Soil Compaction: Where, How Bad, What to Do?

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What is compaction?
What causes it?
What are some of the effects?
How can we measure compaction?
How can we manage compaction?

Thanks to the following for providing some of the slides and data used in this presentation:

- Dr. Randy Raper, Ag Engineer, USDA-ARS National Soil Dynamics Lab, Auburn, Alabama
- Dr. Peter Motavalli, Associate Professor, Soil, Environmental, and Atmospheric Sciences, University of Missouri

What is Compaction?

Compaction is simply a reduction in pore space

Composition of the Soil Volume

- Bulk density ($\rho_b$) = $M_b/V_b$
- Particle density ($\rho_s$) = $M_s/V_s$
- Porosity = $V_f/V_t = 1 - (\rho_b/\rho_s)$

Compaction Definitions

- Soil compaction – Decrease in soil volume and porosity, or increase in soil bulk density, due to mechanical stress on soil, for example, from traffic of agricultural machinery. Compaction can also occur naturally.
- Surface compaction – compaction that occurs in the surface “plow layer”
- Subsoil compaction – compaction that occurs below the plow layer due to a surface load.
What Causes Compaction?

Causes of Compaction

- Vehicle Traffic

Factors in Vehicle Compaction

- Weak soil
  - Moisture Content Effect
  - Density Effect

Factors in Vehicle Compaction

- Weak soil
- Excessive Loads
  - Size of Load at the Surface – Ground Pressure
Factors in Vehicle Compaction

- Weak soil
- Excessive Loads
  - Severity of Load at the Surface
  - Impact at Depth
  - For equal stress at the surface, larger tires affect soil to a greater depth
  - Vehicles have gotten larger!
- Repeated Loadings
  - First pass does 80% of total compaction
  - Repeated loadings increase compaction
  - Controlled traffic / Autoguidance

Causes of Compaction

- Vehicle Traffic
- Natural Soil
- Reconsolidation

Soil Particle Sizes

- Clay (< 0.002 mm)
- Silt (0.002 - 0.05 mm)
- Sand (0.05 - 2 mm)

Basketballs, Baseballs, and Marbles

- Sand and Silt
- Sand and Silt and Clay

Hardpan Profile

- Topsoil
- Hardpan
- Subsoil
Causes of Compaction

- Vehicle Traffic
- Natural Soil Reconsolidation
  - Well-graded soils more susceptible to natural compaction than poorly-graded soils

What are Some Effects of Compaction?

- Increased Soil Erosion
- Decreased Infiltration
- Decreased Water Storage
- Reduced N Uptake
**Effects of Compaction**

- Increased Soil Erosion
- Decreased Infiltration
- Decreased Water Storage
- Reduced N Uptake
- Decreased Root Growth

**Effects of Compaction on Yield**

<table>
<thead>
<tr>
<th>Turkey litter (dry Mg ha⁻¹)</th>
<th>Corn grain yield (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>7.6</td>
<td>7.6</td>
</tr>
<tr>
<td>12.8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Data collected at MU Bradford Farm (Columbia) by Motavalli et al.

<table>
<thead>
<tr>
<th>Turkey litter (dry Mg ha⁻¹)</th>
<th>Check</th>
<th>Compacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

NS

LSD (0.05)

**Compaction and Site-Specific Management**

- What is most often the major cause of within-field variation in crop productivity?
- It’s the water!

**It’s the water!**

- Soil and landscape factors that affect plant water availability are often the major causes of within-field yield variability.
- Soil water holding capacity
- Redistribution of water over landscapes
- Ability of roots to extract water
- Compaction affects all of these
How can we measure compaction?

• Directly:
  • Change in soil volume
  • Porosity
  • Bulk density

Measuring Compaction

• Measuring Compaction
  • Bulk density
    • Time consuming
    • Difficult to compare across soil types

Measuring Compaction

• Soil cone penetrometer
  • Measures the resistance of the soil to vertical insertion of a cone
    • Cone Index (CI) in units of pressure – psi or MPa
    • Standardized by ASABE (American Society of Agricultural and Biological Engineers) to allow data comparison between devices/locations
  • Difficult to get consistent readings with handheld, human-powered units

Measuring Compaction

• Soil cone penetrometer
  • Human-powered units with electronic data collection are more useful, but pushing them into the ground at a consistent speed can still be difficult

Compaction vs. Yield

Using Penetrometer Measurements

Data from a greenhouse study by Motavalli et al. using different Missouri soils

Y = 2.6 - 4.6X + 4.4X^2 - 1.4X^3
R^2 = 0.84***, n = 11

Sandy loam
Y = 0.98 - 0.20X
R^2 = 0.53*, n = 11

When BD < 1.4 Mg m^-3 then Y = -0.32X + 1.32
When BD > 1.4 Mg m^-3 then Y = -1.58X + 3.08
Measuring Compaction
- Soil cone penetrometer
  - Automated units use a power source to push them into the soil and record data simultaneously
  - Trailer-mounted
  - Tractor-mounted
  - Improved data collection
  - But still a point measurement

Within-Field Variation
- Using a penetrometer, it’s difficult to collect enough data to understand how compaction varies across fields
- Tillage draft sensors can collect surface compaction-related data on whole fields, but don’t indicate depth variations

A New Compaction Sensing Approach
- Desirable characteristics for a compaction sensor
  - Rapid, efficient data collection at the intensity needed for spatial within-field compaction mapping (i.e. on-the-go)
  - Describe compaction profile to identify the depth of restrictive layers
  - Repeatable, consistent measurements
- One solution:
  - Tractor-mounted shank that collects soil strength data at multiple depths
Soil Strength Sensors

- USDA-ARS, Auburn, AL (Raper et al.)
  - On-the-go Soil Strength Sensor (OSSS)
  - One sensor tip, moves up and down
- University of Nebraska (Adamchuk et al.)
  - Integrated Soil Physical Properties Mapping System (ISPPMS)
  - Blade-based sensor, measures total force and depth trend

USDA-MO SSPS – 5 extended sensing tips

- Width is 1 in. with cover on

USDA-MO SSPS Field Test Results

- Sensor worked well in field tests, showing both short-range and longer-scale variations in soil compaction

Compaction Mapping

How can we manage compaction?

- Avoiding Compaction
- Undoing Compaction
Avoiding Compaction

- Reduced Axle Load
  - Near surface
    - Compaction caused by specific pressure
  - Subsoil
    - Compaction caused by axle load

Avoiding Compaction: Research Results

- Assuming moist, arable soil:
  - 4.4 tons/axle compacts to 12 in.
  - 6.6 tons/axle compacts to 16 in.
  - 11 tons/axle compacts to 20 in.
  - 16.5 tons/axle compacts to 24 in. and deeper
- It’s common to see subsoil compaction persist for 6-7 years.

Approximate Axle Loads

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Axle Load (ton/axle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 hp 2-wheel drive tractor</td>
<td>4</td>
</tr>
<tr>
<td>200 hp 2-wheel drive tractor</td>
<td>5</td>
</tr>
<tr>
<td>330 hp 4-wheel drive tractor</td>
<td>8</td>
</tr>
<tr>
<td>6-row combine (empty)</td>
<td>10</td>
</tr>
<tr>
<td>6-row combine (full)</td>
<td>12</td>
</tr>
<tr>
<td>Single axle 27 yd³ grain cart (full)</td>
<td>26</td>
</tr>
<tr>
<td>Double dual-axle 50 yd³ manure tanker (full)</td>
<td>30</td>
</tr>
<tr>
<td>Double dual-axle 50 yd³ manure tanker (front)</td>
<td>28</td>
</tr>
</tbody>
</table>

Radial Tires & Proper Inflation Pressure

- 18 psi
- 6 psi

Tractive Performance Data
Benefits of Duals

- Reduced Axle Load
- Spread the Load
  - Increased Tire Size
  - Tire Construction - Radial tires
  - Multiple tires
- Tire Construction - Radial tires
- Multiple tires
- Tracks

Avoiding Compaction

- Reduced Axle Load
- Spread the Load
  - Increased Tire Size
  - Tire Construction - Radial tires
  - Multiple tires
  - Tracks

Effects of Duals and Tracks on Soil Density

- D-over
- C65
- C75
- D-correct
- Untraffic

Avoiding Compaction

- Reduced Axle Load
- Spread the Load
- Controlled Traffic
  - Wide-span vehicles
  - Automatic steered vehicles

Avoiding Compaction

- Reduced Axle Load
- Spread the Load
- Controlled Traffic
  - Wide-span vehicles
  - Automatic steered vehicles
Controlled Traffic Using AutoSteer

Undoing Compaction

- Natural Compaction Alleviation
  - Freeze-thaw
  - Shrink-swell

- Conservation Agricultural System
  - Reduced Vehicle Traffic
    - Conventional Tillage System
      - 80% of field may be trafficked from numerous field operations
      - 1st pass is responsible for 80% of compaction
    - Conservation Tillage System
      - Greater soil strength in row middles
      - Plant into old rows – controlled traffic
      - Fewer field trips reduces compaction over entire field
      - Residue management and cover crops improve soil structure

- Natural Compaction Alleviation
- Conservation Agricultural Systems
- Subsoiling
  - Subsoiling is not recommended on some Missouri soils, including claypan soils.

Undoing Compaction

- Conservation Agricultural System
  - Increased infiltration
  - Decreased evaporation
  - Increased carbon sequestration
  - Increased water storage

Strip Till, In-Row Subsoil, Non-inversion Subsoil
Once variably compacted areas are identified, management options could include:
- Variable-depth tillage
- Variable tillage (e.g., different operations in different parts of a field)
- Other variable management that takes compacted areas into account
- Variable-depth tillage based on cone penetrometer data has been investigated in the SE US

Site-specific Subsoiling

- Same crop yields for site-specific subsoiling as uniform deep subsoiling
- 27% fuel savings for site-specific subsoiling

Compaction Management Suggestions

- Only traffic when soil moisture is low
- Adopt conservation tillage system including cover crops
- Use controlled traffic systems
- Use smallest vehicle possible for job
- Use radial tires
- Minimize inflation pressure in radial tires
- Reduce contact pressure by using duals or tracks
- If necessary to remove effect of traffic, use in-row or bentleg subsoilers that minimally disturb soil surface

Questions?

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