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Measuring the Impact of Site Development on the Physical and Chemical Properties of Landscape Soils

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Introduction

From a horticultural perspective, it is generally acknowledged that site development has a negative impact on the physical and chemical properties of soils (Harris et al 1999). Construction activities cause substantial increases in soil compaction and this affects drainage (infiltration and percolation rates), aeration (oxygen diffusion rate), and root penetration (Craul 1985, 1999). Impacts on soil pH, salt concentration, and specific ion concentration also may result. These changes have a direct impact on the health and performance of landscape plants (Patterson 1977).

Although Lichter and Lindsey (1994) found that surface protective treatments such as mulch can be used to prevent soil compaction on selectively-graded sites, Randrup (1997) and Randrup and Dralle (1997) indicate that protection and amelioration efforts generally have not been successful at construction sites in Denmark. Rolf (1992a,b) found that subsoiling decreased soil bulk density in compacted soils and improved plant growth, while Spomer (1983) addressed the use of amendments to improve physical properties. Day and Bassuk (1994) reviewed the effects of soil compaction and amelioration treatments on landscape trees, and Day et al (1995) described the results of four remediation methods.

These studies have generated useful information for landscape professionals, but attention has been focused largely on evaluations of soil compaction. Although compaction is a very important physical property to assess, other properties are important as well. These include soil pH, salt level, sodium absorption ratio, boron content, percolation rate, and moisture retention characteristics. This study was initiated to evaluate both soil physical and chemical properties in a developed site as part of a more comprehensive approach to the assessment of soil qualities that may be affected by development.

Methods and Materials

A recent building project in Davis, CA, provided an opportunity to compare soil qualities at a developed site with two undeveloped sites (fig. 1). The developed site, a one-year-old residential retirement community, had significant problems with many plant materials due to unfavorable soil conditions. A preliminary assessment of soil conditions indicated limitations associated with soil pH, salt content, texture, and bulk density. In many locations, soils remained highly saturated or flooded for days after irrigation or rainfall (fig 2).

Fig. 1. Soil evaluations were conducted at 3 locations within 500 yards of one another. The developed site is in the foreground and samples were taken from the construction area on the left (not landscaped). The agricultural field is in the background: a green field beyond the trees at the top of the photo. The fallow field is between the developed site and agricultural field, to the right of the stand of mature trees.

Soil conditions at two nearby undeveloped sites, a fallow field and an agricultural field, provided a comparison with the developed site. The fallow field, located within 500 yards of the developed site, had not been planted or cultivated in many years. The agricultural site was located adjacent to the fallow field and had been planted to annual grain crops. Differences in soil conditions found at the developed site versus the undeveloped sites were considered to be an indication of the type and magnitude of construction impacts that may occur in landscape soils.

A. Soil Sampling and Analysis

Soil inspection and sampling pits were excavated at each location using a backhoe (fig 3). Two trenches were excavated to form a T-shaped pit. Trenches were 6-feet deep and

approximately 2-feet wide and 6-feet long. Soil samples were collected on a smooth and uniform sidewall at the juncture of the two trenches.

Samples for laboratory analysis were collected in October, 2001, at 3 depths: 10, 24, and 48 inches. Composite samples at each depth were analyzed for texture, organic matter content, pH, salt content, sodium adsorption ratio, and boron content by the University of California Division of Agriculture and Natural Resources (DANR) Analytical Laboratory (Davis, CA). Visual assessments of the soil profile (texture, structure, and color) also were made at each location.

Fig. 2. Within a year after the landscape had been installed at the developed site, many trees declined. Here, a maidenhair tree (Ginkgo biloba) shows symptoms of an aeration deficit: chlorosis, leaf drop, and little or no growth. The aeration deficit was attributed to excess water in the root zone from irrigation and poor drainage.

Three soil core samples (4-inch) were taken at each depth using a field core sampler (AMS, American Falls, Idaho) for bulk density analysis, as described by Lichter and Costello (1994). In addition, an assessment of percolation rate was made at the developed site in January, 2002. The percolation test followed a standard protocol described in Singer and Munns (1999), which is used to determine the suitability of soils for septic leach field installations. Three parallel trenches (6-feet long, 4-inches deep, and 10-inches wide) were excavated 18 inches apart from one another. Using a 3-inch open barrel soil auger (AMS), three holes in each trench were excavated to depths of 12, 24, and 36 inches. The holes were cleaned and roughened and filled with water. After 24 hours, the pits were topped with water and the percolation rate was determined by measuring the decline in water level over a 30-minute period. This test will be performed at the fallow field and agricultural field in 2003 and results will be given in the final report.

Fig. 3. Soil inspection and sampling pits were excavated in all three locations using a backhoe. Here, a pit is being dug at the developed site.

B. Soil Remediation Treatments

To evaluate the effect of soil remediation on plant growth, three planting locations at the developed site were selected (where trees had declined). At each site, a radial trenching technique was used to replace existing soil with an imported soil. Radial trenching has shown favorable results for mature trees impacted by development (Watson 1996), but has not been tested on newly planted trees. Trees were removed and trenches created using a hydroexcavation technique (Gross 1993) where high-pressure water is used to remove soil, and the soil-water slurry is withdrawn into a holding tank using a vacuum unit (fig. 4). Two trenches configured in an X-shape at each

Fig. 4. To remediate soil conditions that limited tree development (principally compaction), soil around declining trees was removed using a hydroexcavation technique and replaced with a higher quality soil. Here, soil is being dislodged with water (under high pressure) and the slurry is being vacuumed.

planting site were excavated, with each trench being approximately 10-feet long, 12-inches wide, and 16- to 26-inches deep. After water drained from the trenches, a soil with high sand content was installed, irrigated, and allowed to settle for several days (see table 1 for analysis of replacement soil). Replacement trees (*Zelkova serrata*, *Ginkgo biloba*, and *Acer rubrum*) were planted at each of 12 sites with replacement soil. In addition, trees were planted at 3 sites where a declining tree was removed but no soil remediation was performed. Since both tree and soil conditions at the site did not allow for complete replicates of treatments, however, this work was conducted for demonstration purposes only. Measurements of tree trunk diameter and canopy density (visual assessment) were taken at planting, and subsequent measurements will be taken annually.

Table 1. Chemical and physical analyses of soils collected at 3 sites (developed, fallow, and agricultural) and at 3 depths (10, 24, and 48 inches). Last column gives analysis of replacement soil used in remedial treatments.

	Developed Site			Fallow Field			Agricultural Field			
Depth (inches)	**10**	**24**	**48**	**10**	**24**	**48**	**10**	**24**	**48**	**Replacement soil**
pH	7.3	7.5	7.8	7.3	7.6	7.8	7.6	8	8.7	7.1
EC (mmhos/cm)	0.97	0.45	0.39	0.27	0.36	0.53	0.42	0.44	1.58	0.5
SAR	<1	1	2	1	2	5	1	17	31	<1
Boron (ppm)	0.2	0.3	0.4	0.3	0.4	1.5	0.6	4.1	12	
OM (%)	1.34	0.61	0.61	1.41	0.77	0.61	1.12	0.65	0.51	0.35
Sand (%)	22	53	29	31	26	21	20	22	12	86
Silt (%)	55	34	53	46	54	45	55	56	54	9
Clay (%)	23	13	18	23	20	34	25	22	34	5
Bulk density (g/cc)	1.61	1.58	1.38	1.57	1.5	1.68	1.61	1.62	1.55	NA

Results and Discussion

Texture varied among all three sites and at depth for each site, with a strong silt component in all soils (Table 2). The developed site was largely silty loam, but at 24 inches there was a substantial sand component (53%). Texture was different at each depth in the fallow field, changing from a loam (10 in.) to silt loam (24 in.) to clay loam

(48 in.). In the agricultural field, soil texture was similar at 10 and 24 inches (silt loam), but a higher clay content was found at 48 inches (silty clay loam). These textural differences provide strong evidence that soil variation can be substantial in areas relatively close to one another and within the soil profile. In fact, there was as much variation at depth as there was from site to site. These differences in texture can have substantial effects on key soil characteristics, such as aeration, moisture retention/release, and drainage. Actual effect on these soil characteristics will depend on structure as well as texture, however.

Table 2. Soil textural classification, bulk density, and growth-limiting bulk density (GLBD) for 3 locations (developed, fallow, and agricultural) and 3 depths (10, 24, and 48 inches). GLBD values from Daddow and Warrington (1983).

Location	Soil Depth (inches)	10	24	48
Developed site	Texture	silt loam	sandy loam	silt loam
	Bulk Density (g/cc)	1.61	1.58	1.38
	GLBD (g/cc)	1.45	1.61	1.47
Fallow Field	Texture	loam	silt loam	clay loam
	Bulk Density (g/cc)	1.57	1.50	1.68
	GLBD (g/cc)	1.50	1.46	1.46
Agricultural Field	Texture	silt loam	silt loam	silty clay loam
	Bulk Density (g/cc)	1.61	1.62	1.55
	GLBD (g/cc)	1.45	1.45	1.43

Organic matter (OM) was less than 1.5% in all cases. As little as 0.51% was found at 48 inches in the agricultural field. OM declined with depth in all locations. These values are typical of organic matter content of many soils in California.

Soil pH was found to be greater than 7.0 at all locations and depths. Similar values were found in the developed and fallow field locations, while values in the agricultural field were substantially higher. pH increased from 10 to 48 inch depths in all cases, with the highest value (8.7) occurring in the agricultural field at 48 inches. The increase in pH from shallow to deep levels may be related to the decline in organic matter with depth. In addition, in the agricultural soil, high sodium content likely caused an increase in pH.

Electrical conductivity (EC) values from 0.5 to 2.0 mmhos/cm generally indicate that salt levels are safe for most landscape plant species (Harris et al 1999). All EC values at all sites and depths were found to be less than 1.6 mmhos/cm, suggesting that soil salt content would not be a limitation to plant growth.

Sodium adsorption ratio (SAR) values less than 6.0 are generally safe for most plants (Harris 2003). Although SAR values at the developed site and the fallow field were less than 6.0, very high values were found at 24- and 48-inch depths in the agricultural field (17 and 31, respectively). This indicates that the sodium concentration relative to that of calcium and magnesium is very high. High sodium content generally results in water permeability and percolation problems (poor drainage). Drainage will be evaluated in 2003 by conducting a percolation test at each site.

Boron content is satisfactorily low in all locations except the agricultural field. Boron is generally safe for most plants at < 0.5 ppm, while sensitive species may show injury when concentrations range from 1 to 5 ppm (Costello et al 2003). Above 5 ppm, severe injury may occur on many species. Boron concentrations of 4.1 and 12.0 ppm found at 24- and 48-inch depths (respectively) would suggest that boron toxicity injury would occur on species with root development at these depths.

Bulk density (BD) was greater than the growth-limiting bulk density (GLBD) in 7 of 9 sampling sites (Daddow and Warrington 1983, Vepraskas 1988). Soil at all three depths in the agricultural field was substantially greater than the GLBD, while values in the fallow field were marginally higher (Table 2). Only the uppermost depth (10 inches) in the developed site was found to have a BD greater than the GLBD. It is unclear, however, whether this BD was the result of development or a pre-existing condition, such as a plow pan (Aljibury et al 1982). Since all 3 locations were found to have similar BD at 10 inches, it is likely that high BD (plow pan) preceded development. All three sites had been in agricultural production for many years in the past. Very high BD values at 24 and 48 inches in the agricultural soils may be related to the high sodium content (SAR) found at both depths. Sodium causes a loss of structure and increase in micropore space.

High silt content and high clay content (2 cases) increase the potential for compaction and limited plant growth (Jones 1983). GLBD for soils with little macropore space (such as silty and/or clayey soils) is less than that for soils with greater macropore space (such as sandy soils).

Although these results indicate growth-limiting conditions at each site, a comparison of soil properties at the three neighboring sites was not an effective means of assessing the effects of development. Even though the three sites were in close proximity to one another, soil properties were notably different and made comparisons tenuous. An alternative approach of measuring properties before and after development likely would have generated a better assessment, but this option was not available at the beginning of the study.

These results strongly emphasize the need for careful site analysis prior to development, however. Growth limiting conditions were found at each location. If these conditions remain uncorrected prior to landscape installation, problems are likely. This was found to be the case at the developed site: slow drainage and restricted root development can be attributed to high bulk density found in the upper root zone (10 inches). Whether this soil condition existed prior to development or resulted from development is unclear. Nonetheless, soil compaction existed prior to landscape installation and problems resulted. Site analysis would have identified conditions requiring remediation before landscape construction, thereby avoiding subsequent problems with the installed landscape.

Although limitations to plant development were found in the developed site, potentially greater problems were found in the agricultural site. Growth-limiting bulk density at all depths, high pH, high boron concentration, and very high SAR indicate that perhaps only

shallow rooted plants (such as annual grains) would perform well. At some point, however, the agricultural field likely will be developed and landscape plants installed. If a pre-construction soil assessment is not made, then problems in landscape plant performance (more serious than the developed site) would be expected.

Work on this project will continue in 2003. Tree growth measurements will be taken and an assessment of soil percolation characteristics will be made at each site (as described by Wildman 1969).

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