How does soil compaction influence the growth of spruce seedlings?

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Presentation roadmap

- Relative bulk density concept
- Methods with focus on compaction procedure
- Overview of main results
Machine and soil interaction

- Impacts of forest machines on their operating environment has been well researched.

- Not uncommon to experience 15–20% increases in absolute soil bulk density between pre and post impact.

- More operations are performed on un-frozen soils or soils with high moisture content.
Relative bulk density

- Concept developed in geotechnique as a measure of quality control of the bearing layer of roads.

\[ \text{RBD} = \frac{\text{FBD}}{\text{MBD}} \]

- In 1990, Carter tested the effect of varying RBD's on the growth of agricultural crops and reported reduced growth beyond 80% of the MBD.

- What about high value tree species found in Germany?
Relative bulk density

MBD = 1.61 g/cm³ or 15.8 kN/m³
OMC = 18.8%
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Testing

- 24 chamber system (42 cm × 30 cm × 8 cm)
- 4 RBD thresholds (0.67, 0.72, 0.77, 0.82)
- RBD thresholds were randomly assigned to each chamber
Compaction procedure

- Added required amount of wet soil to reach desired density, based on the volume per lift.

- Used load frame to apply vertical force needed to compact the lift to target height (12.3 cm).

- Applied same procedure for two additional lifts of equal heights.

6 chambers at 0.67 (1.08 g cm$^{-3}$)
6 chambers at 0.72 (1.16 g cm$^{-3}$)
7 chambers at 0.77 (1.24 g cm$^{-3}$)
5 chambers at 0.82 (1.32 g cm$^{-3}$)
In-situ root growth monitoring

- Scanning frequency of once per 4–5 days as soon as roots were visible.
- High resolution scans at 1,200 dpi (±30 MB/scan).
- Identical positioning of chamber in scanning frame.
Results

Root depth = 5 cm

RBD of 0.67
Results

Root depth = 6.8 cm

Root growth = 1.8 cm
Results

Root depth = 27.4 cm

Root growth = 2.4 cm

Growth of 22.4 cm in 55 days (0.4 cm day\(^{-1}\))

RBD of 0.67
Extraction
Response of biomass to varying RBD levels

Average dry mass per seedling (mg)

48% reduction

Relative bulk density

43% reduction
## Root length, root collar and shoot height

### Root length (cm)

<table>
<thead>
<tr>
<th>RBD levels</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
<th>Std. Dev. a</th>
<th>Percent difference to RBD 0.67</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>9.34</td>
<td>65.17a</td>
<td>141.92</td>
<td>38.69</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td>0.72</td>
<td>2.77</td>
<td>49.41ab</td>
<td>173.21</td>
<td>46.20</td>
<td>-24.18</td>
<td>25</td>
</tr>
<tr>
<td>0.77</td>
<td>6.09</td>
<td>35.28b</td>
<td>86.78</td>
<td>21.19</td>
<td>-46.86</td>
<td>32</td>
</tr>
<tr>
<td>0.82</td>
<td>10.93</td>
<td>30.44b</td>
<td>67.87</td>
<td>18.59</td>
<td>-53.29</td>
<td>21</td>
</tr>
</tbody>
</table>

### Root collar diameter (mm)

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
<th>Std. Dev. a</th>
<th>Percent difference to RBD 0.67</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>0.93</td>
<td>1.52a</td>
<td>2.30</td>
<td>0.29</td>
<td>-</td>
</tr>
<tr>
<td>0.72</td>
<td>0.74</td>
<td>1.40a</td>
<td>3.12</td>
<td>0.56</td>
<td>-8.27</td>
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<tr>
<td>0.77</td>
<td>0.75</td>
<td>1.36a</td>
<td>2.41</td>
<td>0.37</td>
<td>-10.94</td>
</tr>
<tr>
<td>0.82</td>
<td>0.92</td>
<td>1.35a</td>
<td>2.22</td>
<td>0.40</td>
<td>-11.12</td>
</tr>
</tbody>
</table>

### Shoot height (cm)

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
<th>Std. Dev. a</th>
<th>Percent difference to RBD 0.67</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>3.20</td>
<td>6.10a</td>
<td>10.20</td>
<td>1.81</td>
<td>-</td>
</tr>
<tr>
<td>0.72</td>
<td>2.90</td>
<td>5.95a</td>
<td>12.60</td>
<td>2.18</td>
<td>-2.49</td>
</tr>
<tr>
<td>0.77</td>
<td>2.80</td>
<td>5.53a</td>
<td>10.10</td>
<td>1.81</td>
<td>-9.39</td>
</tr>
<tr>
<td>0.82</td>
<td>2.70</td>
<td>4.90a</td>
<td>7.30</td>
<td>1.26</td>
<td>-19.80</td>
</tr>
</tbody>
</table>
Root growth – per diameter class

![Box plots showing average root length per seedling (cm) for different diameter classes and relative bulk density levels.](image)

- **<0.10 mm**: Lower average root length, no significant differences between treatments.
- **0.10–0.20 mm**: Increased average root length, with significant differences between treatments marked by different letters.
- **0.21–0.30 mm**: Further increase in average root length, with consistent differences.
- **0.31–0.40 mm**: Similar pattern as previous classes.
- **0.41–0.50 mm**: Additional increase in root length and more pronounced treatment effects.
- **0.51–1.00 mm**: Highest root length with marked differences between treatments.

*Note: Treatments marked with different letters indicate significant differences.*
Future work…one of the missing links

- What does this imply for forest operations?

- How can we be proactive instead of reactive when scheduling forest machines to harvest sites?

- How do laboratory results compare to seedlings and trees growing in the forest?

- What type of traffic can be allowed not to exceed growth impeding thresholds?
Thank you for your kind attention!

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Appendices
Shoot growth over time

[Graph showing the growth of seedlings over days since seeding, with lines representing different levels of growth and their corresponding equations and R-squared values.]

- **RBD**
  - **Levels**
  - Level 0.67: $y = 2.101 + 0.04162x - 0.000033x^2$, $R^2 = 99.0$, $N = 6$
  - Level 0.72: $y = 2.305 + 0.04349x - 0.000076x^2$, $R^2 = 97.8$, $N = 6$
  - Level 0.77: $y = 1.673 + 0.06292x - 0.000237x^2$, $R^2 = 98.2$, $N = 7$
  - Level 0.82: $y = 2.437 + 0.03248x - 0.000057x^2$, $R^2 = 98.7$, $N = 5$
Soil sampling and preparation

- 800 kg of soil
- Material was air-dried, oven-dried at 60°C, and then pulverized
- Sieved through 4.00 mm sieve

Particle size distribution:
- Gravel (> 2.00 mm) = 11.0%
- Sand (0.063 mm < x ≤ 2.00 mm) = 25.4%
- Silt (0.002 mm < x ≤ 0.063 mm) = 52.2%
- Clay (< 0.002 mm) = 11.4%

Atterberg limits:
- Liquid limit = 34.8%
- Plastic limit = 21.5%
- Plasticity index = 13.3%
Relative bulk density

\[ y = -0.0016x^2 + 0.0606x + 1.0414 \]
\[ R^2 = 0.9213 \]
Seeding

- Initial tests performed with European beech.
- 5 Norway spruce seeds planted in a 1 cm deep furrow on April 9, 2018.
- Furrows were back-filled.
Accuracy and repeatability
Compaction procedure

- Added 550 g of sand followed by 550 g of coarse gravel at the bottom of each chamber.
Future work…the missing link

- What does this imply for forest operations?

- **Phase 1**: Determine growth impeding relative bulk density thresholds for different tree species growing in soils with different textures.

- **Phase 2**: In-stand testing of machinery impacts. How are residual trees and seedlings responding in the forest?
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