Compaction; Machinery Selection and Operation

FarmSmart Compaction
Waterloo, Ontario

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Food, Agricultural and Biological Engineering
Trends in Ballasted Tractor Weight

Spark Ignition Engines

Compression Ignition Engines

Note: Maximum tractor weight is increasing at a rate of 900 lb/yr.
Fixed-Frame 500 hp Tractor

http://www.used-fendt-tractors.com

http://farmindustrynews.com
How big is too big?

http://www.bauerbuiltmg.com/db-series-planters.html
High GVW Loads at Harvest
Traction vs. Transport
Contact and Internal Soil Pressures
  Tires - Soehne (1957)
  Tires and Tracks - Rethmel and Harris (2013)
Traction Mechanics
Proper Ballasting
Yield Loss Estimation
  High Resolution Yield Maps
Recent Developments
Summary
Traction vs. Transport
Traction vs. Transport

• **Device** – tires or tracks that provide vertical support (mobility) and, sometimes steering capability

• **Vertical Support** -- arises from soil and tire deformation, soil pressure distribution, tire load capacity, and stiffness and damping characteristics of tire

• **Traction Device** -- powered to provide tractive capability to the vehicle (overcome rolling resistance and support draft loads)

• **Transport Device** -- unpowered, provides flotation and reduced rolling resistance
Figure 13.1. In a general off-road situation, both the tire and terrain deform. (From Aubel, 1993.)
Soehne (1957)
Soil Pressure Modeling
Fig. 3 Curves of equal pressure (pressure bulbs) under a point load at different concentration factors

Source: Soehne (1957)
Soil Pressure vs. Wheel Load

Fig. 6 Calculated curves of equal pressure (pressure bulbs) under different tractor tires

Source: Soehne (1957)
Fig. 4 Contact areas between tire and soil for different soil conditions

Source: Soehne (1957)
Fig. 15 Track depth under narrow, wide and twin trailer tires at different inflation pressures

Source: Soehne (1957)
Fig. 7 Calculated curves of equal pressure (pressure bulbs) under a tractor tire for different soil conditions

Source: Soehne (1957)
Fig. 8 Calculated curves of equal pressure (pressure bulbs) under narrow, wide and twin trailer tires with different inflation pressures

Source: Soehne (1957)
• Contact area between tire and soil is a function of soil moisture – don’t traffic wet soils.
• Contact area (tire size and numbers) affects quantity of displaced soil – more tire contact area is better.
• Majority of compaction accomplished on first pass – multiple passes not additive.
• Surface contact pressure very close to tire inflation pressure – run tires at lowest allowable pressure.
• Depth of compaction influence is a function of tire load, not tire pressure – reduce axle loads to reduce compaction.
• Multiple axles better option than multiple tires on fewer axles.
• Multiple or wider tires better option for high axle loads.
Rethmel and Harris (2013)
Soil Pressure Measurements
Source: Rethmel and Harris (2013)
Preliminary Test Setup

Source: Rethmel and Harris (2013)
Sand Pit Construction

Source: Rethmel and Harris (2013)
520/85R42 Footprints at Various Depths

Source: Rethmel and Harris (2013)
Time-Varying Soil Pressures

Source: Rethmel and Harris (2013)
<table>
<thead>
<tr>
<th>Tractor Comparisons</th>
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<tbody>
<tr>
<td><strong>Brand</strong></td>
<td>John Deere</td>
<td>John Deere</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>8335R</td>
<td>8320RT</td>
</tr>
<tr>
<td><strong>Rated HP Engine (Gross)</strong></td>
<td>335</td>
<td>320</td>
</tr>
<tr>
<td><strong>Total Machine Weight (lbs.)</strong></td>
<td>35900</td>
<td>35900</td>
</tr>
<tr>
<td><strong>Front Axle Weight (lbs.)</strong></td>
<td>15500</td>
<td>22000</td>
</tr>
<tr>
<td><strong>Rear Axle Weight (lbs.)</strong></td>
<td>20400</td>
<td>13900</td>
</tr>
<tr>
<td><strong>Front Tire Size</strong></td>
<td>Firestone 420/86R34 RAT DT (Duals)</td>
<td>18&quot; Wide Tracks</td>
</tr>
<tr>
<td><strong>Rear Tire Size</strong></td>
<td>Firestone 480/80R50 DT 23 (Duals)</td>
<td>18&quot; Wide Tracks</td>
</tr>
</tbody>
</table>

Source: Rethmel and Harris (2013)
Std., IF Tires and Tracks at 3.0 in. Depth

Source: Rethmel and Harris (2013)
Std., IF Tires and Tracks at 7.0 in. Depth

Source: Rethmel and Harris (2013)
Rethmel and Harris Summary

- Based on the testing conducted it was determined that standard dual tires create more subsurface pressure compared with 1 in. wide tracks.
- Operating tires at IF conditions offer an advantage in subsurface pressure.
- Additional testing required for all traction devices for high draft loads.
- Additional testing required to determine what level of subsurface pressure correlates to measurable crop yield impact.
• Empirical methods using field and/or soil bin laboratory tests of traction devices either by themselves or as part of a complete vehicle are the most used technique for assessing tractive performance by both vehicle and traction device manufacturers.

• Plots of the typical quantities (input torque $T$ and net tractive force $H$) that are measured in such tests and free body diagrams illustrating the forces acting on the wheel during different portions of the test.

• Although a wheel is shown and discussed here, the same concepts apply to a tracked traction device.
Figure 13.11. (a) Net traction (pull)-torque-slip relation for wheels on soil. (From Wismer and Luth, 1974.) (b) Free body diagram of a towed wheel. (c) Free body diagram of a driving wheel.
Figure 13.13. Tractive efficiency, net traction ratio, and motion resistance ratio versus slip results for a typical traction test. (From Zoz, Turner, and Shell, 2002.)
Figure 13.14. The traction test results from Figure 13.13 plotted as a function of net traction ratio. (From Zoz, Turner, and Shell, 2002.)
Figure 13.15. Effect of tire overinflation on tractive performance. (From Zoz, 1997.)
Figure 13.16. Comparison of tractive performance of three different width rubber tracks to a pneumatic tire on a tilled soil condition. (From Zoz, 1997.)
Tractive Efficiency and Soil Type

![Graph showing tractive efficiency for different soil types.](image)

- **Concrete**
- **Firm soil**
- **Tilled soil**
- **Soft or sandy soil**

- **Wheel slip (percent)**
- **Tractive efficiency (percent)**

- Power is limited by rolling resistance
- Power is limited by wheel slip
• Tracks are more efficient than wheels.
• Optimal tractive efficiency occurs at 10-15% slip for wheels and 4-10% slip for tracks.
• Tractive efficiency is a function of soil type.
Proper Ballasting
Tire Construction

Radial

Bias Ply
Figure 13.17. Tire Parameters. (From Brixius, 1987.)
Radial vs. Bias

- Radial tire construction is substantially different from bias tire construction.
- Crossed plies of the bias tire (right) run diagonally from bead to bead.
- Carcass plies run in a radial direction from one bead to another for radial tires.
- Radial tires also have stiff belts in the tread area that restrict growth and stabilize the lugs when they contact the ground.
- Radial tires have more supple sidewalls than bias tires that, in combination with the stiff belts, provide traction and efficiency superior to bias tires.
<table>
<thead>
<tr>
<th></th>
<th>Total Tractor Weight</th>
<th>Percent on Front Axle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4WD</strong></td>
<td>85-125 pounds per engine horsepower.</td>
<td>For towed implements, use 51-55%. This is very important to help in control of power hop. With no hitch, PTO or ballast, the front will be 60% or more out of the factory. For hitch-mounted implements, use 55-60%. For towed implements with very high downward loads on drawbars, use 55-65%.</td>
</tr>
<tr>
<td><strong>MFWD</strong></td>
<td>120-145 pounds per PTO horsepower. 130 is most common.</td>
<td>35-40% for all types of implements. Power hop is easier to control as front split is reduced.</td>
</tr>
<tr>
<td><strong>2WD Row Crop</strong></td>
<td>Same as MFWD.</td>
<td>25-35%. Use higher percentage with heavy hitch-mounted implements.</td>
</tr>
</tbody>
</table>
Yield Loss Estimation; Modeling
Surface vs. Sub-Surface Compaction

Source: Hakaansson and Reeder (1994) and Duiker (2004).
Surface vs. Sub-Surface Compaction

Source: Hakaansson and Reeder (1994) and Duiker (2004).
Empirical Yield Loss Model

\[ Y_{cf} = T_{df} S_{tf} \left[ 0.2D_{tc} T_{tt} (5 - Y_{att}) (c_1 L_a + c_2) + 0.1D_{sc} T_{st} (10 - Y_{ast}) (c_1 L_a + c_2) \right] \]

- \( Y_{cf} \) – yield compaction reduction factor (0.0 to 1.0)
- \( L_a \) – axle load (tons)
- \( S_{tf} \) – soil type factor (0.0 to 1.0)
- \( c_1 \) – compaction factor 1
- \( c_2 \) – compaction factor 2
- \( Y_{att} \) – years after topsoil trafficking event (0 to 5)
- \( Y_{ast} \) – years after subsoil trafficking event (0 to 10)
- \( D_{tc} \) – topsoil depth compaction factor
- \( D_{sc} \) – subsoil depth compaction factor
- \( T_{tt} \) – topsoil tillage correction factor
- \( T_{st} \) – subsoil tillage correction factor
- \( T_{df} \) – traction device factor (0.0 to 1.0)
Yield Loss vs. Axle Load – Corn

\[ y = 0.0111x - 0.0113 \]
\[ y = 0.0046x - 0.1136 \]
\[ y = 0.0078x - 0.0624 \]
Empirical Depth of Influence Model

Source: Hakaansson and Reeder (1994)

\[ y = 5.8862x^{0.5013} \]

\[ R^2 = 0.9884 \]
<table>
<thead>
<tr>
<th>Equipment axle load</th>
<th>Tons/axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 WD tractor, 200 hp, front axle</td>
<td>7.5</td>
</tr>
<tr>
<td>4WD tractor, 325 hp, front axle</td>
<td>13</td>
</tr>
<tr>
<td>4WD tractor, 530 hp, front axle</td>
<td>18</td>
</tr>
<tr>
<td>TerraGator, rear axle</td>
<td>12-18</td>
</tr>
<tr>
<td>Slurry tanker, 4,200 gal.</td>
<td>10-12</td>
</tr>
<tr>
<td>Slurry tanker, 7,200 gal.</td>
<td>17-18</td>
</tr>
<tr>
<td>Class 9 combine, 590 hp, 360 bu. capacity</td>
<td>20</td>
</tr>
<tr>
<td>12-row combine, full, with head</td>
<td>24</td>
</tr>
<tr>
<td>Grain cart, 720 bu., full, 1 axle</td>
<td>22</td>
</tr>
<tr>
<td>Grain cart, 1,200 bu., full, 1 axle</td>
<td>35-40</td>
</tr>
</tbody>
</table>

Loads greater than 10 tons/axle will cause subsoil compaction when the soil is wet.
## Compaction from combine tires and half-tracks

*Ranked from most (top) to least severe*

<table>
<thead>
<tr>
<th>Tires/Tracks</th>
<th>PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.5 L32 singles</td>
<td>34</td>
</tr>
<tr>
<td>Half-track</td>
<td>Average 10 psi</td>
</tr>
<tr>
<td>18.4 R38 duals</td>
<td>26</td>
</tr>
<tr>
<td>68 x 50.0-32</td>
<td>24 psi (overinflated)</td>
</tr>
<tr>
<td>68 x 50.0-32</td>
<td>15 psi (correctly inflated)</td>
</tr>
</tbody>
</table>

Lower tire inflation pressure causes less topsoil compaction.
Compaction Problem Flow Chart

Surface Compaction

- Increased Soil Strength
  - More root branching (if moderate compaction)
  - Less root growth (if high compaction)
  - Better seed-soil contact
  - Less evaporation
- Fewer Large Pores
  - Fewer large organisms such as pest predators
- Decreased Infiltration
- Decreased Water Holding Capacity
- Slowed Drainage
  - Cool soil in spring
  - Low microbial activity
  - Low oxygen
  - Growth of anaerobic bacteria
  - Slow germination
  - Reduced nutrient availability
  - Reduced nutrient and water uptake
  - Drought susceptibility
- Shallower Rooting

Subsoil Compaction

Better traction, but requires more energy to pull implements through soil

More nutrient and water uptake (if moderate compaction)*

More nutrient and water uptake (if high compaction)

Faster germination (if moderate compaction)*

Decreased complexity of the soil food web
Potential changes in nutrient cycling and pest dynamics

Increased runoff

*Moderate compaction is that created by less than 5 ton axle loads on dry soil.
Yield Loss Estimation; High Resolution Yield Maps
Yield Map Resolution Enhancement

Visible V12  
Yield Map  
Adjusted Map

Yield (bu/ac)
- 10 to 90
- 90 to 125
- 125 to 150
- 150 to 175
- 175 to 200
- 200 to 226
Recent Developments
IF and VF Tire Technology
Mitas PneuTrac Tire Technology
Proliferation of Tracks

(Source: bourgault.com)

(Source: oemoffhighway.com)
\[ y = 6.2884e^{0.0534x} \]

\[ R^2 = 0.9992 \]

Seeding rate of 65 ac/h – 13.5 mi/h!
What did we learn?

Traction:
1. Need proper ballast for anticipated load (120 lb/hp for MFWA) – lowest possible GVW for operation.
2. Need proper weight split between front and rear axles (40% front and 60% rear for MFWA).
3. Tractive efficiency is maximized for wheel slip by tractor type (10-20% slip for MFWA tractor).
4. Adjust ballast if slip is too high or too low.
5. Tracks are better than wheels – higher tractive efficiency. Note: Can buy a lot of fuel for added cost of tracks.
6. Run lowest allowable tire pressure (observe warranty) to maximize surface contact area.
7. Radial tire construction better than bias ply – sidewalls flex allowing more contact area.
8. IF and LF tires are great! Size options may be limited.
What did we learn?

High GVW Loads

1. Alex load determines depth of compaction, more axles better for alleviating compaction.
2. More tires per axle is less attractive alternative to more axles.
3. Axle loads of 10 Tons or less do minimal damage.
4. IF and LF tires are great! Size options may be limited.
5. If you are limited by row crop requirements (18.4 section width), big diameter tires are better – more contact area.
6. Tracks are typically better than row crop tires.
7. Wide tracks better than narrow.
8. High inflation pressures lead to more serious compaction events.
9. Limit field activities in wet soils!
10. Soil movement (wheel track depth) good indication of compaction problems.
Questions?