

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

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

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

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

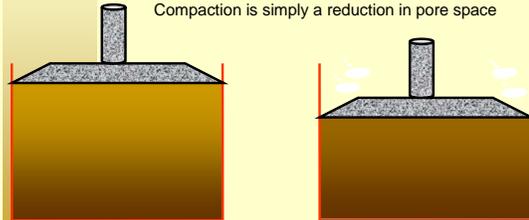
Thanks to the following for providing some of the slides and data used in this presentation:

- 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

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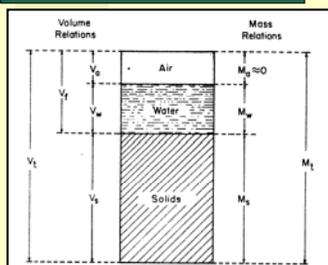
What is Compaction?

Compaction is simply a reduction in pore space



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Composition of the Soil Volume



- Bulk density (ρ_b) = M_s/V_t
- Particle density (ρ_s) = M_s/V_s
- Porosity = $V_t/V_t = 1 - (\rho_b/\rho_s)$

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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.

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What Causes Compaction?



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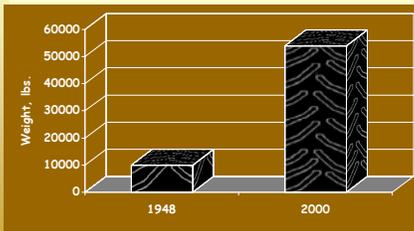
Causes of Compaction

- Vehicle Traffic



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Vehicle Traffic



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Vehicle Traffic



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Factors in Vehicle Compaction

- Weak soil
 - Moisture Content Effect
 - Density Effect



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Factors in Vehicle Compaction

- Weak soil
- Excessive Loads
 - Size of Load at the Surface – Ground Pressure



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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!



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Factors in Vehicle Compaction

- Weak soil
- Excessive Loads
 - Severity of Load at the Surface
 - Impact at Depth
 - Repeated Loadings
 - First pass does 80% of total compaction
 - Repeated loadings increase compaction
 - Controlled traffic / Autoguidance

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Causes of Compaction

- Vehicle Traffic
- Natural Soil Reconsolidation



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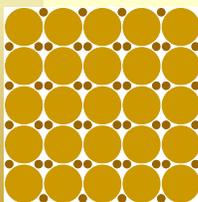
Soil Particle Sizes

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

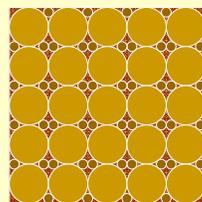
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Basketballs, Baseballs, and Marbles

Sand and Silt

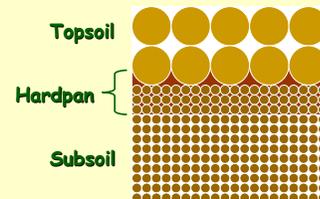


Sand and Silt and Clay



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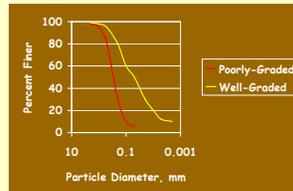
Hardpan Profile



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Causes of Compaction

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



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What are Some Effects of Compaction?



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Effects of Compaction

- Increased Soil Erosion



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Effects of Compaction

- Increased Soil Erosion
- Decreased Infiltration



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Effects of Compaction

- Increased Soil Erosion
- Decreased Infiltration
- Decreased Water Storage



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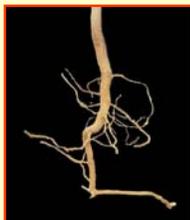
Effects of Compaction

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



Effects of Compaction

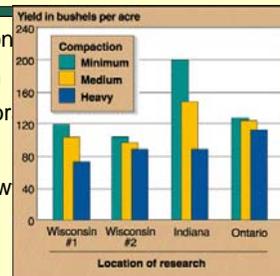
- Increased Soil Erosion
- Decreased Infiltration
- Decreased Water Storage
- Reduced N Uptake
- Decreased Root Growth



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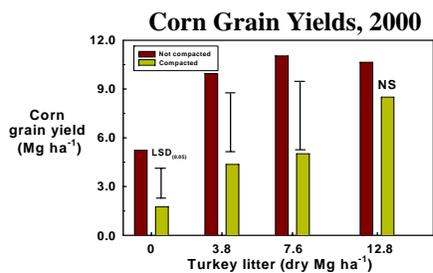
Effects of Compaction

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



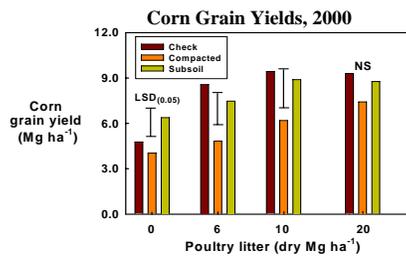
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Effects of Compaction on Yield



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

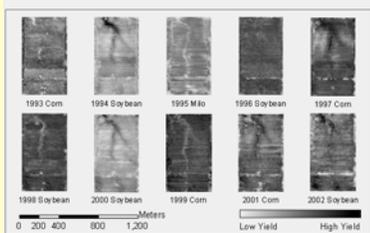
Effects of Compaction on Yield



Data collected at MU Delta Center (Portageville) by Motavalli et al.

Compaction and Site-Specific Management

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



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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

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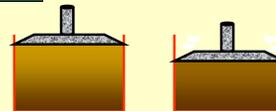
How can we measure compaction?



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Measuring Compaction

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



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Measuring Compaction

- Bulk density
 - Time consuming
 - Difficult to compare across soil types



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Measuring Compaction

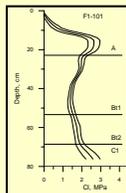
- Soil cone penetrometer
 - Measures the resistance of the soil to vertical insertion of a cone
 - Cone Index (CI) in units of pressure – psi or MPa
 - Standardized by ASABE (American Society of Agricultural and Biological Engineers) to allow data comparison between devices/locations
 - Difficult to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



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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

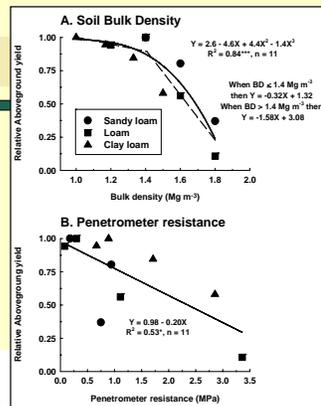


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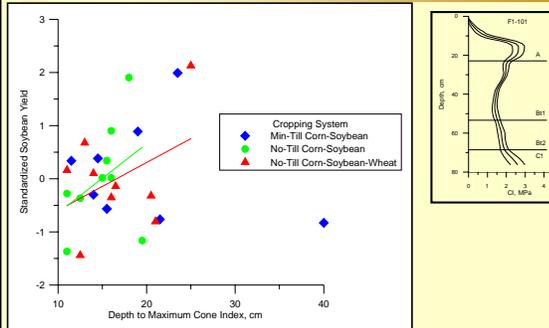
Compaction vs. Yield

Using Penetrometer Measurements

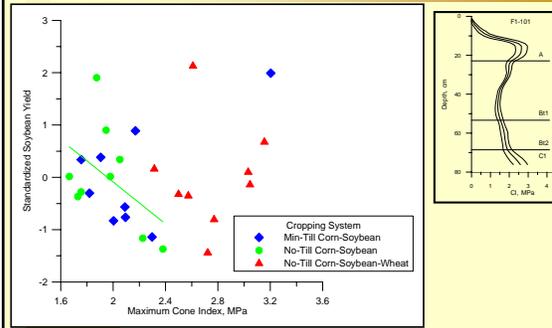
Data from a greenhouse study by Motavalli et al. using different Missouri soils



Compaction vs. Yield



Compaction vs. Yield



Measuring Compaction

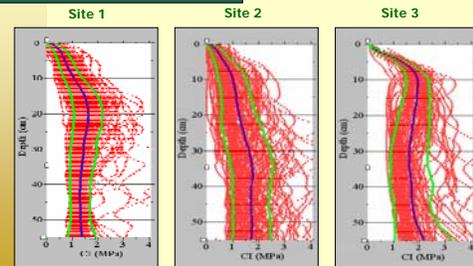
Soil cone penetrometer

- 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



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Within-Field Variation



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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



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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



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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



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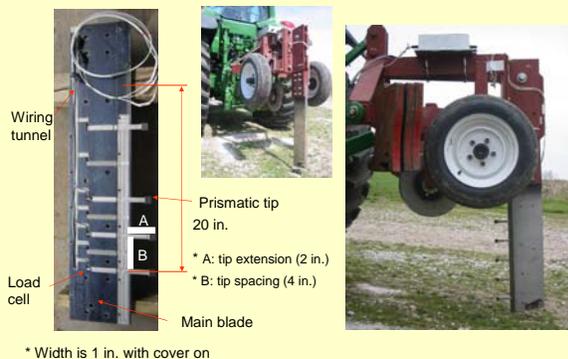
Soil Strength Sensors

- University of California (Upadhyaya et al.)
 - Compaction Profile Sensor (CPS)
 - Five sensor tips to 40 cm depth
- USDA-ARS, Columbia, MO (Sudduth et al.)
 - Soil Strength Profile Sensor (SSPS)
 - Five sensor tips to 50 cm depth



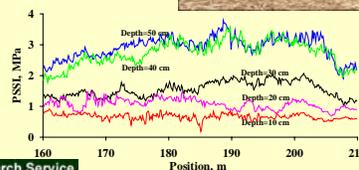
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USDA-MO SSPS – 5 extended sensing tips



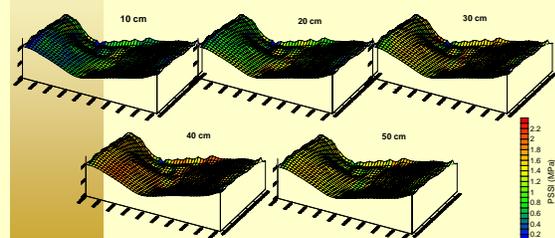
USDA-MO SSPS Field Test Results

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



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Compaction Mapping



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How can we manage compaction?

- Avoiding Compaction
- Undoing Compaction

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Avoiding Compaction

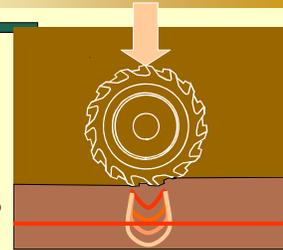
- Reduced Axle Load
 - Near surface
 - Compaction caused by specific pressure
 - Subsoil
 - Compaction caused by axle load



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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.



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Reeder, 1994

Approximate Axle Loads

Equipment	Axle Load (ton/axle)
100 hp 2-wheel drive tractor	4
200 hp 2-wheel drive tractor	8
320 hp 4-wheel drive tractor	9
6-row combine (empty)	11
12-row combine (full)	26
Single axle 27 yd ³ grain cart (full)	22
Double dual-axle 50 yd ³ manure tanker (full)	35 (rear) 15 (front)

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Avoiding Compaction

- Reduced Axle Load
- Minimize Tractive Element-Tire Contact Stress (Spread the Load)
 - Increased Tire Size
 - Height
 - Width
 - Tire Construction - Radial tires

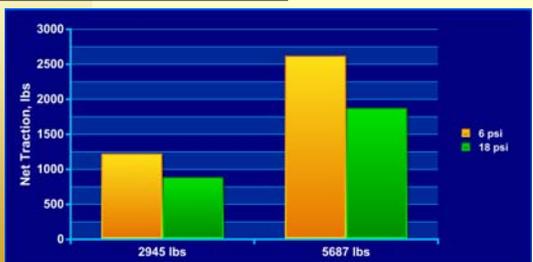
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Radial Tires & Proper Inflation Pressure



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Tractive Performance Data



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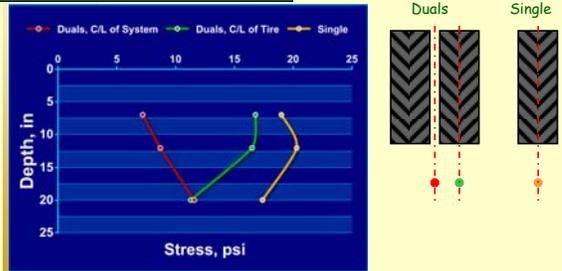
Avoiding Compaction

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



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Benefits of Duals



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Taylor et al., 1975

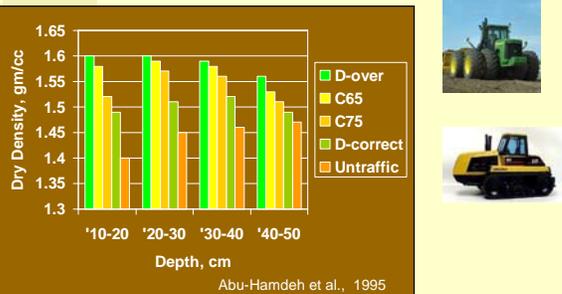
Avoiding Compaction

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



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Effects of Duals and Tracks on Soil Density



Abu-Hamdeh et al., 1995

Avoiding Compaction

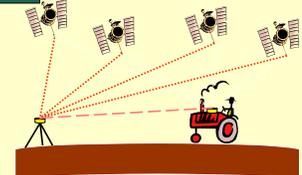
- Reduced Axle Load
- Spread the Load
- Controlled Traffic
 - Wide-span vehicles



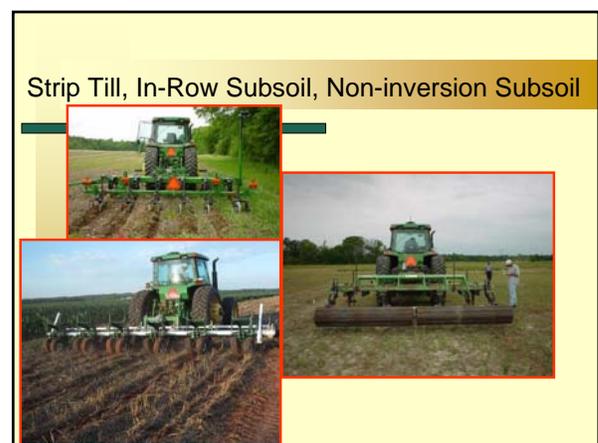
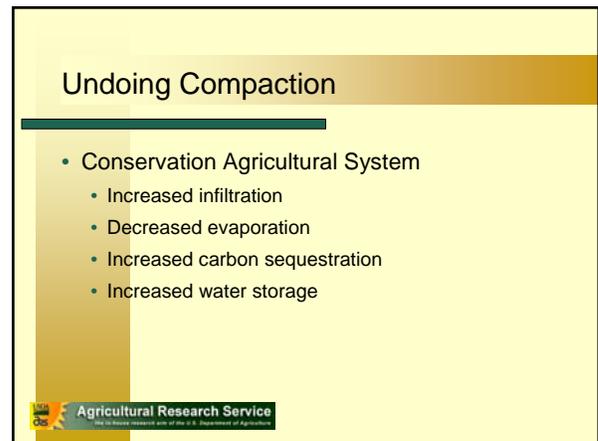
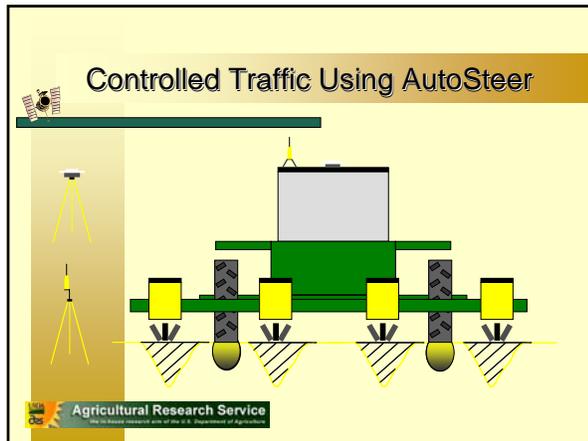
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Avoiding Compaction

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



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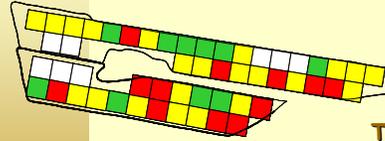


Site-specific compaction management

- 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

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Site-specific Subsoiling



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

Tillage Depth

- 25 cm-1.0 ha
- 35 cm-2.2 ha
- 45 cm-1.2 ha

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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

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Questions?

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