

Crossing scales and systems in root phenotyping

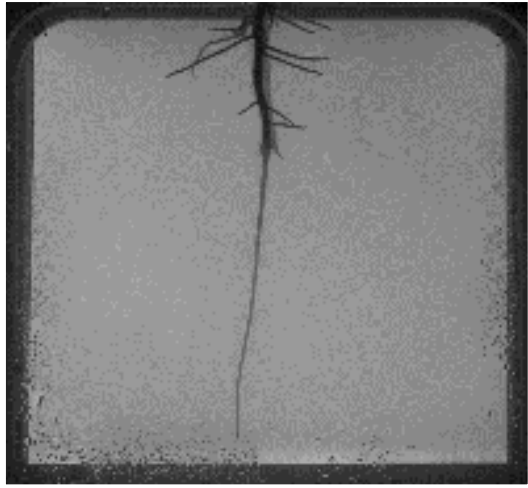
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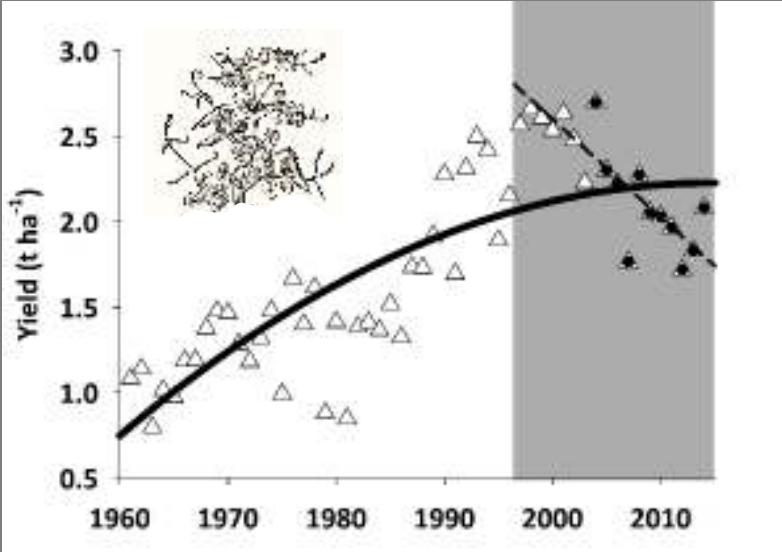
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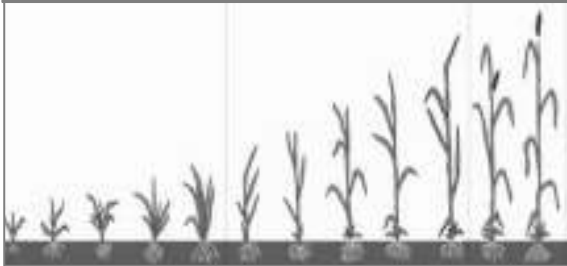
MAIN OBJECTIVE	ASPECTS	IMPLICATIONS
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HIGH AND STABLE YIELD



Yield trend dry pea in Europe (Data source: FAOStat)

Yield relevant ontological stages



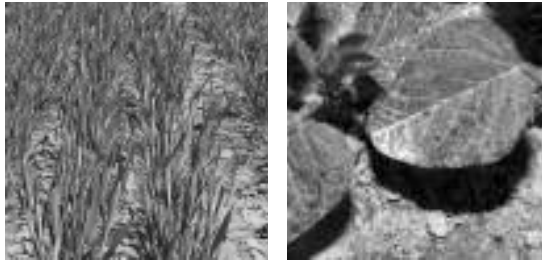
Non-destructive

Diverse genetic resources



High throughput

Abiotic and biotic stresses



Functional

KEY (AGRO-) ECOSYSTEM FUNCTIONS

Stress resistance

e.g. 27% arable land water limited, 30 % arable land P shortage (FAO/IIASA, 2000; MacDonald et al. 2011)

Resource efficiency

e.g. global N fertilizer use efficiency 47 % (Lassaletta et al. 2014)

Soil organic matter

e.g. 45 % of European soils with low organic carbon (European Soil Database 2003)

Soil structure

e.g. 20 % of soils in Europe are endangered by erosion (EEA, 2016)



PHENOTYPING CHALLENGES

Throughput

Methods use artificial media and short growth duration

Representativity

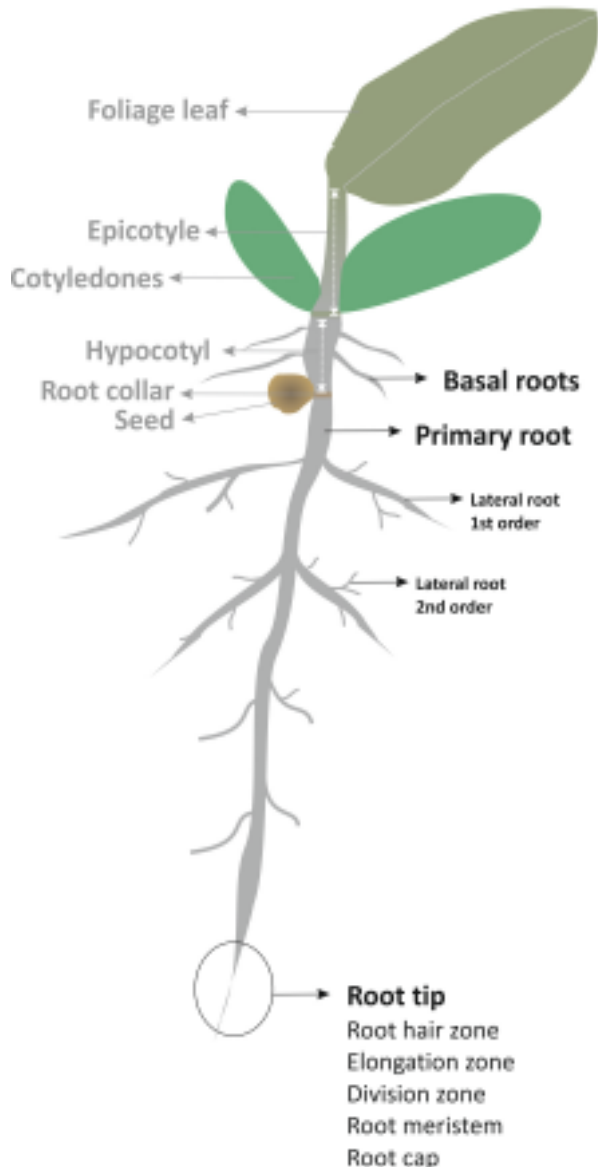
Methods are questionable to resemble „real“ root systems



Model assisted upscaling

Root system dicots

following Zobel and Waisel (2010) RSA taxonomy



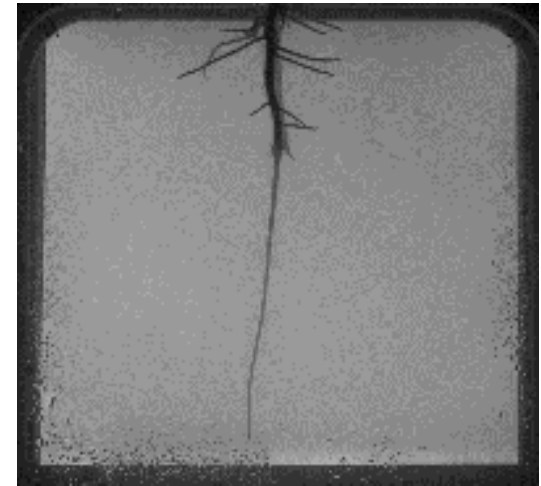
Trait	Function (examples)
Angle	Deep water exploration
Branching frequency	P foraging
Elongation rate	NO ₃ - competition advantage
Total surface (length)	Absorption capacity
Specific surface	Immobile nutrient uptake
Diameter	Dense layer penetration

Other traits: root hairs, exudation rate and chemistry, membrane transporters, xylem,...

Bridging ontological stages



High-throughput seedling stage



Low-throughput mature stage



Eurolegume pea sortiment

Abbreviation	Eurolegume number	Gene bank accession number	Local name	Country of origin
Estonia1	P58	EST2882	Eesti hall	Estonia
Estonia2	P56	EST894	Eesti kollane söögihermes	Estonia
Estonia3	P61	EST37	Jõgeva kirju	Estonia
Estonia4	P65	EST41	Seko	Estonia
Latvia1	P02		Alma	Latvia
Latvia2	P48		Bruno	Latvia
Latvia3	P12		k-4833 Stendes Hero	Latvia
Latvia4	P03		Retrija	Latvia
Norway1	P79	NGB10778	Aslaug	Norway
Norway2	P82	NGB20045	Onkel Niels	Norway
Portugal1	P53		Gp 3263	Portugal
Portugal2	P51		Gp 3491	Portugal
Portugal3	P52		Gp 3497	Portugal
Portugal4	P54		Grisel	Portugal
Sweden1	P90	NGB 102513	Svalöf Butter	Sweden
Sweden2	P88	NGB 13138	Odalett	Sweden

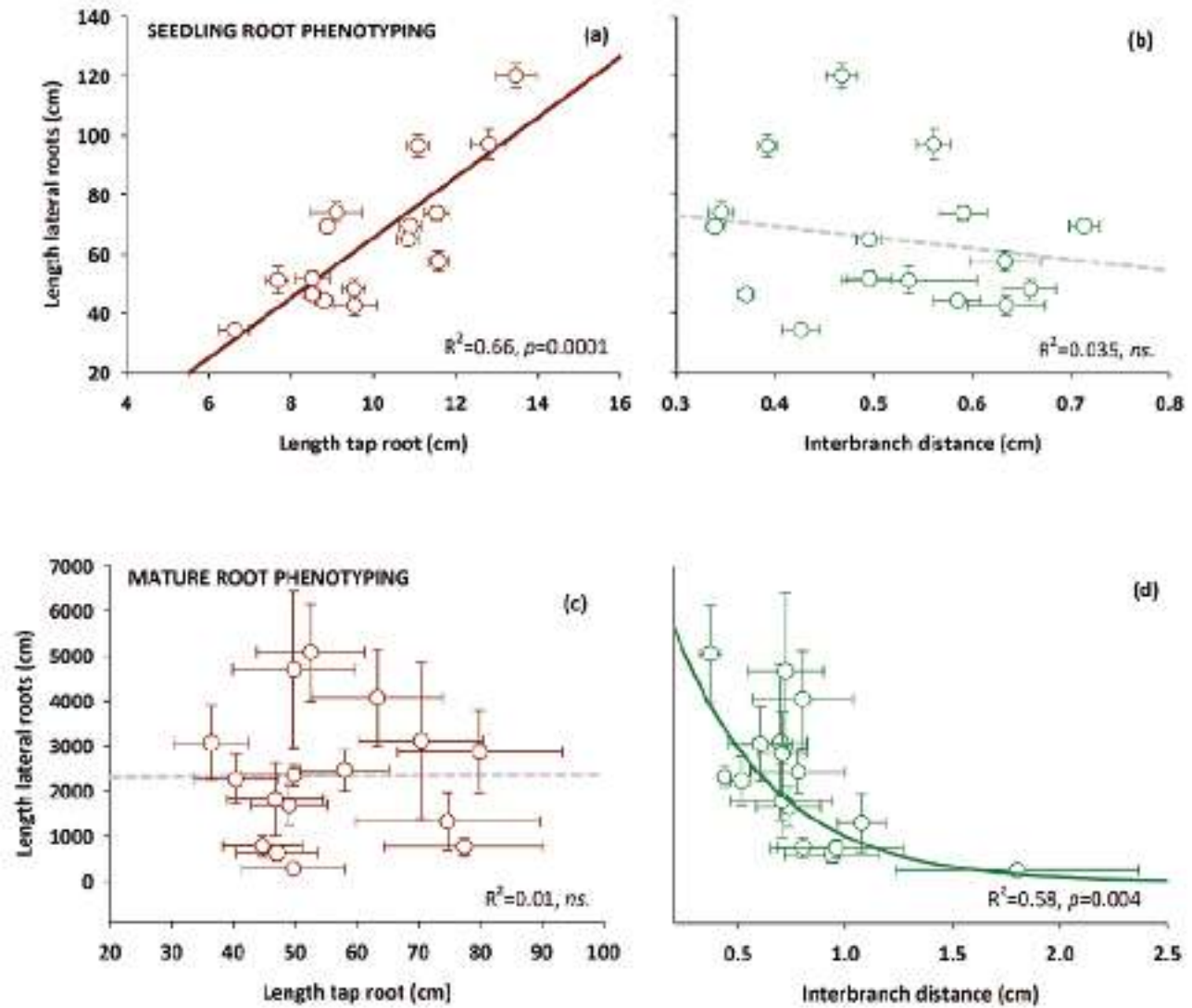
Zhao, J., Bodner, G., Rewald, B., Leitner, D., Nagel, K. A., & Nakhforoosh, A. (2017). Root architecture simulation improves the inference from seedling root phenotyping towards mature root systems. *Journal of Experimental Botany* 68(5), 965-982.

Relation between seedling and mature root phenotyping

Result Lack of direct functional relation between traits measured at different ontological stages.

Conclusion Even for dicot plants, neither genotype ranking (superior rooting types) nor prediction of mature root system characteristics is possible from seedling based screenings.

Relation between seedling and mature root phenotyping



Reason Driving parameters for total root length are changing over ontological stages.

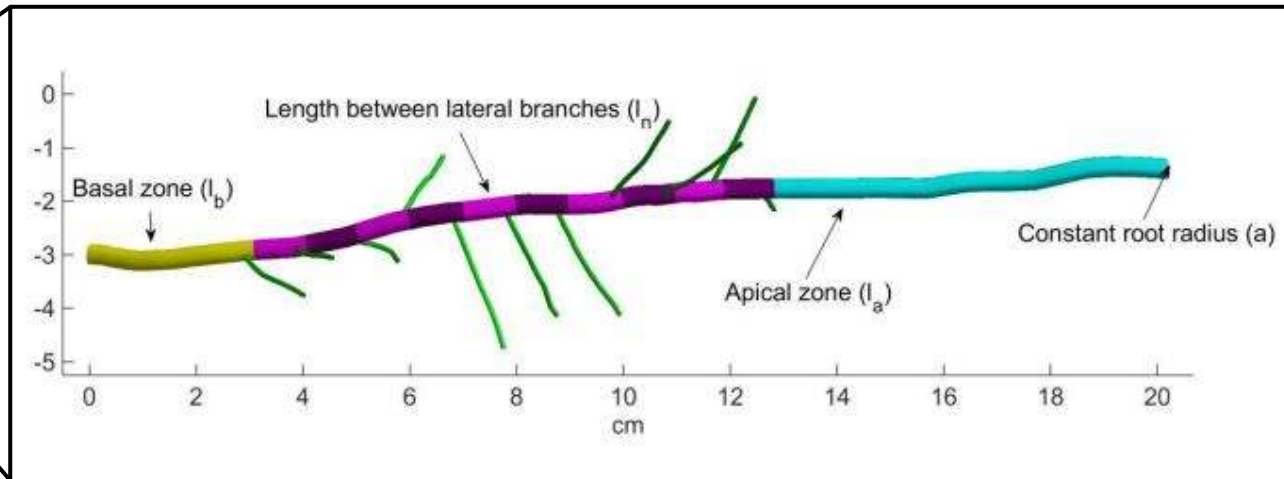
Seedling stage: tap root elongation as constaint

Mature stage: Interbranch distance as constraint.

Root Box Model

Matlab based root architecture model (using L-systems) using biological growth and branching rules; capable of simulating root-soil interactions (tropisms) by coupling with a soil model.

Root axis representation in RootBox

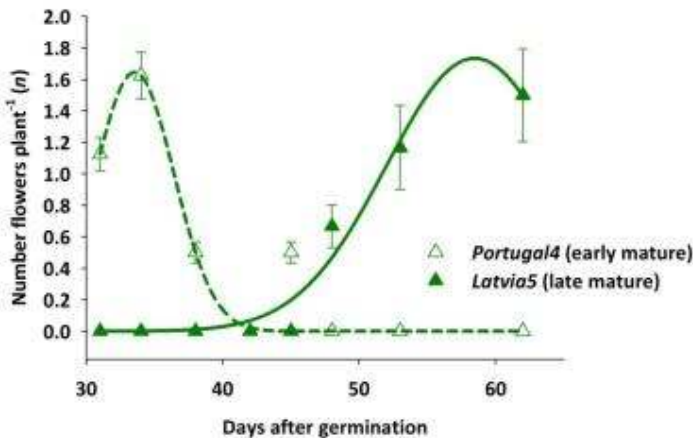
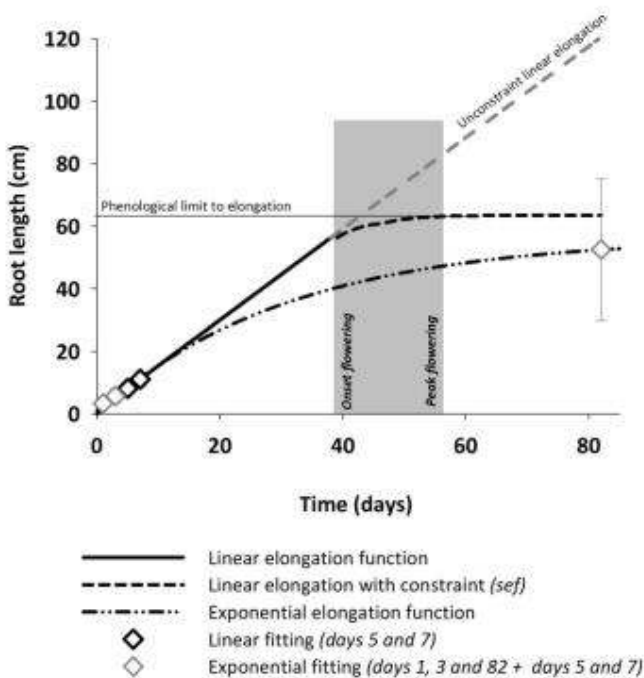


Leitner, D., Klepsch, S., Bodner, G., & Schnepf, A. (2010). A dynamic root system growth model based on L-Systems. *Plant and Soil* 332(1-2), 177-192.

Parameters of the RootBox model

Root trait class	Parameter Description
Growth	Initial elongation rate
	Growth function
	Phenological constraint
Morphology	Length of basal zone
	Length of apical zone
	Length between lateral branches
	Maximal number of branches
Spatial arrangement	Distribution of interbranch distance
	Branching angle
	Tropism type
	Tropism strength
	Root flexibility
Biomass	Root radius
	Root life span

Parameterization of growth function

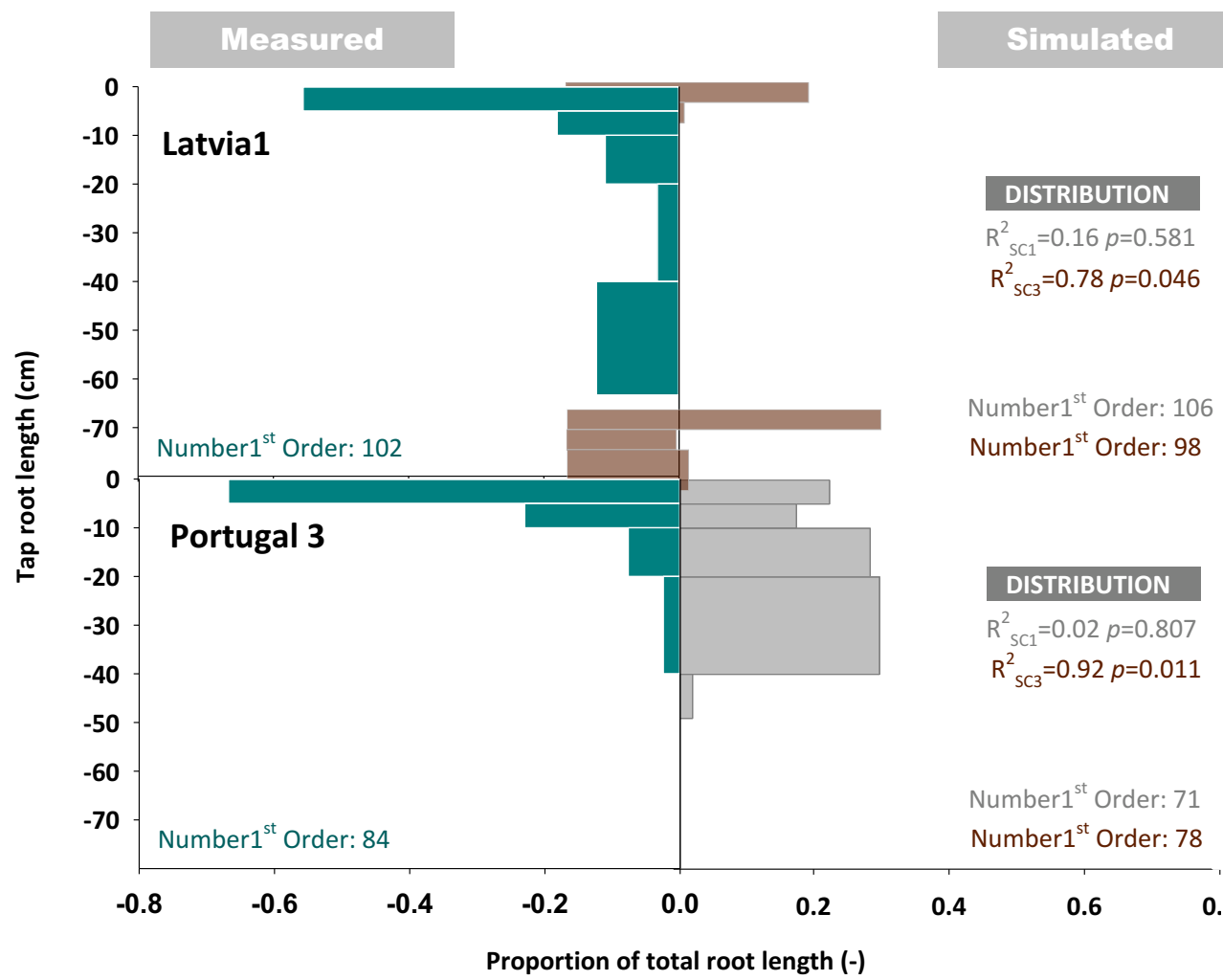


Bridging between phenotyping situations (1)

- Substantial improvement compared to direct inference
- Phenological constraint allows deriving elongation parameters from seedling observations.
- Ranking and prediction of absolute values with high precision.

Scenario 3. Linear elongation with phenological constraint, scaled branching frequency.

Bridging between phenotyping situations (2)



Prediction of root architecture (first order lateral numbers, depth distribution) requires improved parameterization of branching intervals (here: linear decrease with tap length).

Conclusion

Phenotyping outcomes should be **validated between platforms** and with field observations (target environment and target ontological stage).

Simulation models can be integrated into the phenotyping pipeline for **biologically based extrapolation** beyond the immediate phenotyping situation.

Thereby simulation models can provide significant **added value** to phenotyping outcomes in the extension **towards plant breeders**.

Classification of genotypes based on root system characterization is a key for selecting promising accessions for abiotic stress resistance*

Still unexploited possibilities to join root phenotyping and genotyping...

*Zhao, J., Bodner, G., & Rewald, B. (2016). Phenotyping: using machine learning for improved pairwise genotype classification based on root traits. *Frontiers in Plant Science*, 7.

Zhao, J., Sykacek, P., Bodner, G., & Rewald, B. (2017). Root traits of European *Vicia faba* cultivars—Using machine learning to explore adaptations to agro-climatic conditions. *Plant, Cell & Environment*, in press

Thank you for your attention!

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Genotype	Tap root length (cm)		Lateral root length (cm)		Interbranch distance ² (cm)			
	Seedling	Mature	Seedling	Mature	Seedling		Mature	
Estonia1	9.1	44.7	0.1	782.9	0.34	(0.14)	0.80	(0.19)
Estonia2	12.8	70.4	97.1	3114.2	0.54	(0.17)	0.70	(0.14)
Estonia3	7.7	74.7	51.2	1326.4	0.71	(0.30)	1.07	(0.13)
Estonia4	11.6	47.0	57.6	623.2	0.70	(0.18)	0.94	(0.26)
Latvia1	11.5	63.3	73.9	4072.7	0.58	(0.19)	0.80	(0.22)
Latvia2	10.9	36.4	69.5	3089.7	0.72	(0.18)	0.60	(0.13)
Latvia3	8.8	79.9	44.4	2872.4	0.59	(0.19)	0.71	(0.23)
Latvia4	11.1	52.5	96.6	5080.4	0.41	(0.11)	0.37	(0.11)
Norway1	8.5	49.8	46.4	2354.1	0.37	(0.12)	0.44	(0.12)
Norway2	6.6	58.0	34.4	2462.0	0.38	(0.17)	0.78	(0.12)
Portugal1	8.9	49.0	69.4	1685.2	0.35	(0.11)	0.73	(0.13)
Portugal2	8.5	46.8	51.8	1817.6	0.52	(0.16)	0.70	(0.17)
Portugal3	9.5	40.4	42.7	2260.7	0.69	(0.24)	0.51	(0.11)
Portugal4	10.8	77.4	65.0	784.8	0.51	(0.14)	0.98	(0.15)
Sweden1	13.5	49.8	120.2	4699.0	0.47	(0.12)	0.72	(0.21)
Sweden2	9.5	49.7	48.3	277.9	0.67	(0.24)	1.80	(0.53)
SED	0.3	3.3	2.9	179.5	0.02	0.003	0.05	0.05
CV (%)	26.4	49.2	36.6	77.7	31.2	42.1	50.5	41.8
G	0.013		<0.001		<0.001 (<0.001)			
PLATFORM	<0.001		<0.001		<0.001 (<0.001)			
G×PLATFORM	0.009		<0.001		0.018 (<0.001)			

