from the test trees. Based on this information, temperature was tracked hourly the following year. No differences were found within and between treatments in the hourly data sets; Figure 6 displays aggregated measurements at each depth. There were wide temperature fluctuations in excess of 14°C (57°F) near the surface. The lower two measurement depths show relatively little change in temperature over the testing period shown (Figure 6).

While the neutron and gamma data are not completely converted to density or volumetric moisture levels, pending further calibration, analysis of the raw data yields no within-treatment differences at each testing depth. The expected differences between each pavement layer material and the significant differences between treatments ($P < .001$) were verified. Consistency of moisture content and bulk density within and between the two structural soil profiles was inferred because the analysis yielded no difference between the trenches (P moisture = 0.48, bulk density 0.87) or by depth in trench (P moisture = 0.91, bulk density 0.99).

Roots were first observed in the viewing chamber windows August 5, 1996, during a weekly observation check of the profiles. Root distribution was recorded October 4, 1996, when there were enough roots to make a meaningful data set. Figures 7, 8, and 9 detail the results of the root-grid intersection counts for each species in the two pavement profiles. Most notable is the differential root distribution between the two pavement profiles. The root counts in the standard sidewalk profile were as expected, with no *Acer campestre* or *Tilia cordata* roots penetrating the subgrade, which occurred at the 8-in. (20-cm) depth (Figures 7 and 8). *Malus* 'Adirondack' penetrated 0.4 to 0.8 in. (1 to 2 cm) into the subgrade (Figure 9). The few observations recorded in the standard profile below 8 in. were roots originating higher in the profile, which ran along the viewing window. The test profile surprisingly demonstrated a preferentially deeper root distribution in all three tree species. There were roughly twice as many total root-grid intersections in the test profile for all three species when compared to the standard profile (Figures 7, 8, and 9), but the differences statistically were not well defined ($P = 0.334$), presumably due to the low replication as a pilot study.

The SPAD meter data convincingly demonstrated the differences in plant performance with significant differences ($P < .001$) between the standard sidewalk profile and the other two treatments (Figure 10). The differences in the crabapple may be misleading because all values indicate a healthy condition and were at or above the top range of accuracy for the instrument.

Conclusions

There was an observed benefit to plant establishment by planting trees in the structural soil profile for *Acer campestre* and *Tilia cordata* 'Olympic'. The root distribution of *Malus* 'Adirondack' was preferable in the structural soil profile because it moved the roots away from the wearing surface without negatively impacting on the tree. The proposed structural soil provided a well-aerated rooting zone even after full compaction, as verified by the oxygen data.

Roots moved away from the wearing surface in all trees installed in the structural soil. The density, oxygen content, and relative moisture in the structural soil did not vary with depth, thus eliminating them as causal factors for this phenomena. The even moisture distribution could be an artifact from lateral movement of moisture from beyond the test profile; moisture release studies have been initiated to further clarify the plant-available moisture on hydraulic behavior of these materials. The temperature data roughly agree with prior investigations under pavement structures (7). These large fluctuations and the potential for excessive maximum temperatures suggest that near-surface temperature fluctuations could partially contribute to the preferentially deep root growth in the test profile.

The standard sidewalk profile did not encourage tree establishment and root penetration at depth due to the requisite subgrade and base compaction. The lowered oxygen data and the high soil densities suggest problems for root penetration and establishment in the soil subgrade. The stone base had very little water- or nutrient-holding capacity because silts and clays are carefully avoided when specifying a base material. The trees responded to the problematic situation. Malus fared better than the two other species, with root penetration and leaf color remaining comparable between treatments. Further tests beyond the scope of this discussion indicate a possible reduction in total root volume and above-ground shoot extension in the standard sidewalk profile.

Relative chlorophyll content estimations from the SPAD meter data confirmed a negative impact on plant establishment in the standard sidewalk profile. As noted earlier, *Malus* may or may not have been significantly affected by the differing profiles due to the very high output from all replicates in the study. Two possible causes for the lowered chlorophyll content in the standard sidewalk are high pH and low nutrient availability in the base materials where all roots were observed to exist. Initial testing revealed pH levels of 8.8 to 9.1 during current excavation of the root zones. The base material in the standard sidewalk profile had less than 5% of material passing through the #200 sieve. There is virtually no clay or organic matter in this zone; therefore, moisture retention, cation exchange, and buffer capacities were severely diminished. These possibilities require verification and supplemental testing.

Further work in this area is necessary to verify the root-growth distribution patterns observed in this pilot study, as well as the influencing factors. A repeat of this study might include a carefully devised method for long-term temperature tracking to confirm the data presented. It would also include provisions for tracking the pH creep because the alkaline leachate from the concrete interacts with the near-surface base and sub-base materials. Moisture could be tracked very effectively using a carefully calibrated neutron probe. Time domain reflectrometry should also be considered after calibration to the specific material.

Further testing in this study includes relative chlorophyll content coupled with tissue analysis, shoot growth increment, and total root excavation architecture. All early indications and analysis confirm the improved performance of all species in the structural soil materials. Further establishment of a possible gamma-neutron probe calibration for the structural soil materials is also in progress. These data are not complete but will be presented in a cogent format in the near future.

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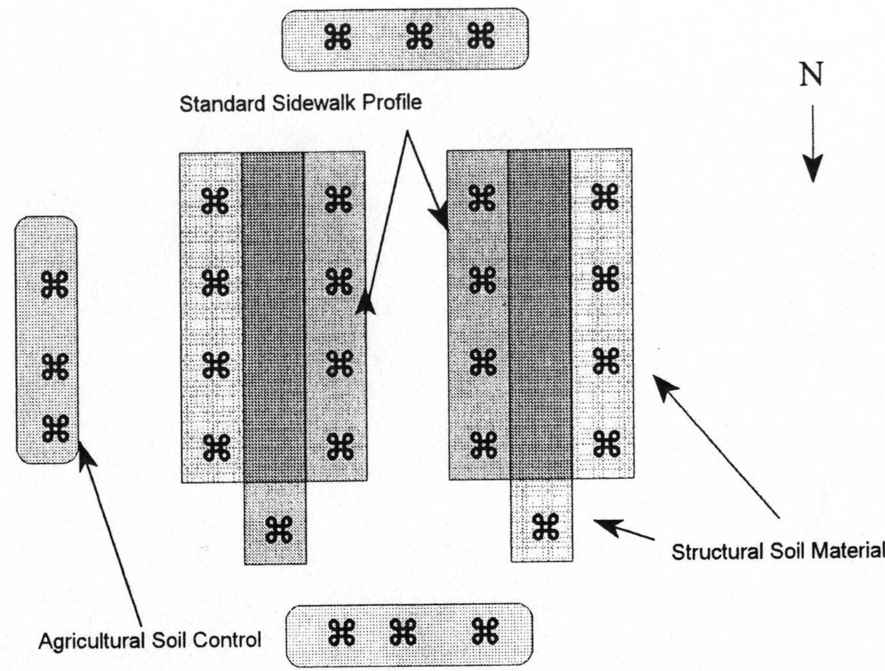
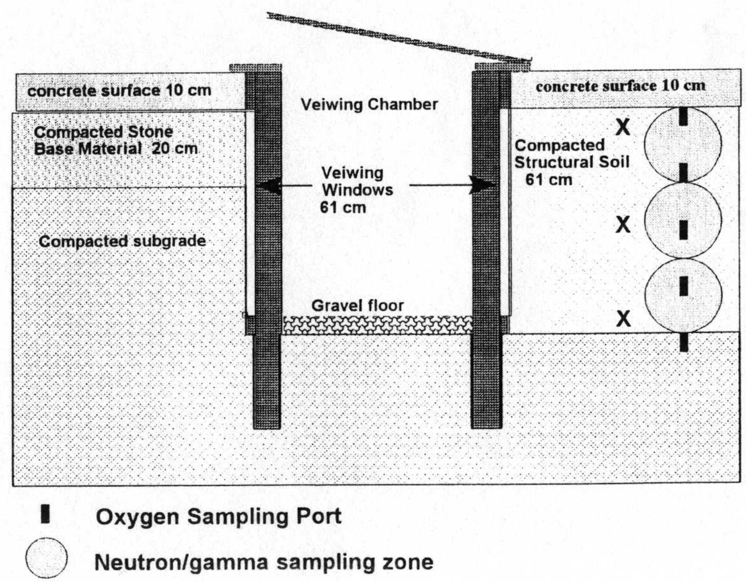


Figure 1. Plan view of pavement-tree study.



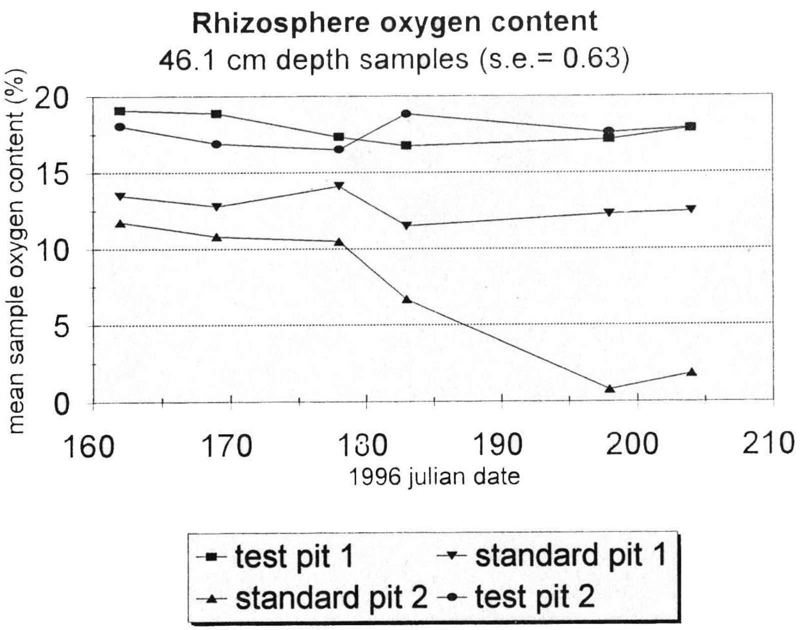


Figure 3. Mean oxygen levels in each trench at 18.2 in. (46.1 cm) show slightly depressed levels in the standard sidewalk profile.

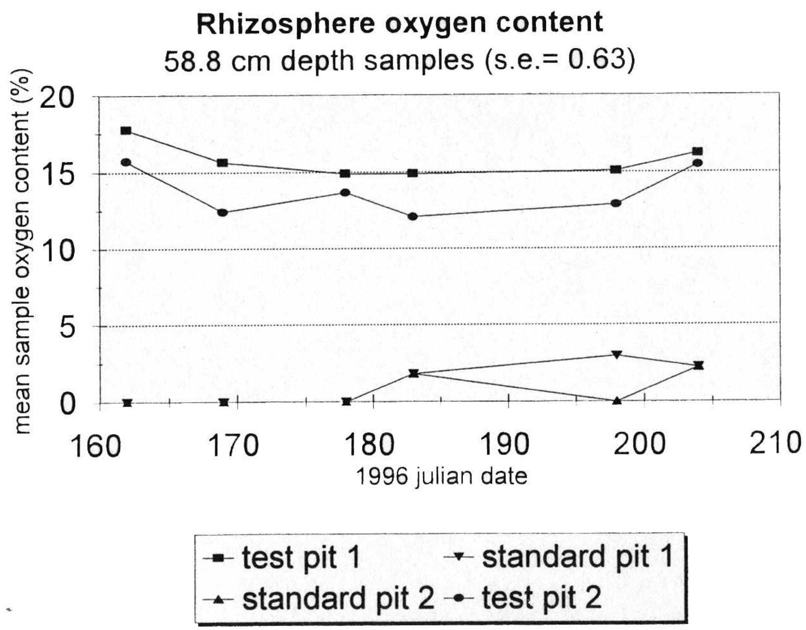


Figure 4. Mean oxygen levels in each trench at 23.2 in. (58.8 cm) show deficient

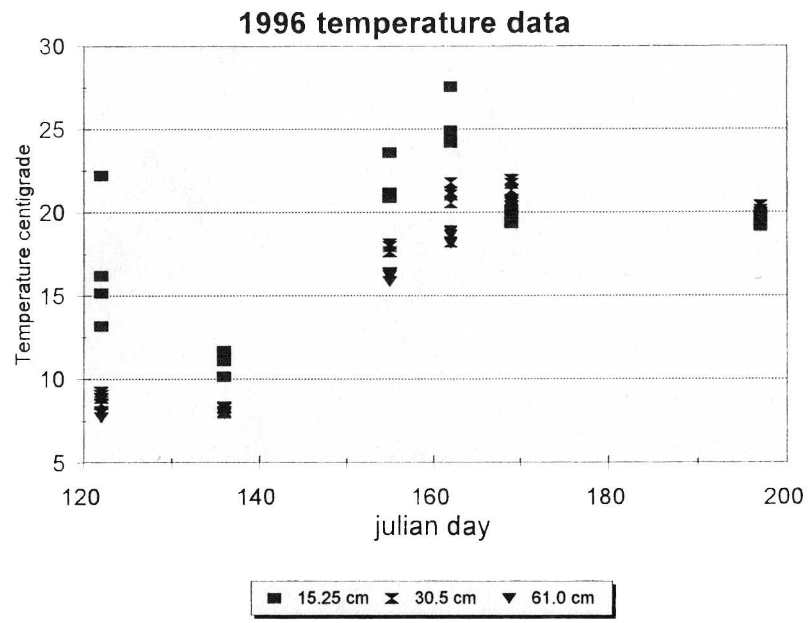


Figure 5. Soil temperatures were similar below each pavement section, with greater variation near the surface.

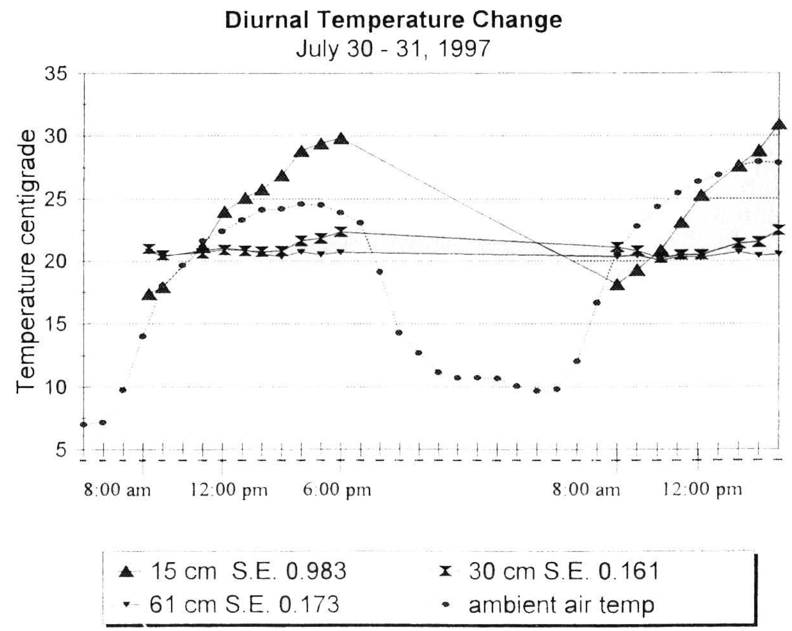


Figure 6. Temperatures below the pavement varied slightly at 12 and 24 in. (30 and

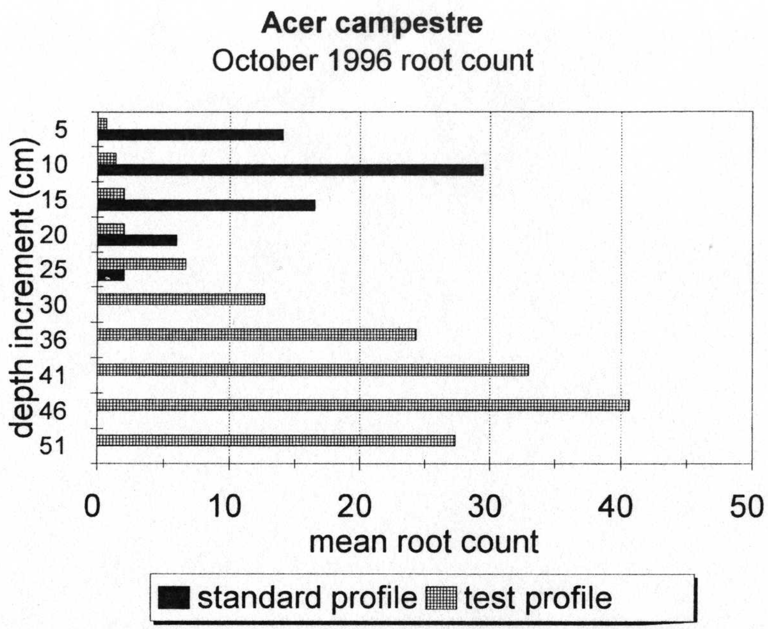


Figure 7. ***Acer campestre*** **root distribution at observation windows. Counts are root-wire grid intersections at each 4-in. (10.1-cm) depth increment.**

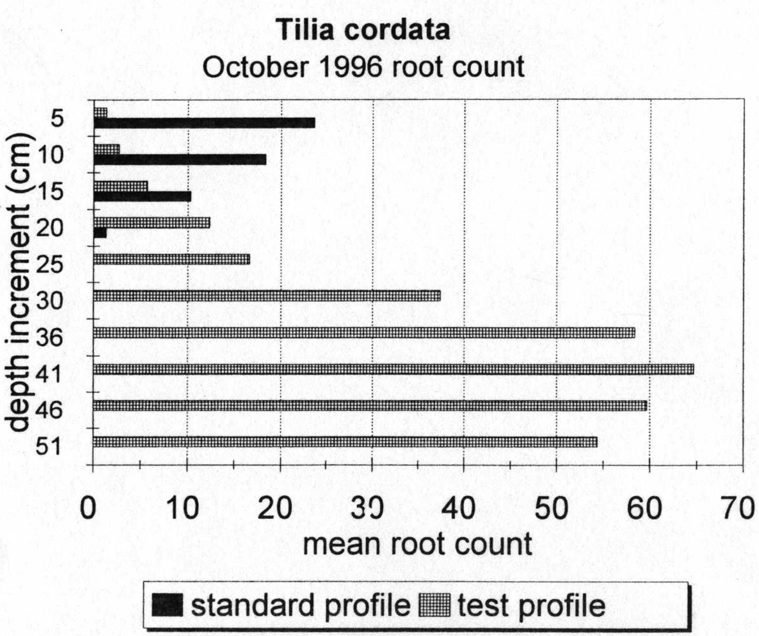


Figure 8. ***Tilia cordata*** **root distribution at observation windows. Counts are root-wire grid intersections at each 4-in. (10.1-cm) depth increment.**

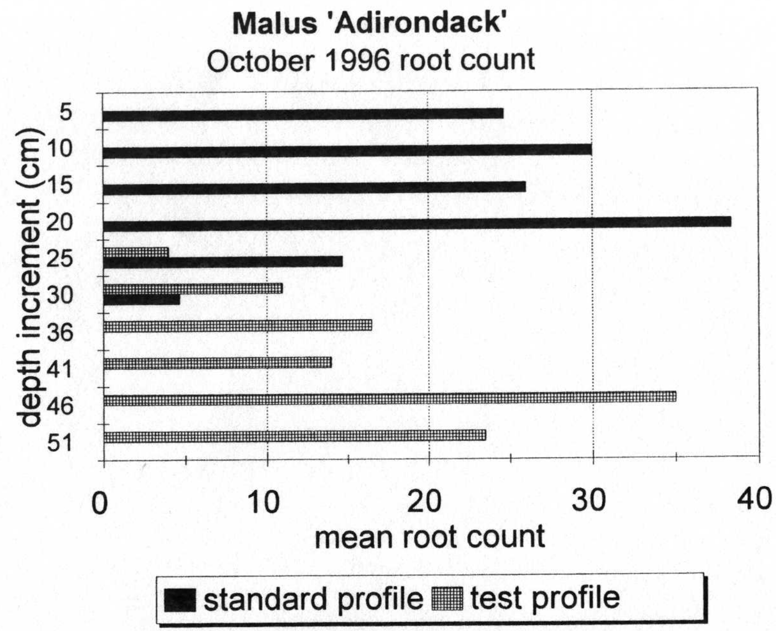


Figure 9. ***Malus*** **'Adirondack' root distribution at observation windows. Counts are root-wire grid intersections at each 4-in. (10.1-cm) depth increment.**

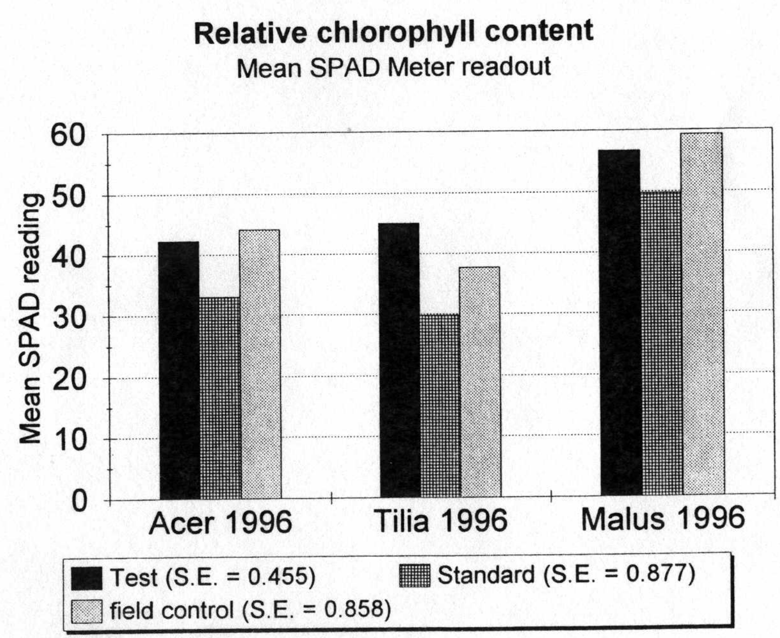


Figure 10. 1996 SPAD meter data confirming a depression in chlorophyll content in the standard sidewalk treatment.