Model-assisted phenotyping of root system construction and function

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Model-assisted phenotyping of root system architecture and function

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Outline

Part 1. Phenotyping of root system architecture
   Trends: throughput, dynamic, modeling

Part 2. Functional phenotyping (water capture)
   Getting plant biology and soil hydrodynamics together
Part 1. RSA phenotyping platforms

**Evolution in the level of phenotyping details**

- **2000:**
  - Root mass, deep root mass, root volume

- **2000-today:**
  - Number and length of root axes
  - Lateral root length and density
  - Surrogates for growth rate
    - Root axes: LAUZ
    - Lateral roots: conical aperture
  - Root angles
  - Direct growth rate measurements

- **Future:**
  - 3D entering the scene
  - More dynamics
Current demand: capturing genetic variability with high throughput
Which level of detail?

- Maximum leaf length (mm)
- Maximum axis length (mm)
- Axis diameter (mm)
- Number of tillers
- Number of axes
- LAUZ (mm)
- Leaf dry weight (g)
- Total length of axes (mm)
- LR density (mm⁻¹)
Detailed phenotyping is worth the effort
Dreaming of throughput and dynamics (Arabidopsis... again)

X. Draye & G. Beemster, unpublished
Root imaging in rhizotrons

Soil-grown plants, transparent tubes
↓
High resolution images
↓
Length & area → diameter
(e.g. Lemnatec®, Traitmill®)

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New in the field: statistical modeling approach

Growth of axile and lateral roots of maize: I development of a phenotyping platform

A. Hund • S. Trachsel • P. Stamp

Flat filter-paper substrate
↓
Root scan (every 2 days)
↓
Length-diameter histograms (WinRHIZO)
↓
Statistical model
↓
Growth parameters estimates
Another one: explicit architectural modeling

**RootTyp (PlantSoil 258:103)**

- **Model**: Plant [RootTyp (Plant and Soil)]
- **Parameters**:
  - NameOfTypeZeroRoots [mesocotyl]
  - NumberOfTypeZeroRoots [1]
  - RadialGrowthCoefficient [0]
- **Groups**:
  - ReiterationWaves
  - RootType: mesocotyl
  - RootType: stem
  - RootType: seminal
  - RootType: adventitious
  - RootType: adventitious
    - Name [adventitious]
    - InsertionAngleMean [1.8]
    - InsertionAngleSD [0.0]
  - Growth
  - Branching
  - Direction
  - Reiteration
  - Transition
Another one: explicit architectural modeling

Strategy:

1. Time-dense phenotyping
2. Target a small set of parameters (distribution)
3. Simulate realistic root systems (many)
4. Calculate... calculate... calculate
   - Age-specific information
   - Hydraulic architecture
   - ...
Towards automated phenotyping
Benefits
- High resolution
- Time-lapse
- Root-background separation

Issues
- Root joining
- Overlap in dense regions
- Registration not possible

Strategy
- Focus on few roots
- Skeletonize → Vector-based
  [SmartRoot software]

Improvements
- Better separation from the top
- Interactive image mining
Part 2. Functional phenotyping

RSA

Distribution of soil resources

Water demand

Distribution of root uptake activity
Working hypotheses in root water capture

Spatial 1D approach

Root length density (RLD) and root depth
Basis for irrigation scheduling, crop growth models

Typical working hypotheses (observations):

Water uptake usually proportional to RLD in wet soils
Deeper roots lead to improved access to water under drought

Motivations for a 3D approach

RSA is closer to underlying biological processes than RLD
RSA is the backbone of hydraulic architecture
Opportunities to address fine-scale phenomena
Understanding/sorting of key parameters or mechanisms
Can be ultimately reduced to lower dimensions
Modeling approach of the soil/root hydraulic architecture

\[ \theta(x, y, z, t) \]
\[ \psi(x, y, z, t) \]
\[ K_s(x, y, z, t) \]

\{ node: (x, y, z, d, age, parent) \}
\[ \psi_x(node, t) \]
\[ K_r(node, t) \]
\[ K_a(node, t) \]
Modeling approach of the soil/root hydraulic architecture

Hypotheses:
- Negligible osmotic gradient
- Negligible capacity

Boundary conditions:
- Flux or water potential at the collar
- Water potential of the deep soil

Negligible osmotic gradient
Negligible capacity

Flux or water potential at the collar
Water potential of the deep soil
Light transmission experiments
NIR estimation of surface $\theta$

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Experimental dataset

3D structure

Root hydraulics ($K_r$, $K_x$)

Soil hydraulics ($\theta$ - $\psi$)

Transpiration

Time series of soil water content maps
Typical output of the model: from $\Delta \theta$ to sink term
Inverse modeling: Estimating unknown parameters
Inverse modeling provides estimates of biological parameters

\[
err_\theta = \sqrt[\sum_{j=1}^{n_j} \sum_{i=1}^{n_i} (\theta_{i,j} - \hat{\theta}_{i,j})^2 / n_i n_j]
\]

100 x Err_\theta [-]
QTL analysis: Sophie de Dorlodot, René Civava, Pierre Faux, Jean-François Dumasy, Charlotte de Mey, Bill Thomas, Brian Forster
Aeroponics: Tristan Lavigne, Aurélie babé, Beata Orman, Imaging: Eric Aussemis, Olivier Monnart
Modeling: Loïc Pagès
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