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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.

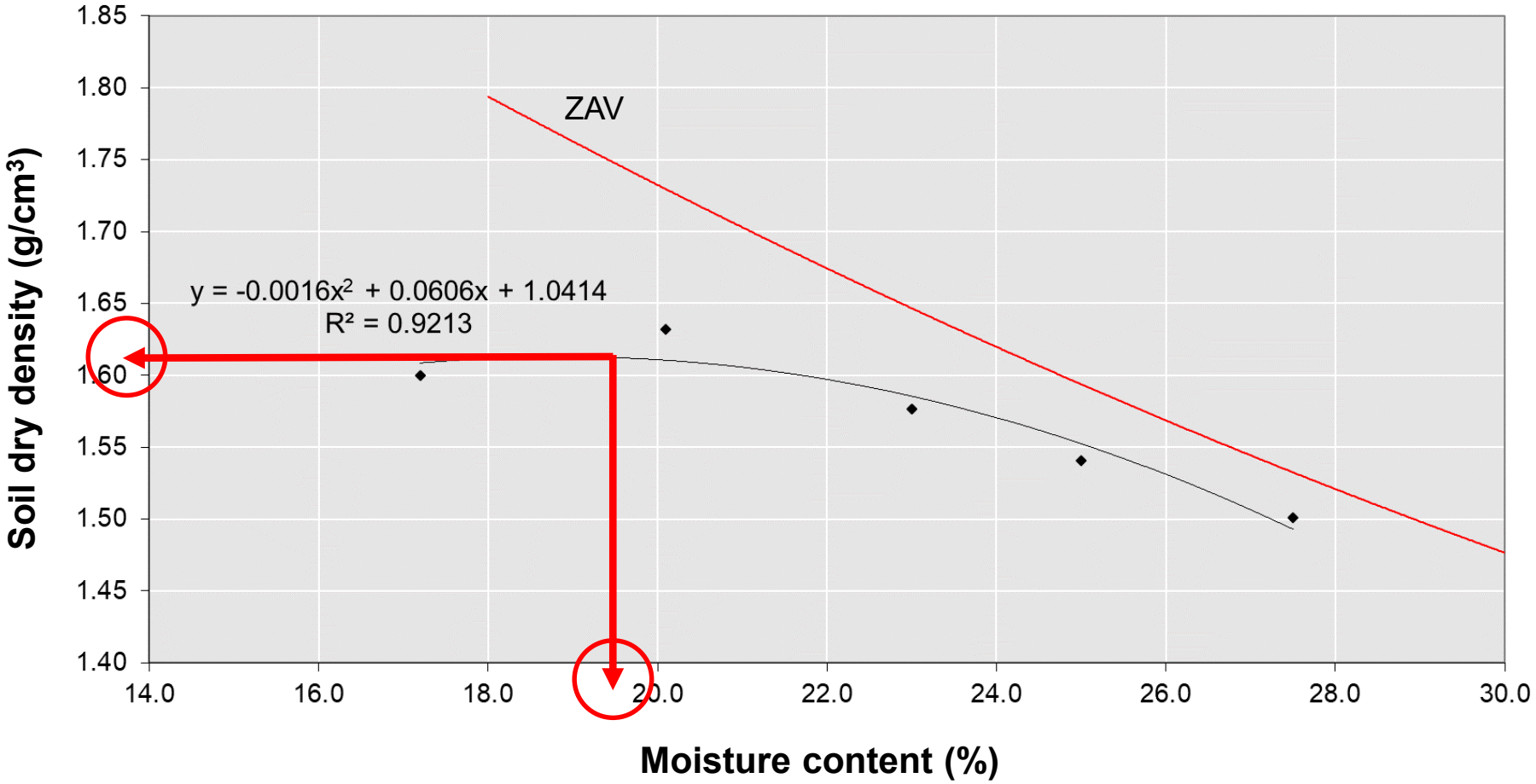
$$RBD = \frac{FBD}{MBD}$$

- 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.

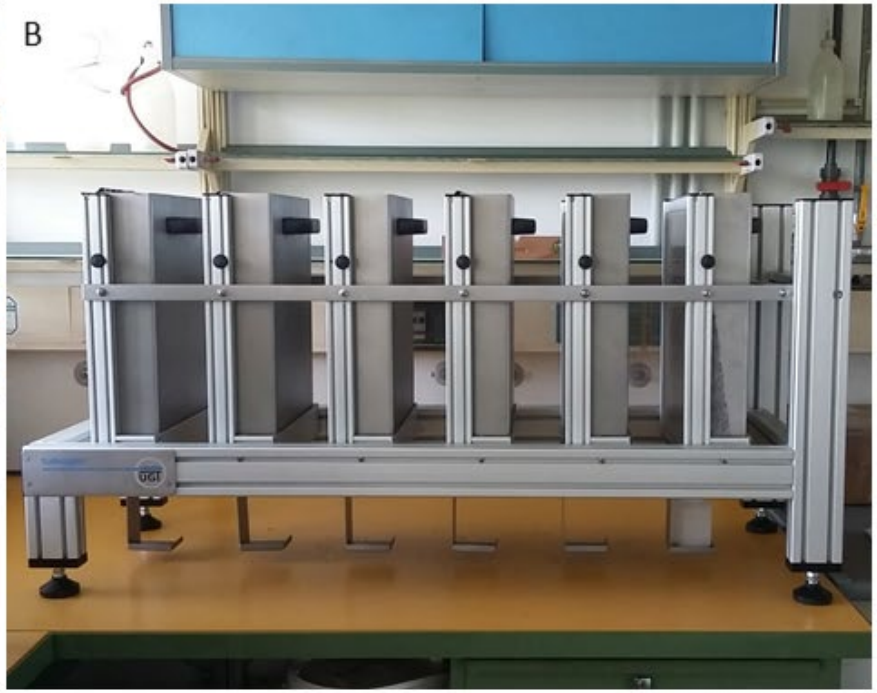
- What about high value tree species found in Germany?

Relative bulk density

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



Testing

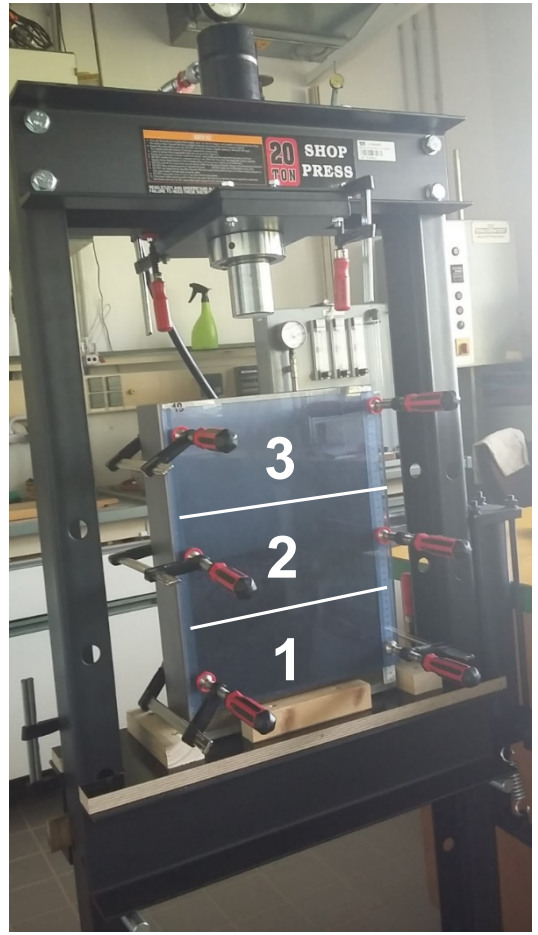


- **24 chamber system (42 cm × 30 cm × 8 cm)**
- **4 RBD thresholds (0.67, 0.72, 0.77, 0.82)**
- **RBD thresholds were randomly assigned to each chamber**

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})



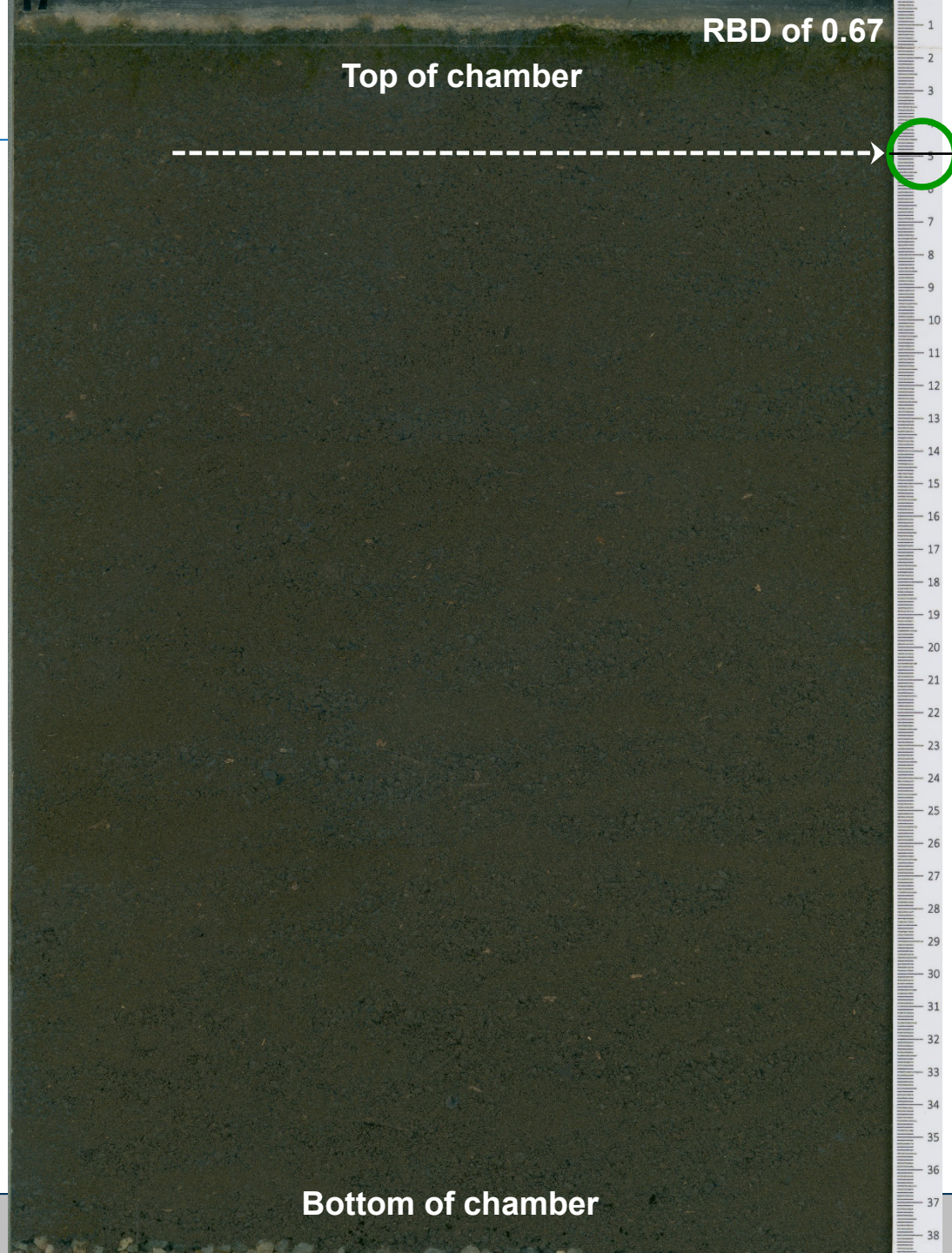
In-situ root growth monitoring

- 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.

Adapted from UGT

Results

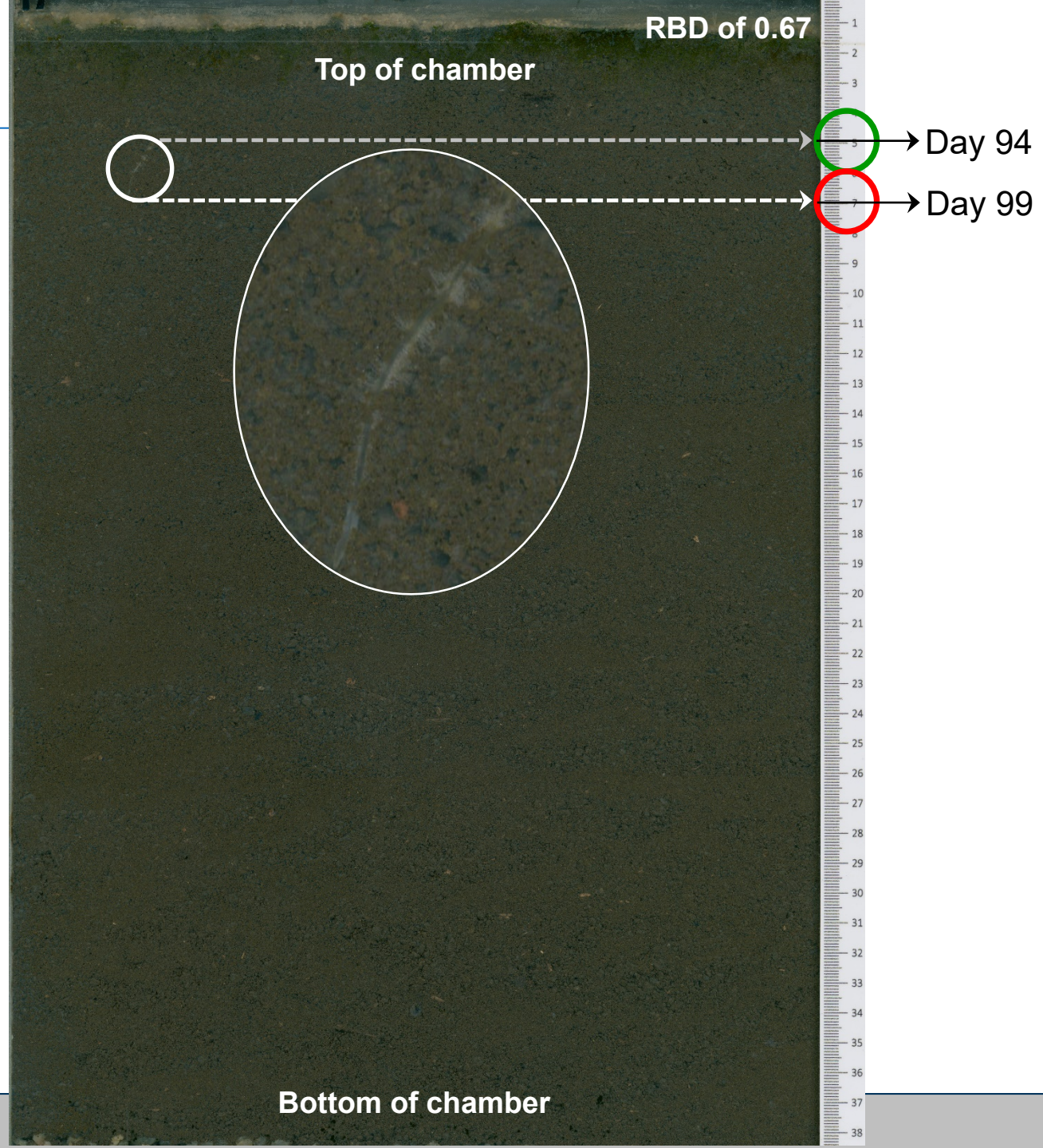
Root depth = 5 cm



Results

Root depth = 6.8 cm

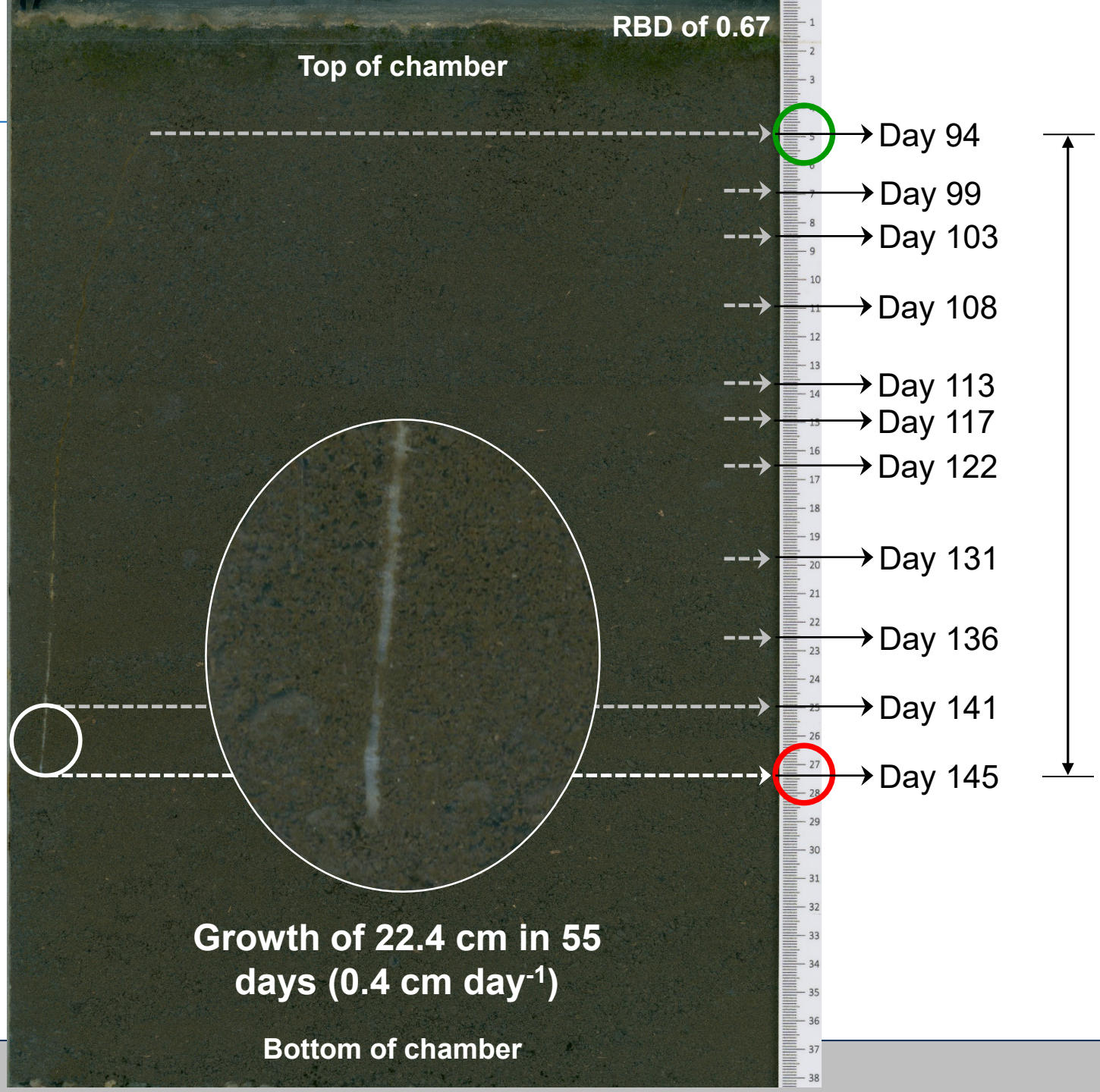
Root growth = 1.8 cm



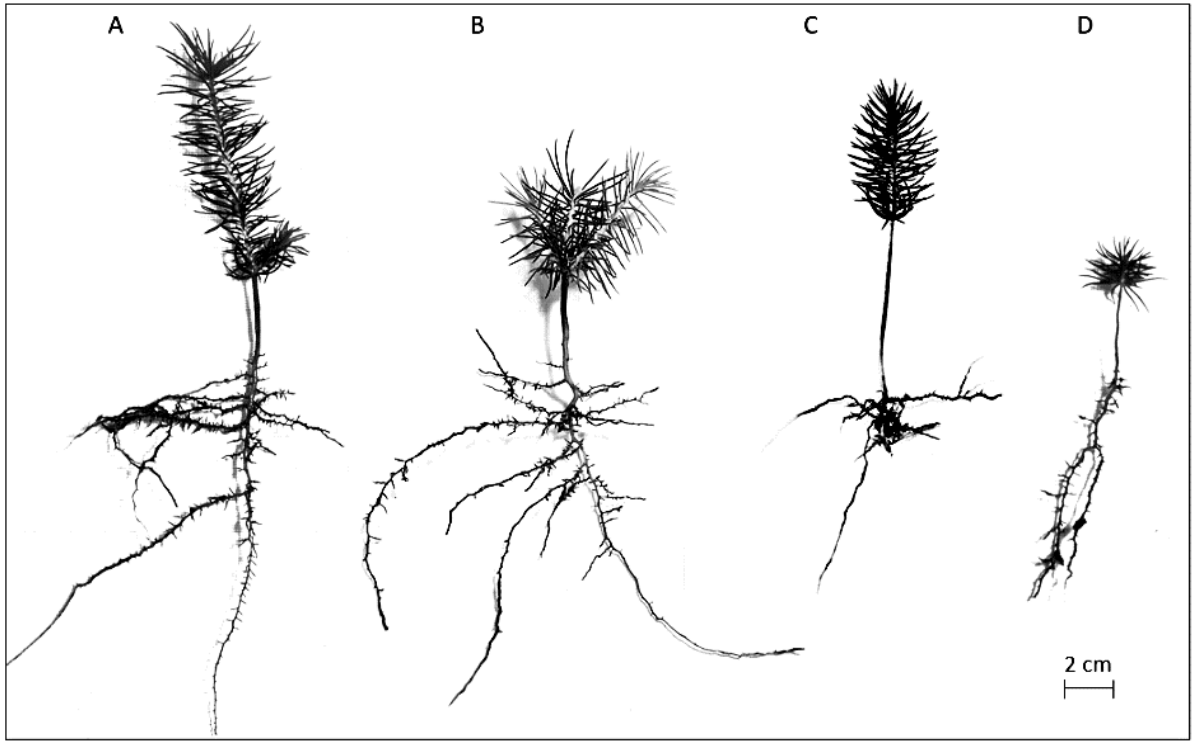
Results

Root depth = 27.4 cm

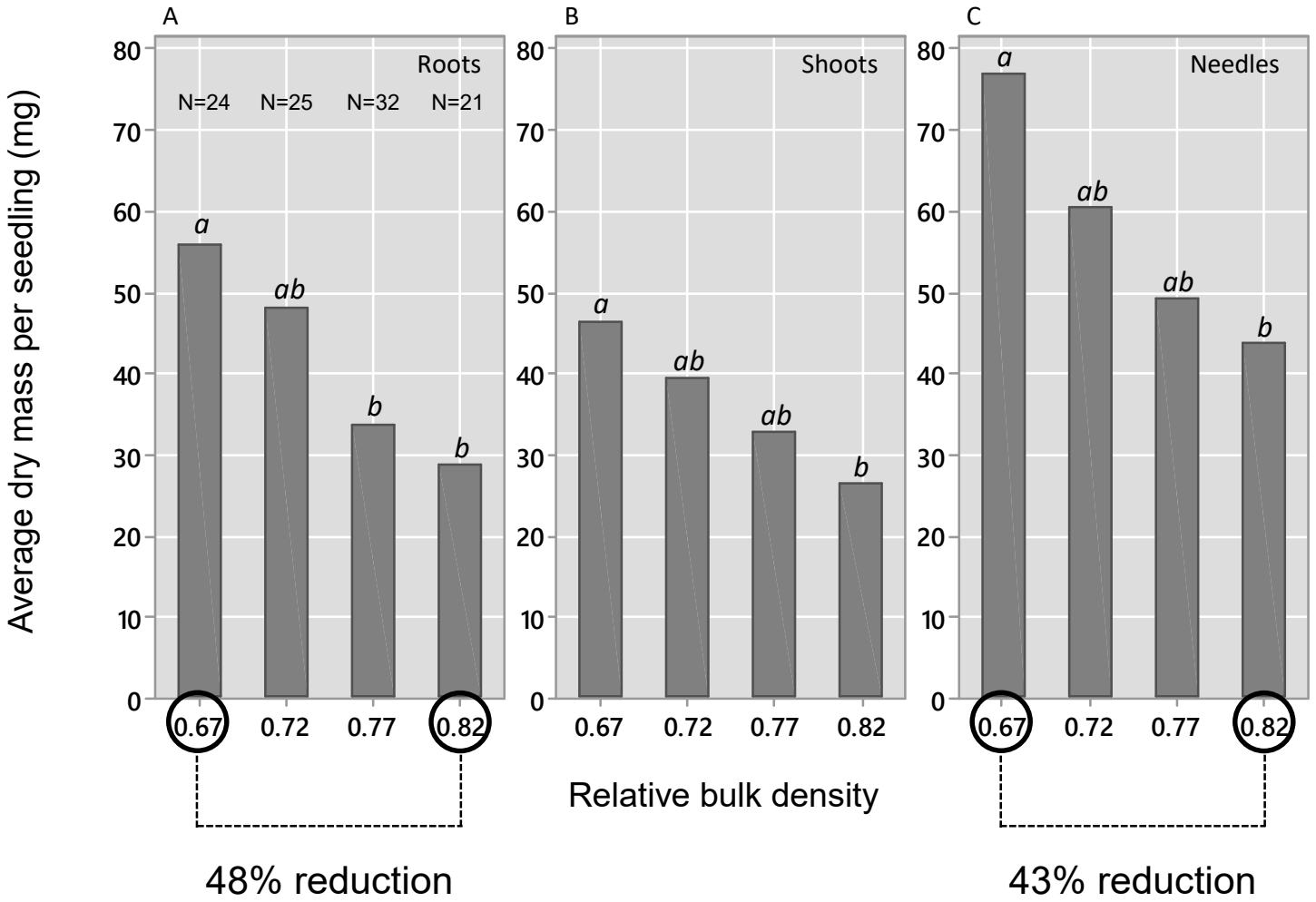
Root growth = 2.4 cm



Extraction



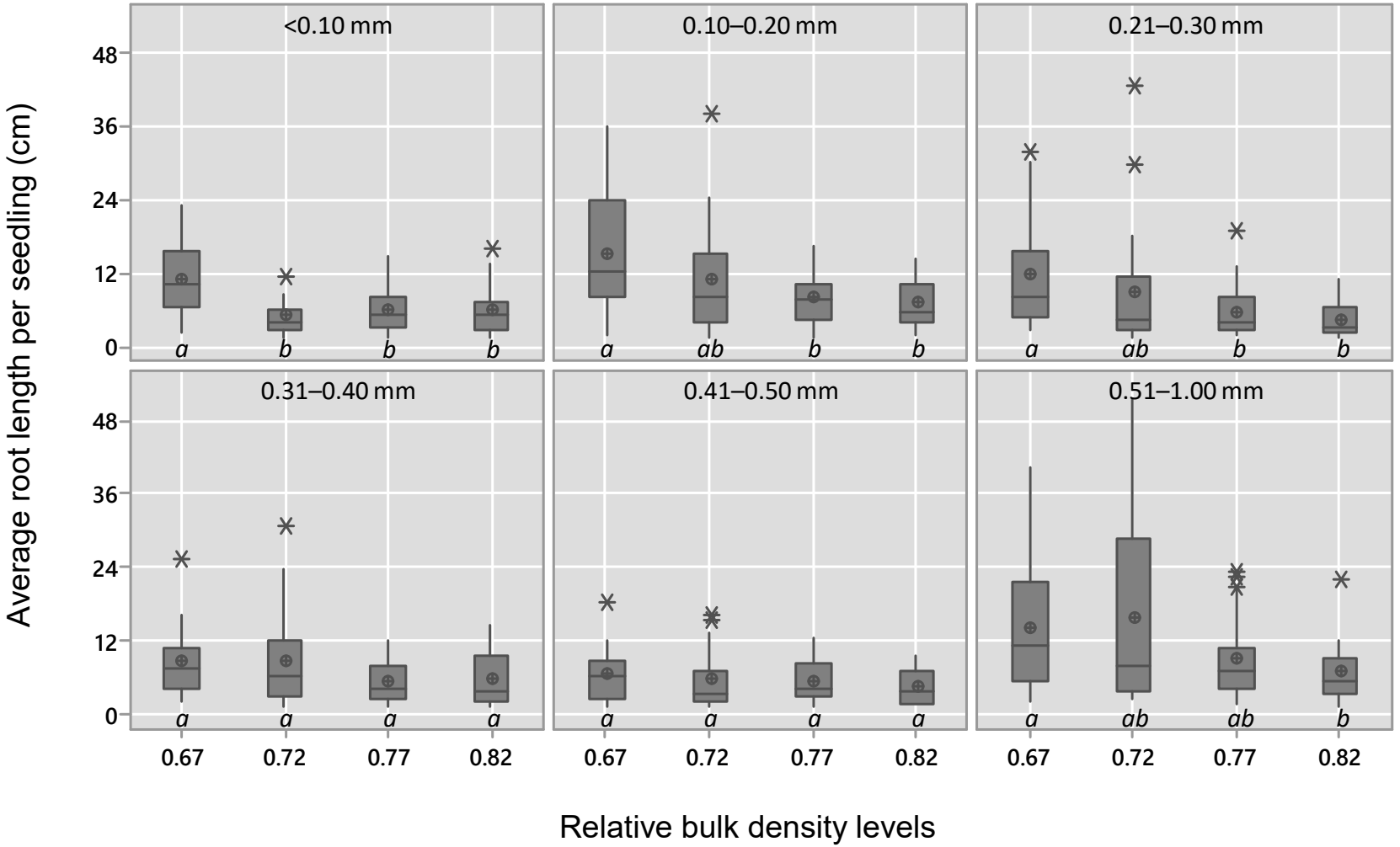
Response of biomass to varying RBD levels



Root length, root collar and shoot height

Root length (cm)						
RBD levels	Minimum	Mean	Maximum	Std. Dev. [a]	Percent difference to RBD 0.67	N
0.67	9.34	65.17*a*	141.92	38.69	-	24
0.72	2.77	49.41*ab*	173.21	46.20	-24.18	25
0.77	6.09	35.28*b*	86.78	21.19	-46.86	32
0.82	10.93	30.44*b*	67.87	18.59	-53.29	21
Root collar diameter (mm)						
	Minimum	Mean	Maximum	Std. Dev. [a]	Percent difference to RBD 0.67	N
0.67	0.93	1.52*a*	2.30	0.29	-	24
0.72	0.74	1.40*a*	3.12	0.56	-8.27	25
0.77	0.75	1.36*a*	2.41	0.37	-10.94	32
0.82	0.92	1.35*a*	2.22	0.40	-11.12	21
Shoot height (cm)						
	Minimum	Mean	Maximum	Std. Dev. [a]	Percent difference to RBD 0.67	N
0.67	3.20	6.10*a*	10.20	1.81	-	24
0.72	2.90	5.95*a*	12.60	2.18	-2.49	25
0.77	2.80	5.53*a*	10.10	1.81	-9.39	32
0.82	2.70	4.90*a*	7.30	1.26	-19.80	21

Root growth – per diameter class



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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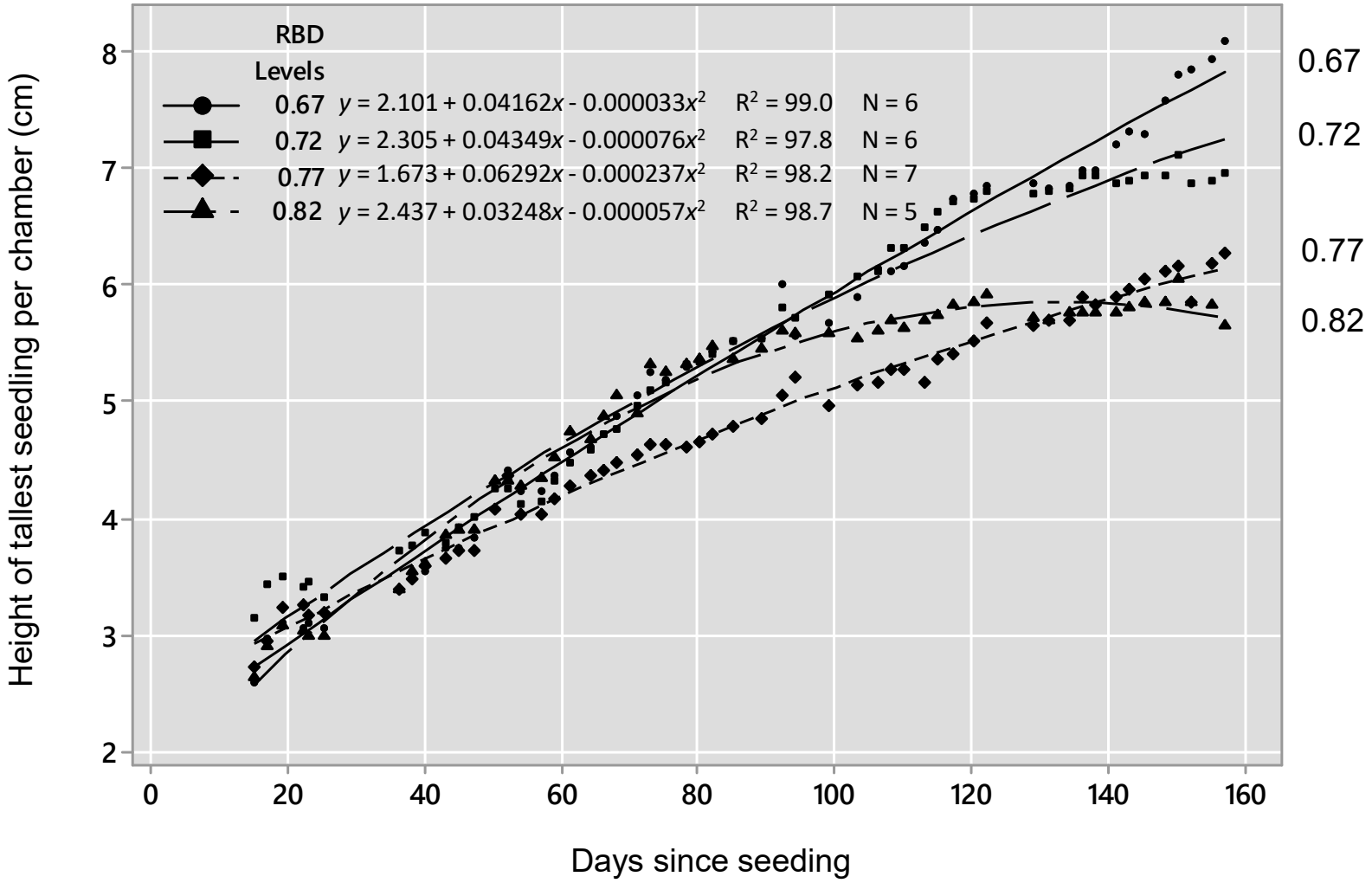
Appendices

Shoot growth over time



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

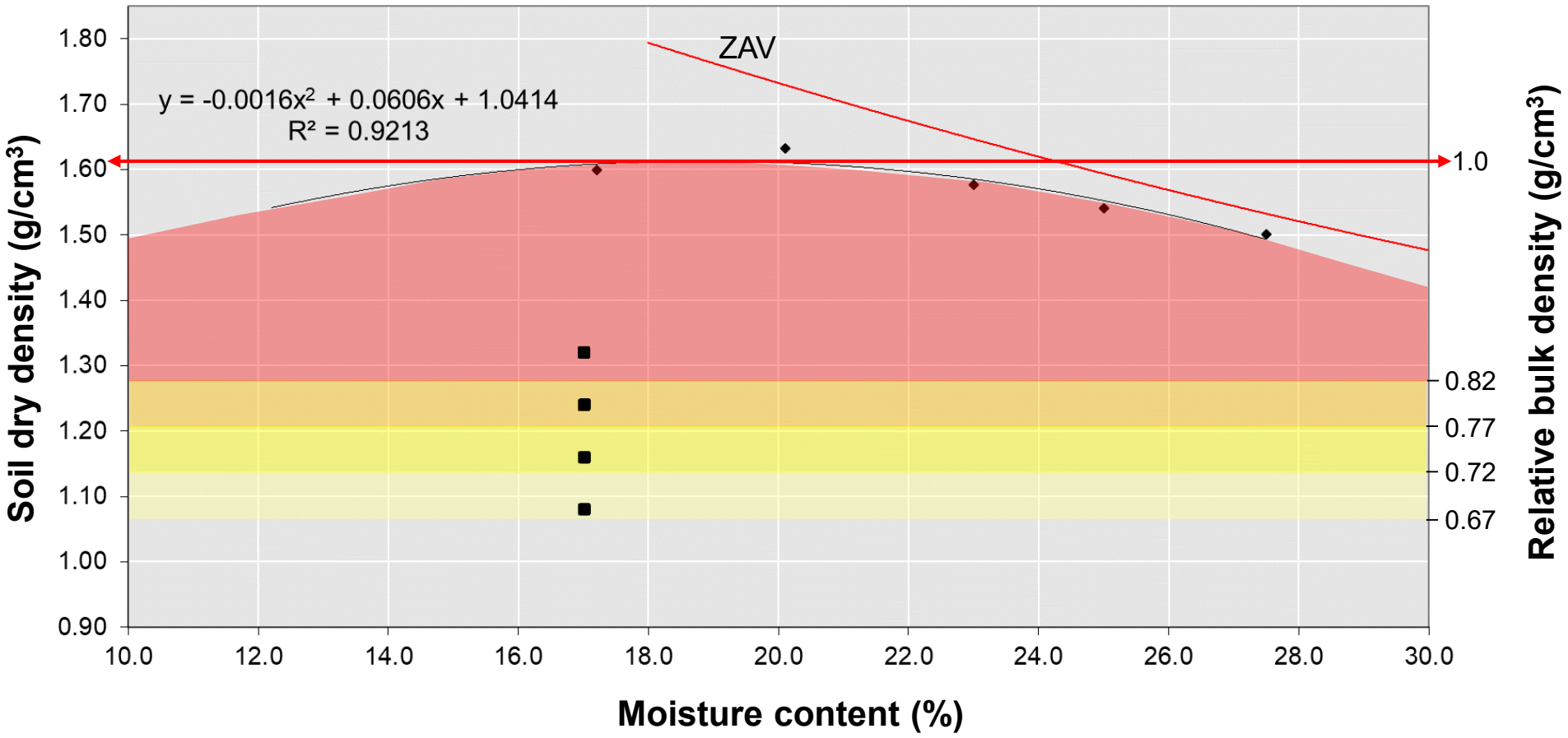
Particle size distribution:

Gravel (> 2.00 mm)	= 11.0%	
Sand (0.063 mm < *x* ≤ 2.00 mm)	= 25.4%	Silt loam
Silt (0.002 mm < *x* ≤ 0.063 mm)	= 52.2%	
Clay (< 0.002 mm)	= 11.4%	

Atterberg limits:

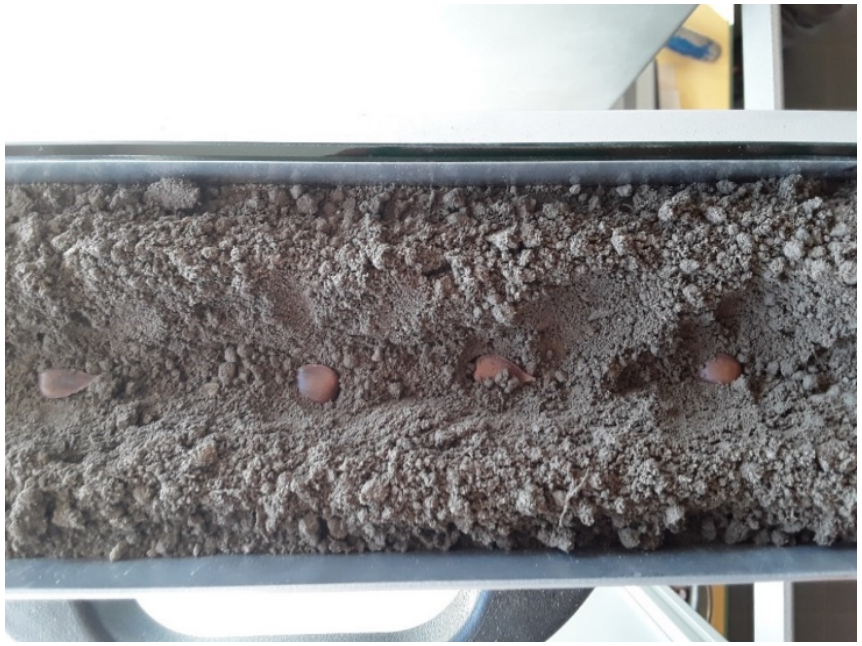
Liquid limit = 34.8%
Plastic limit = 21.5%
Plasticity index = 13.3%

Relative bulk density

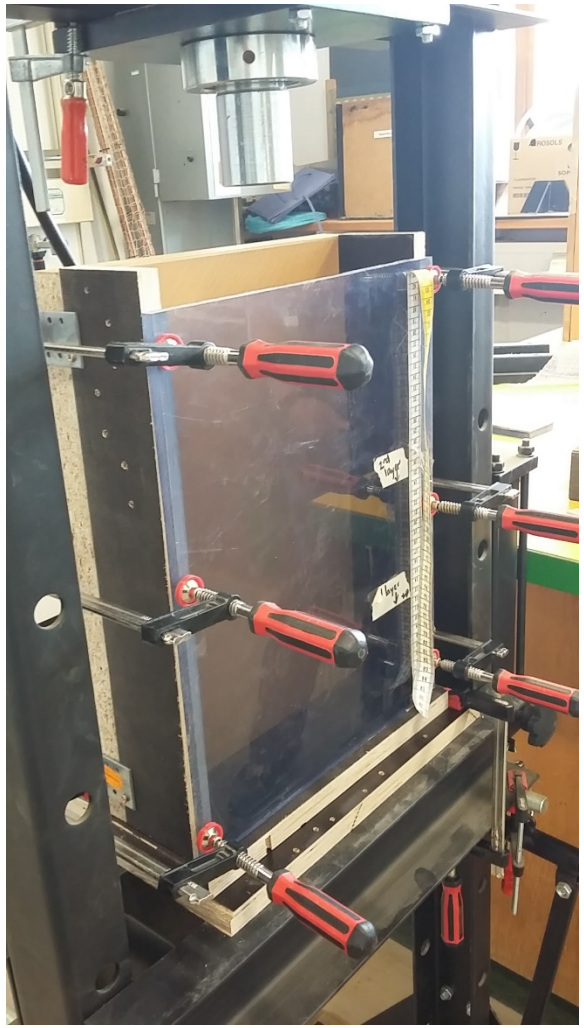


Seeding

- 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.

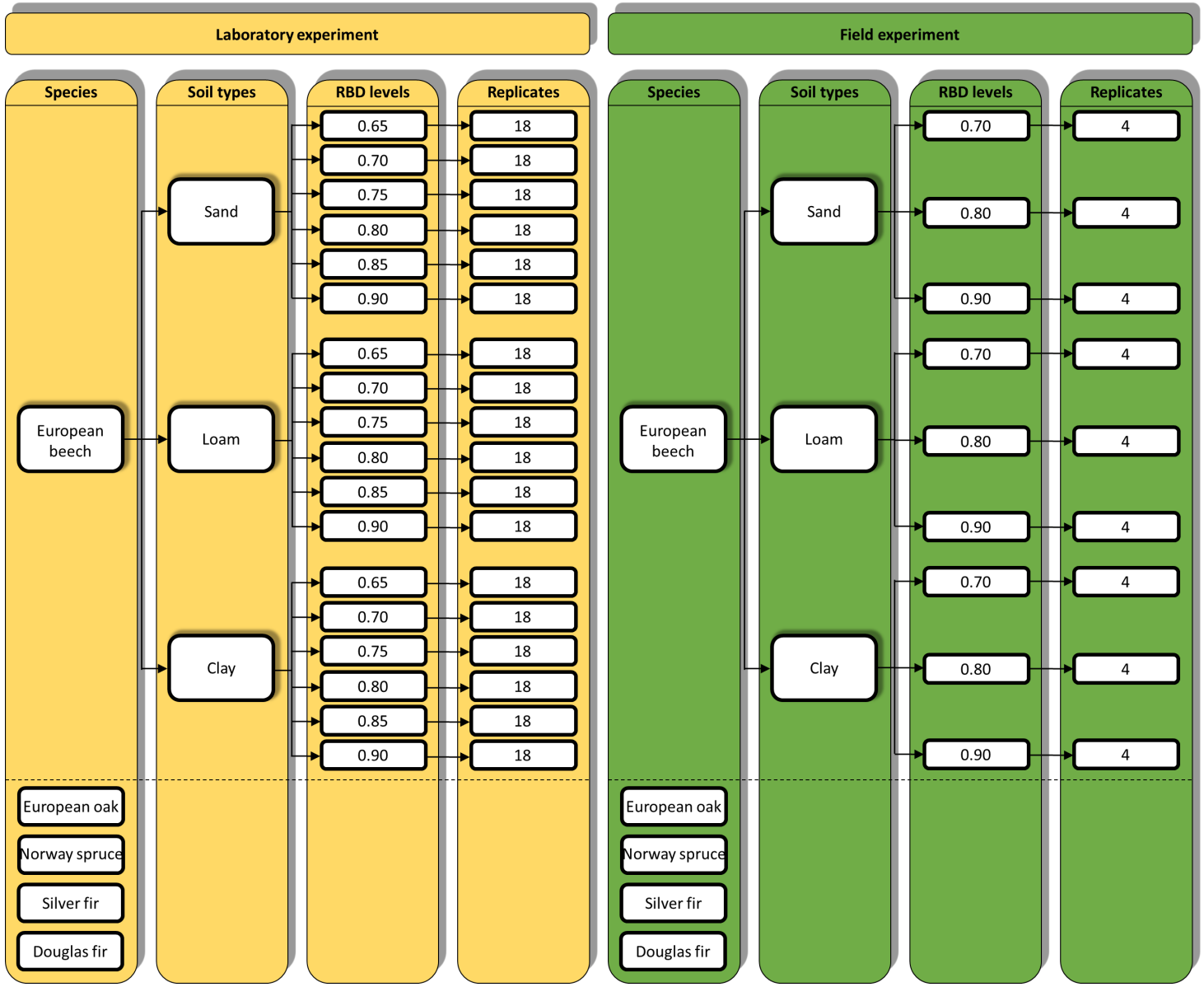


Accuracy and repeatability



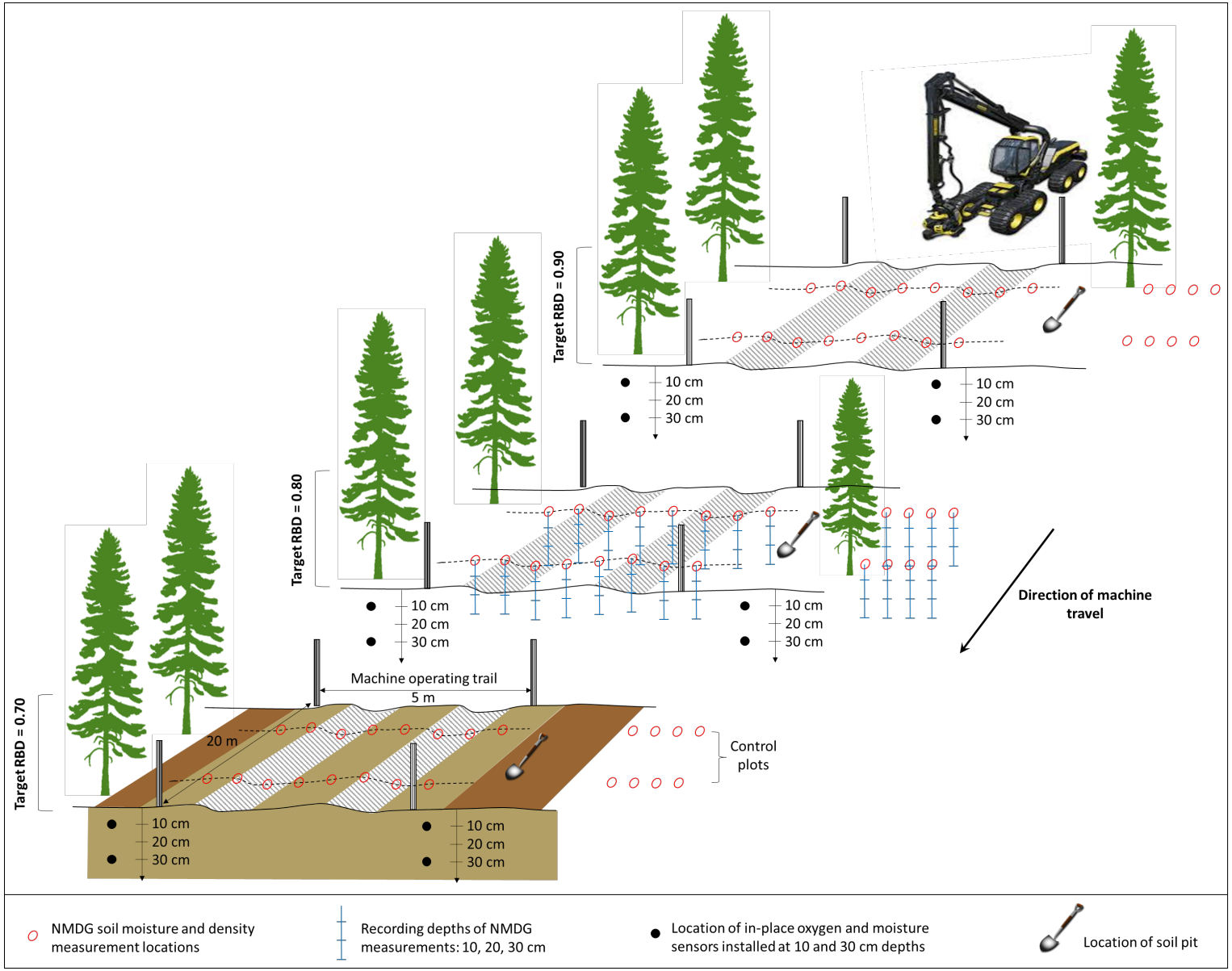
Compaction procedure

- Added 550 g of sand followed by 550 g of coarse gravel at the bottom of each chamber.


Laboratory experiment
Field experiment
Species
Soil types
RBD levels
Replicates
European beech
European oak
Norway spruce
Silver fir
Douglas fir
Sand
Loam
Clay
0.65
0.70
0.75
0.80
0.85
0.90
18
4

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?


Target RBD = 0.90
Target RBD = 0.80
Target RBD = 0.70
10 cm
20 cm
30 cm
Machine operating trail
5 m
20 m
Control plots
Direction of machine travel
NMDG soil moisture and density measurement locations
Recording depths of NMDG measurements: 10, 20, 30 cm
Location of in-place oxygen and moisture sensors installed at 10 and 30 cm depths
Location of soil pit