Fill Soils in Landscapes: A Quantitative Assessment of Soil Aeration, Plant Response and Efficacy of Remediation Systems

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Poor soil aeration is often cited as a direct cause of landscape tree failures, or as a predisposing factor in *Phytophthora* and *Armillaria* root rots. Among the factors leading to poor soil aeration, grade changes (overlays of fill soils) around established trees are well known for their deleterious and often fatal impacts. In the face of little scientific evidence, planners, landscape architects, arborists and horticulturists have adopted a "best guess" approach and recommended the installation of subterranean piping systems or core venting systems to counter the adverse impacts of fills (Harris *et al.*, 1999). Our previous research has shown, however, that such practices have inconsistent, small, or nonexistent effects on aeration levels in urban soils. In 1995-96, we initiated a series of studies involving laboratory and field experiments to quantitatively assess the effects of fill soils on soil aeration, soil moisture status and plant growth. In addition, we sought to evaluate the efficacy of an aeration piping system installed within a fill soil. This report will describe the findings of the final study of this research project, with references to findings of previous work. Application of results to landscape management are discussed.

Research objectives were threefold:

1) to assess the impact of fill soil on the growth and physiology of young cherry trees.

2) to evaluate fill soil effects on soil oxygen diffusion rate (ODR) and moisture content.

3) to determine the effect of an aeration piping system (installed in fill soil) on plant growth, soil ODR, and soil moisture levels.

Research Methods

Three years prior to installation of experimental treatments, 45 cherry trees (*Prunus X yedoensis* 'Afterglow') were planted in a plot (40 x 76 ft.) excavated to a depth of 12 inches (Figure 1) at the Armstrong Field Research Area on the UC Davis campus. All excavated

Figure 1. Three years prior to fill treatments, cherry trees (Prunus X yedoensis 'Afterglow') were planted in a plot which had been excavated to a depth of 12 inches. Excavation provided a condition where, after fill installation was complete, the surface of the fill soil was at the same grade as the field soil. This eliminated the potential for gas intrusion into the fill from the sides of the plot. Trees grew for 3 years before fill treatments were initiated.

soil was retained next to the plot. Trees (5-gallon stock) were spaced 7 feet apart in 9 rows (5 trees per row). All trees were irrigated after planting and at regular intervals thereafter. The plot surface was sloped (approx. 2%) to a pit at the end of the plot where surface water (from rainfall and irrigation) was collected and pumped out. Trees were maintained for 3 growing seasons to establish a network of roots throughout the plot. Excavation provided a plot condition where, after the addition of fill, the intrusion of atmospheric gases from the sides of the plot was eliminated.

Laboratory analysis of plot soil (DANR Analytical Laboratory) determined the following: pH - 7.1, electrical conductivity (EC) - 0.43, organic matter - 1.1%, sand - 44%, silt - 38%, and clay - 18%. Bulk density at the 4 to 8 inch depth was 1.6 $g \cdot cc^{-1}$, and 1.35 $g \cdot cc^{-1}$ in the 16 to 20-inch zone.

In July and August, 1999, fill treatments were initiated. Prior to treatment installation, however, pretreatment measurements of ODR, soil moisture, and bulk density were made. These measurements provided a baseline for post-treatment comparisons.

Three treatments were established: 1) fill soil, 2) fill soil and aeration system, and 3) no fill (control). Soil

***Figure 2. In the fill + aeration treatment, perforated pipe was placed on top of the field soil and between plot trees. Fill soil (12 inches) was then added on top of the aeration pipe and compacted to 1.6* g·cc^{-1}.**

removed during pit excavation was used as fill soil. Plastic pipe (4-inch diameter) was placed on the lower trunk of all trees (18 inches high) to avoid contact between fill soil and trunk tissues. In fill soil treatments (1 and 2), soil was added to a depth of 12 inches in two lifts (6 inches each). Each lift was irrigated and compacted to 1.6 g·cc^{-1}. In treatment 2 (fill and aeration), a continuous line of 4-inch perforated drain pipe was placed on the soil surface (between tree rows) before fill was added (Figure 2). The ends of the aeration line were positioned to be above the surface after fill installation to provide ventilation. Two mid-line vertical vents were included as well.

The study plot was divided into 3 subplots (one for each treatment). Subplots consisted of 3 rows of trees (5 per row), with fill treatments being located adjacent to one another. Header boards (14-inches wide) were used to separate the control (no fill) subplot from the adjacent fill treatment. All plots were irrigated immediately after treatment installation.

Soil and plant measurements were taken periodically after treatment initiation. Soil measurements included oxygen diffusion rate (ODR) and soil moisture content. Plant measurements included shoot length, trunk diameter, and midday stem water potential.

ODR was measured using platinum-tipped microelectrodes connected to an ODR ratemeter (Jensen Instruments, Tacoma, WA). Electrodes were inserted at two depths: 6 and 18 inches. Three locations were monitored in each subplot, with clusters of 5 electrodes being used at each location. A total of 15 electrodes were used to generate one ODR reading (mean) for each measurement interval in each subplot. Measurement periods of 16 and 14 days followed treatment initiation. ODR electrodes were removed and cleaned between measurement periods. An 11-day measurement period preceded treatments.

Soil moisture was measured using tensiometers (Soil Moisture Equipment Corp., Santa Barbara, CA) placed at locations adjacent to ODR electrodes. Measurements were taken at 6 and 18 inch depths, and at 3 locations in each subplot.

Shoot length (3 shoots per tree) was measured on 3 trees in each subplot before treatment installation and after the treatment period. Trunk diameter was measured on all trees. Midday stem water potential was measured using 4 leaves from each of 3 trees in each subplot. Following a method described by Shackel (1998), leaves were enclosed in plastic pouches for 3 hours prior to measurement with a pressure bomb. Measurements were made before and after an irrigation at the end of the study.

Research Results

Plant Response. All trees survived and grew during the study period (Figure 3). Trunk diameter growth was not negatively impacted by fill treatments. In fact, trunk diameter growth of control trees was 40% less than that of fill trees (treatments 1 and 2). Shoot length results were variable for treatments: fill+aeration treatment trees grew 92% greater than controls, while fill treatment trees grew 19% less than controls.

Visually, leaf color and canopy density were similar across all treatment plots (Figure 4). Dieback, leaf drop, or chlorosis was not noted in any trees. Aside from growth increments, trees appeared to be similar before and after treatments were initiated. Similar results were obtained in previous experiments (also with cherry trees). In this study, interior trees appeared to be less vigorous than edge trees but growth measurements were not taken to quantify this difference.

Before irrigation (soil tension, 40 to 55 cb), midday stem water potential measurements were highest in fill treatment trees (19.1 bars) and lower in fill+aeration (16 bars) and control (16.4 bars) trees. After irrigation (soil tension, 6 to 18 cb), stem water potential levels declined in all treatments, but remained highest in fill-treatment

Figure 3. One week after fill installation, all trees were actively growing and appeared equivalent in canopy color and density. Control trees (no fill) are in the foreground, while fill trees are beyond the header board which retained the fill soil and divided the plots.

Figure 4. Two months after fill installation, all trees appeared equivalent in canopy color and density. Fill treatments did not inhibit shoot or trunk growth during the treatment period. Control trees (no fill) are in the foreground, while fill trees are beyond the header board.

trees (13.1 bars) and similar in fill+aeration (11.7 bars) and control (11.2 bars) trees. Measurements prior to irrigation suggest a moderate level of water stress, while those after irrigation suggest a very mild level of water stress (Shackel, 1998).

*Oxygen Diffusion Rate (ODR)***.** Prior to treatment, ODR levels at the 6-inch depth were relatively low, ranging from 0.05 to 0.15 ug/cm^2/min for control, fill, and fill+aeration plots. At 18 inches, however, levels were all greater than 0.15 ug/cm^2/min, with most values ranging from 0.2 to 0.3 ug/cm^2/min.

Following treatment, ODR levels did not change substantially at the 6-inch depth. Most values remained low (less than 0.1 ug/cm^2/min), but the fill+aeration treatment reached 0.15 ug/cm^2/min near the end of the measurement period, and the fill treatment increased to 0.25 ug/cm2/min. Fluctuations in ODR levels at 6 inches appeared to follow changes in soil moisture levels.

At 18 inches, ODR in the control plot did not change from pre-treatment levels. However, in both the fill and fill+aeration treatments, ODR was reduced by approximately 33%. This reduction persisted through both measurement intervals and it occurred in spite of a decrease in soil moisture levels in both treatments.

Soil Moisture. Plots were uniformly irrigated before and after fill treatments to achieve rootzone moisture levels which were consistent across subplots. Following irrigation, moisture levels were monitored at 6 and 18 inches at 3 locations in each subplot. Generally, control plots dried faster than fill plots. This finding is likely a consequence of surface evaporation occurring in control plots and not in fill plots: fill acted as a mulch on the soil surface. In addition, moisture levels were generally lower at the 18-inch depth than at 6 inches.

Notably, the field soil beneath fill (treatment 1) was substantially more difficult to wet than that beneath the fill+aeration treatment (treatment 2). Large amounts of water were required to achieve high soil moisture levels (10 - 15 cb) at 18 inches in the fill subplot. Substantially less water was needed to achieve similar levels in the fill+aeration subplot. It was thought water may have percolated through fill and into the field soil at a greater rate in the fill+aeration plot than the fill plot due to the presence of the aeration system. Possibly, the aeration pipe surfaces offered less resistance to saturated water flow than that found in the fill-only plot. This finding suggests that adequate irrigation of trees impacted by fill soil may be an important consideration.

Discussion and Implications For Management

Although previous reports indicate that fill soils have a negative impact on tree survival, growth and appearance, we were not able to find supporting evidence for these effects. Imposing a 12-inch fill on young cherry trees did not produce any measurable or observable impacts on survival, growth, or appearance. This finding was consistent for two separate field studies. Although it is likely that certain conditions will result in serious tree injury from fill soils, our findings suggest that, in some cases, fill soils will not cause injury.

It is not clear whether fill causes a uniform reduction in rootzone ODR. In previous work, some indication of ODR suppression by fill was found (Tusler et al, 1998). This finding was not consistent for all measurement locations and in all fill plots, however. In this study, a measureable reduction in ODR at 18 inches was found in both fill soil treatments, but this effect was not found at 6 inches. In comparing soil moisture levels within treatments, equivalent differences were found at both depths both before and after treatments. Therefore, it is unlikely that ODR differences found at 18 inches resulted in differences in soil moisture content. More likely, low ODR levels at 6 inches resulted from higher soil bulk density levels in this depth.

Although a fill-induced reduction in ODR was found here, it apparently was not of sufficient magnitude to cause a negative impact on plant growth. ODR reductions of 33% at the 18-inch depth simply may not have been sufficient to affect root function of study trees. Perhaps if an ODR reduction of equivalent magnitude occurred at the 6-inch depth as well, then a measureable effect on growth may be found. Further work will be needed to evaluate this possibility, however.

From both laboratory and field studies, aeration piping systems have not been found to have a positive effect on soil ODR. We have been unable to show that, by providing a low resistance avenue for gas diffusion into a fill soil, an improvement in ODR levels in the body of field soil will occur. Increases in ODR levels in soil immediately adjacent to piping systems or core vents may occur, but this effect has not been found in the body of soil 2 to 3 cm from the aeration source. In this study, ODR levels at 18 inches were roughly equivalent in the fill treatment and the fill+aeration treatment, and therefore, an ODR enhancement effect from the aeration system was not found.

Even though aeration systems have not been found to improve soil ODR, they may still have a beneficial impact. In this study, we found that substantially less irrigation water was needed to wet the rootzone in the fill+aeration subplot than in the fill-only subplot. In addition, midday stem water potential measurements were consistently highest in fill-only plots. If fill acts to reduce water penetration into underlying field soil, then an aeration system may function as a means of accelerating water movement through fill and into the rootzone. If an important effect of fill is the reduction of water percolation into the rootzone, then irrigation management will be an important factor to consider in post-fill tree care. Further work will be needed, however, to test this hypothesis.

In addition to potential impacts of fill on soil moisture levels, other factors which may cause tree injury include soil compaction and mechanical injury to roots (by construction activities). These factors may play important roles in determining the extent of injury resulting from fill events. Attempts to minimize both will likely reduce the potential of fill-related injury. For further discussion of factors which likely contribute to plant injury from fill soils, see Tusler *et al.*, 1998.

Literature Cited

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