Soil Compaction on Campus: How to prevent it... How to correct it

Larry Morris
Community Forestry & Arboriculture
UGA Warnell School of Forestry and Natural Resources

Georgia Tree Council 2019 Campus Tree Conference
September 12, 2019
What is Soil Compaction?
Compression of unsaturated soil that reduces pore space and increased dry mass/volume

Key Factors Affected:
- Bulk Density
- Root Resistance
- Pore Space (Air-filled)
- Water Infiltration

Undisturbed
1.32 g/cm³
50% Solid
50% Pores

Compacted
1.60 g/cm³
60% Solid
40% Pores

Slide courtesy of L. Morris
What is Soil Compaction?
Compression of unsaturated soil that reduces pore space and increased dry mass/volume

Undisturbed
- 1.32 g/cm³
- 50% Solid
- 50% Pores

Compacted
- 1.60 g/cm³
- 60% Solid
- 40% Pores

Key Factors Affected:
- Bulk Density
- Root Resistance
- Pore Space
- Air-filled
- Water Infiltration
Measuring Compaction
Bulk Density (dry wgt/volume)
Measuring Compaction
Resistance to Penetration
Roots Can’t Growth in “Hard” Soil

Growth Relationship to Resistance

Roots growth through soil two ways:
1. Growing through pores larger than root tip diameter
2. Enlarging small pores through pressure generated by turgor

Adapted from Taylor and Barr 1991, Greacen and Sands 1980

Root Penetration (% of Max.)

Resistance to Root Penetration

Root growth stops @ 2 MPa, 290 psi

Slide courtesy of L. Morris
Resistance to Root Growth

Slide courtesy of K Fite
Roots Need Oxygen
Growth Relationship to Air-Filled Pores

Oxygen Diffusion ($D_{soil}/D_{air}$)

Air-Filled Pore Space

adapted from Vomocil and Flocker 1961

Slide courtesy of L. Morris
Compaction Process
Soil Moisture – Compaction Relationship
at a defined pressure (load)

Maximum compaction in moist soils near field capacity

Saturation – no air-filled pores

Soil Moisture Content %

Bulk Density (g/cm³)

Sand
Loam
Clay
Soil Compaction on Campus

- Construction Legacy (Donors!)
- Pedestrian Traffic (Student Life)
- Game Day Compaction
Construction Compaction

Donors and Building = Heavy Vehicles and Equipment
Large Equipment = Deep Compaction

Penetration Resistance (kPa)

Depth (cm)

Native Soil - Not Compacted

Compacted Construction Site

Root Growth Limiting Resistance

Penetration Resistance (psi)

Resistance (psi)

Slide courtesy of L. Morris
Pedestrian Traffic
Student Life

Slide courtesy of L. Morris
Pedestrian traffic = Surface Compaction

Source of surface pressure:
- Bulldozer
- Car
- Larry Standing
- Larry Heel Strike
- Gal Gadot in Heels

Pressure (psi):
- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140

Pressure (Mpa):
- 0.5
- 1.0

Applied Force

Slide courtesy of L. Morris
Game Day Compaction
Vehicles and Pedestrians

Slide courtesy of L. Morris
Soil Resistance

UGA Bus Stop

Root growth limiting

Post Tillage Compaction from Pedestrians

Residual Effects of Surface Tillage

Deep Compaction from Buses

Pressure (lbs/in²)

Depth (in)

0-1.0
1.0-2.0
2.0-3.0
3.0-4.0
4.0-5.0
5.0-6.0
6.0-7.0
7.0-8.0
8.0-9.0
9.0-10.0
10.0-11.0
11.0-12.0
12.0-13.0
13.0-14.0

0 100 200 300 400 500 600 700

Slide courtesy of L. Morris
Avoiding Compaction

1. Protect soil (not just trees) during construction
Avoiding Compaction

1. Protect soil (not just trees) during construction
2. Fit hardscape to use patterns – don’t expect use pattern to fit hardscape &
3. Landscape to encourage traffic concentration to hardscape
Ameliorating Deep Compaction Prior to Planting

- Disk harrowing/rototilling
  - Conventional disking or rototilling
  - 6-8 in. depth is typical
- Subsoiling/ chisel plowing
  - Shank pulled through soil, lifts and fracture
  - 12-16 inches
- Lift and drop
  - Backhoe used to excavate lift and drop soil back into place
  - Often used to prepare planting beds
Disking or Rototilling

Subsoiling

Lift and Drop Bed Preparation

Slide courtesy of L. Morris
## Ameliorating Deep Compaction

### Pre-planting

<table>
<thead>
<tr>
<th>Tillage Method</th>
<th>Depth (in.)</th>
<th>Volume (ft³/100 ft²)</th>
<th>Reduced Bulk Density/Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disking or Rototilling</td>
<td>8</td>
<td>66</td>
<td>Yes</td>
</tr>
<tr>
<td>Subsoiling (4 ft. center)</td>
<td>16</td>
<td>21</td>
<td>Yes</td>
</tr>
<tr>
<td>Lift and Drop</td>
<td>16</td>
<td>130</td>
<td>Yes</td>
</tr>
</tbody>
</table>

All of these are effective but note:

- **Greater Volumes = greater benefits**
- **Disking/rototilling does not ameliorate deep compaction**
- **Subsoiling needs dry soil, no infrastructure in vicinity**

*Slide courtesy of L. Morris*
Deep Compaction

This does not replace this

Lift and Drop with Excavator

Slide courtesy of L. Morris
Ameliorating Deep Compaction
Pre-planting
Lift and Drop Benefits
Compacted Construction Site after 3 Years

Slide courtesy of L. Morris
Ameliorating Deep Compaction Established Trees

• Radial Trenching
• Vertical Mulching
  • 4 in. auger holes at regular intervals, usually 6-8 inches
  • Compost/vermiculite/soil spread over the top and into the holes
• Air fracturing
  • Air forced into soil to lift soil, may inject solution
• Air Tillage (Air Spade)
  • Compressed air-tillage over the entire plot area to a depth of about 6-8 in
  • Compost incorporated, mulched on surface

Slide courtesy of L. Morris
Vertical Mulching

Radial Trenching

Air Fracturing

Air tillage(Air Spade™)
Root Growth and Vertical Mulching
3 years after treatment

Slide courtesy of L. Morris; Data source: Kalitz et al. 1994
Ameliorating Shallow Compaction Established Trees

- Compost or compost in combination with Air Tillage
  
  Encourage natural biota

- Radial Trenching
- Vertical Mulching
  - 4 in. auger holes at regular intervals, usually 6-8 inches
  - Compost/vermiculite/soil spread over the top and into the holes

- Air fracturing
  - Air forced into soil to lift soil, may inject solution

- Air Tillage (Air Spade)
  - Compressed air-tillage over the entire plot area to a depth of about 6-8 in
  - Compost incorporated, mulched on surface
Composting Alone

Air tillage (Air Spade™)
<table>
<thead>
<tr>
<th>Tillage Method</th>
<th>Depth (in)</th>
<th>Volume (ft³/100 ft²)</th>
<th>Bulk Density/Resistance Reduced?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting</td>
<td>1-2</td>
<td>0 → 16</td>
<td>Yes (years?)</td>
</tr>
<tr>
<td>Radial Trenching (15% area)</td>
<td>12</td>
<td>15</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Mulching (4” dia., 16” on center)</td>
<td>12</td>
<td>7</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Air fracturing (5 ft. on center)</td>
<td>12</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Air tillage (33% area)</td>
<td>8</td>
<td>22</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Slide courtesy of L. Morris
Ameliorating Compaction Established Trees
UGA Case Study

- No amelioration - Control
- Vertical Mulching
- Air tillage
Results: Bulk Density

Bulk Density g/cm$^3$

- PreTreat 2006
- Post Treat 2006
- Post Treat 2009

Graph showing the bulk density of different treatments from 2006 to 2009. The treatments include Control, Vertical Mulch, and Air Tillage.

Slide courtesy of L. Morris
Results: Resistance Just After Treatment (2006)

Slide courtesy of L. Morris
Results: Resistance After 3 Yrs. (2009)

- **Soil Resistance (kPa)**
  - 0
  - 1000
  - 2000
  - 3000

**Axes:**
- **Depth (in.)**
- **Soil Resistance (kPa)**

**Legend:**
- **Red:** Vertical Mulch
- **Blue:** Air Spade
- **Green:** Control

**Notes:**
- Slide courtesy of L. Morris
Recommendations

• Avoid compaction in the first place - Soil protection (not just tree protection) always best

• Prior to planting
  – Deep compaction (subsoil large areas; lift and drop to create planting beds)
  – Shallow compaction (disk or rototill)

• Established trees
  – Air tillage (1/3) of area beneath root crown in 3 annual treatments
  – Vertical mulch best when compacted layer (plow pan) penetrated (refill with compost-amended native soil)
Recommendations

• For all treatments, discourage continued trafficking (mulch – but this may not be enough, barriers)

• Periodic amelioration may be required on some sites
Questions?