SOIL COMPACTION AND RESPONSE TO AMELIORATION TREATMENTS AROUND ESTABLISHED TREES IN AN URBAN CAMPUS ENVIRONMENT

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Abstract. Soil compaction is a pervasive problem in urban landscapes occurring as a result of both equipment and pedestrian trafficking during periods when soils are moist and susceptible to damage. Compacted soils have decreased macroporosity, aeration, infiltration rates and hydraulic conductivity as well high mechanical resistance that impedes root growth. Soil around trees on the University of Georgia Campus was studied to 1) quantify the level of soil compaction on campus, 2) identify differences in soil conditions between planting islands and roadside areas, and 3) evaluate the benefits of two treatments (air-tillage and vertical mulching) designed to reduce soil compaction around established trees. Soil compaction was found to be prevalent and widely distributed on the University of Georgia campus in both natural soils near buildings, sidewalks and roads and in soils in islands. Air tillage significantly reduced bulk density and soil resistance to a depth of 17cm. Vertical mulching resulted in no significant differences compared to a mulched-only control plot in the first post-treatment measurement. By the end of the third-year following treatment, all plots had similar bulk densities, apparently due to the effects of mulching.

INTRODUCTION

Soil compaction is a pervasive problem in urban landscapes as a result of equipment trafficking during construction and both equipment and pedestrian trafficking during periods following construction when soils are moist and susceptible to damage. Compacted soils have decreased macroporosity, aeration, infiltration, and water movement through the soil profile (Harris et al. 2004). Soil resistance is excessively high in compacted soils, resulting in mechanical impedance of root growth. Compaction is most frequently measured by bulk density change. For a given soil texture, Daddow and Warrington (1983) established a threshold above which plant growth is severely reduced. Many urban soils approach or exceed these thresholds.

Soil compaction in urban setting is a result of two major factors: surface traffic and grading (Harris et al. 2004). Surface traffic from either pedestrians or light vehicles results in compaction that is generally confined to the upper 10cm of the soil profile (Chancellor 1976). Grading, or the remodeling of the land surface mixes soil horizons, destroys soils structure and may result in compaction deep within the soil profile (Harris et al. 2004).

The degree and pervasiveness of soil compaction in campus environments is unknown. It is likely that soil compaction is a widespread problem. As with most urban landscapes, campuses are heavily graded with highly mixed, poorly structured subsoil horizons in which trees are planted. Surface soils are likely to be compacted as a result of both foot traffic and parking of vehicles along roads during sporting events. Soils along roadsides, at bus stops and in locations near campus buildings receive almost daily foot traffic. Similarly, islands in parking areas may receive considerable foot traffic and, depending on how islands were installed, may exhibit residual compaction from construction.

A number of techniques have been developed in effort to ameliorate soil compaction, ranging from organic matter integration to mechanical soil manipulation. On sites that are being prepared for tree establishment, these techniques range from simple to intensive mechanical soil manipulation. Traditional sub-soiling and tilling are often used prior to planting on large areas without in-place hardscape, such as during subdivision establishment. Fewer techniques are available to ameliorate compaction in situations where established trees exist. Vertical mulching is one of the commonly used techniques in situations where intact root systems must be protected. Vertical mulching involves filling excavated holes approximately 5cm wide and 45 cm deep with organic mulch. Varying numbers of holes are excavated depending on the degree of compaction and drip-line diameter. The total volume of soil affected by vertical mulching is relatively small. More recently, air tillage treatments have been used to ameliorate soil compaction. Air tillage uses a turbulent stream of compressed air at a relatively low pressure to lift and fracture the soil. This approach was developed to excavate buried cable and military ordinance and has been adapted by Bartlett Tree Experts Laboratories (Air Spade$^{TM)}$ and others to aerate soil around intact root systems and incorporate organic matter into the soil.

The objectives of this study were to 1) quantify the level of soil compaction around mature campus trees, 2) compare soil compaction around island planted trees to natural-area planted trees, and 3) evaluate the efficacy of operationally installed vertical mulching and air-spading amelioration techniques applied to established trees on the University of Georgia campus.

MATERIALS AND METHODS

Study Locations

Two areas on the University of Georgia campus were chosen for study. The first area was located near the University of Georgia Graduate and Family Housing. This area contained mature species of *Quercus alba*, *Q. lyrata*, *Q. palustris* located near buildings, sidewalks and roads that receives regular pedestrian traffic. Although disturbed, soils in this area were natural soil profiles. The second area was within a large parking lot for East Campus Village dormitories. It contained a variety of island planted mature trees including *Quercus phellos*, *Acer rubrum*, and *Ulmus parviflora*. Initial tree health observations also indicated tree stress. All trees within the islands had been mulched within the previous three growing season and had fairly high levels of coarse organic material remaining on the surface.

Block and Treatment Selection

To evaluate the effect of planting design and soil compaction amelioration techniques, matched tree blocks were selected. Blocks consisted of established trees of the same species of similar age and vigor that are in close proximity to one another and within the same soil condition. Each block consisted of 3 matched-plots, each receiving one of three treatments. Fourteen total blocks were identified and selected. Thirteen blocks consisted of three individual tree plots, and 1 block consisting of 9 trees with separate 3-tree clusters. Of these 14 total blocks, 6 blocks were established in natural soils around university buildings and 8 blocks were established in planting islands within parking lots. Individual tree areas within each block were marked, measured, and recorded so that each tree received a similar level of treatment and assessment. All assessment was considered to a depth of 35cm.

A treatment was randomly assigned to each plot so that every block had all of the three treatments installed. The treatments consisted of a control treatment (CON), vertical mulching treatment (VML), and air tillage treatment (ATP). The control treatments received only compost and mulch additions. The vertical mulching treatments consisted of multiple 5cm diameter auger holes excavated throughout the plot, with compost and mulch added on top. The air tillage treatment received compressed air-fracturing throughout the plot, and included compost and mulch additions. All treatments were installed operationally to these specifications by the University of Georgia Grounds Department.

Pre-Treatment Characterization

Prior to treatment installation, pre-existing soil conditions were characterized. Hammer-driven soil cores were collected to determine bulk-density at 2 random sites within each individual tree area. Each core was 7.5cm diameter x 7.5cm in height and cores were taken at a depth beginning from 0-2 cm below the mineral soil surface. The samples were oven-dried at 100^{o}C to constant weight before weighing. Texture class was determined in the field.

A Rimik^{TM} CP40II digital penetrometer (RFM, Clifton, Australia) was used to take soil resistance measurements. The plots were divided into quadrants, based on cardinal direction lines, and resistance was measured at a random location within each quadrant. Resistance readings were taken from the mineral soil surface to a depth of 35cm, with each measurement interval corresponding to a 2.5cm change in depth. In this initial sampling, time domain reflectrometry (TDR) (Topp et al. 1982) was used to collect soil moisture readings from the mineral soil surface to 30cm at each penetrometer insertion.

An analysis of variance (GLM procedure) with Duncan's mean separation was used to find significant pre-existing differences among blocks and treatment selections using SAS (SAS Institute Cory, NC). These pre-characterization measurements were also used to test for differences between blocks established in islands and established in natural areas.

Treatment Installation and Characterization

Treatments were installed operationally, by the UGA Grounds Department, during the months of December 2005 and January 2006. Vertical mulching holes were excavated with a gas-powered 5cm diameter auger at regular intervals throughout the treated plots. Air tillage was completed to a nominal depth of 15 cm using a and Air-Spade™ Coarse organic material was removed from the surface of air-spade plots, and fine surface organic matter was integrated into the soil. All plots received the operational organic compost and hardwood mulch commonly used by the UGA Grounds Department.
After installation, treatments were characterized to assess the volume of soil affected by treatment. For vertical mulching treatments, the number of auger holes within meter-squared area was counted at 2 random locations

within a subsample of the treated plots. The depth of air-spade treatment was measured at 5 random locations within treated plots. The depths of compost and mulch additions were also measured at these locations. Control plots were assessed by measuring the depth of compost and mulch additions at five random locations with treated plots.

Post-Treatment Soil Characterization

Soil bulk density and soil resistance to penetration were determined in March 2006 and, again, in March 2009, three years after treatment installation using the same procedures used during pretreatment characterization. This end-of-winter sampling period provided conditions where soil moisture content was near field capacity and differences in soil resistance due to differences in soil moisture conditions would be minimized. To assess the effects of treatments on 3-year tree growth, increment cores were taken from each tree and radial growth determined during the three-year period prior to treatment and the three-year period following treatment.

RESULTS AND DISCUSSION

Pre-treatment bulk densities were generally below the threshold for growth limitation (Table 1) (Daddow and Warrington 1983). Block E was the only block that exceeded the associated growth-limiting bulk density. Although these values did not generally exceed root growth limits, they were close to the threshold values. In addition to being near the threshold values, these bulk densities were highly variable among and within blocks. This variation in bulk density is characteristic of urban soils and is likely related to the variation in traffic patterns. There was no significant difference in measured bulk density between islands and natural area soil of the Graduate and Family Housing area.

Air tillage had a significant effect on soil bulk density during the immediate post treatment sampling (Table 2). Differences in soil bulk density were much smaller by the end of the third-year following treatment and not statistically significant. Mulching, even in the absence of other treatments, improved bulk density of these soils. Both the control soils and vertical mulched soils had more favorable bulk densities than in the pre-treatment or immediate post treatment sampling. Although air tilled areas still had the lowest bulk density, some post treatment settling and, perhaps, light foot compaction had occurred since treatment and the bulk density was slightly greater than measured immediately after treatment. The improvement in bulk densities over the three-year study period is likely a combination of both fauna activity at the base of the mulch and incorporation of the mulch into the surface of the mineral soil by light foot traffic.

Table 1. Pre-treatment surface soil bulk densities for each block with the associated growth limiting bulk density determined from field textures (Daddow and Warrington 1983)

Block	Mean bulk density (g/cm^3)	Field Texture	Limiting bulk density (g/cm^3)
E	1.58	sandy clay loam	1.55
G	1.53	sandy loam	1.65
H	1.22	sandy loam	1.65
I	1.32	sandy loam	1.65
J	1.38	sandy loam	1.65
K	1.53	sandy clay loam	1.55
L	1.44	sandy clay loam	1.55
M	1.41	sandy loam	1.65
N	1.20	sandy loam	1.65
O	1.52	sandy clay loam	1.55
P	1.55	sandy clay loam	1.55
Q	1.15	sandy loam	1.65
R	1.33	sandy clay loam	1.55
S	1.28	sandy clay loam	1.55
Average	1.39		
Coeff. Var	16.26		

Table 2. Influence of compaction amelioration treatments on surface soil bulk density averaged across 14 treatment blocks

Treatment	----------------------Mean bulk density (g/cm³)---------------------		
	Pre-Treatment	Post-Treatment 2006	Three Years Following Treatment 2009
Control	1.36[a]	1.34[a]	1.20
Vertical Mulching	1.43[a]	1.37[a]	1.23
Air tillage	1.38[a]	1.03[b]	1.18

Air tillage treated plots had significantly lower soil resistance than control (mulched-only) or vertically mulched plots in the surface 15 cm of soil (Fig. 1). In comparison to both the control and vertically mulched plots, air tillage more than doubled the depth to the commonly accepted root limiting soil resistance of 2000 kPa (Greacan and Sands 1980). Again, these results indicate the effectiveness of the air tillage treatment in ameliorating shallow soil compaction. Due to the relatively shallow depth of treatment, air tillage had no effect on ameliorating compaction in the deeper soil depths such as might occur as a result of trafficking by heavy equipment. Vertical mulching treated plots were only significantly less resistance than control plots at one depth. Although vertical mulching ameliorates compaction in each hole, the area of holes is a relatively small percentage of the surface.

Reduced resistances measured in air tillage treated plots immediately following treatment were also observed three years following treatment. As was observed for bulk density, these differences were not as great as observed immediately following treatment.

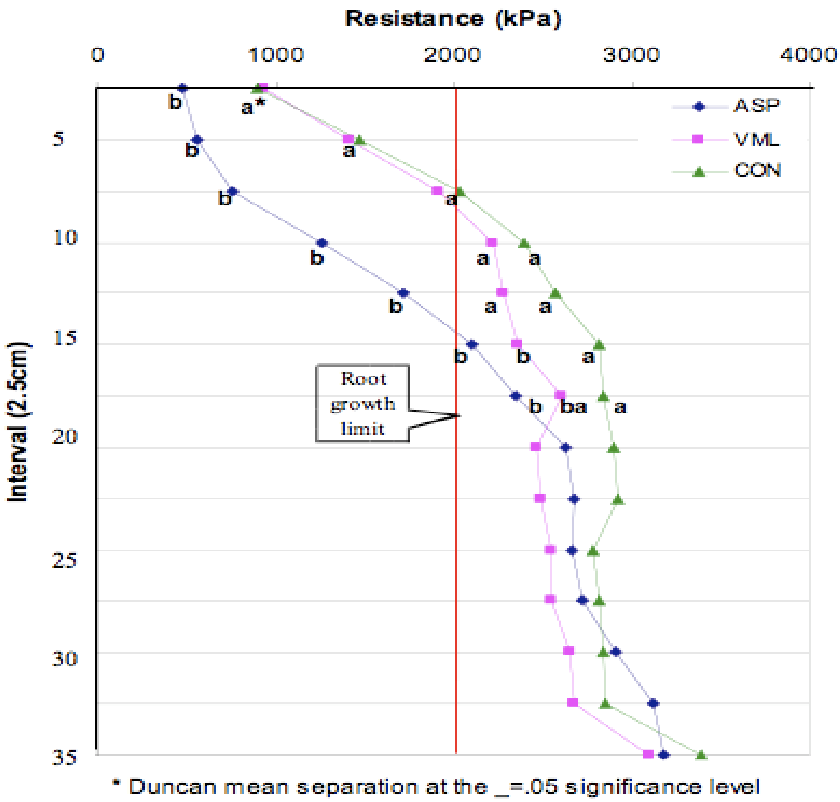

Figure 1. Mean resistance to penetration by 2.5 cm soil depth intervals in March 2006 following three soil amelioration treatments (ASP = air tillage with an Air Spade, VML = vertical mulching Con = mulching only)

Finally, preliminary results indicate several of trees had a positive growth response to air tillage, but differences were not measurable for most of the blocks.

CONCLUSIONS

Soil compaction is common on the University of Georgia campus. Air tillage is effective at ameliorating surface soil compaction and, as a result, may increase soil infiltration, reduce runoff and improve tree growth. Mulching alone is also effective at ameliorating soil compaction, but its benefits were only observed after three years. Vertical mulching has little beneficial effect on soil conditions when measured at a plot scale.

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