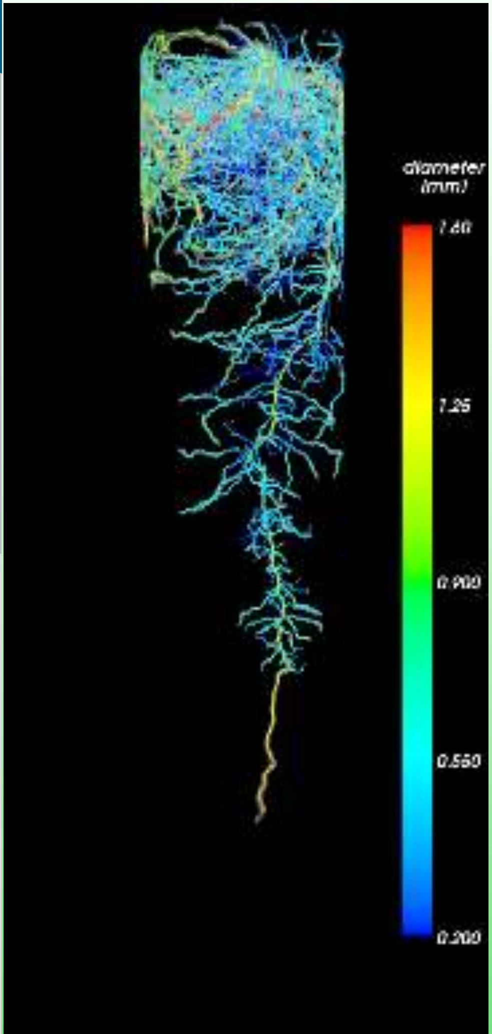
Quantification of local root water uptake by means of the soil water profiler



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EPPN2020 Workshop, Vienna

Main interest: Plant hydraulics

Transpirational demand – stomatal conductance

Xylem transport

Root water uptake

Abundant technologies for studying shoot

- Several imaging methods
- Tools for assessing function

Sparse technologies for roots

- Where are the roots? How many?
- What do they do?

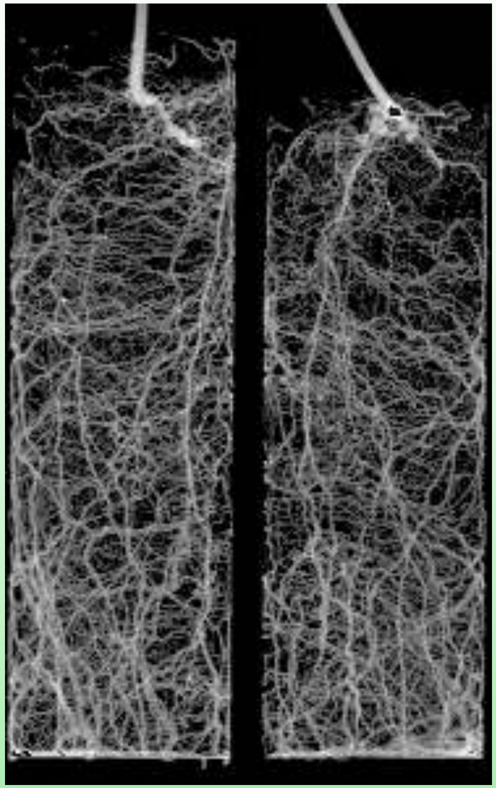
MRI versus X-ray CT

	CT	MRI
Resolution	30-40 μm	300-500 μm
Scanning time	10-60 mins	20-80 mins
Root diameters- normal	~300 μm	200-300 μm
Root diameters-special	100 μm	100-150 μm
Harmful	Limited up to killing	None
Data analysis	Complicated-manual	Simple-automated
Pot size	Φ ~ 5cm, <20cm	Φ ~ 8cm, 30-40cm
Samples per day	Varies 10-20	~20

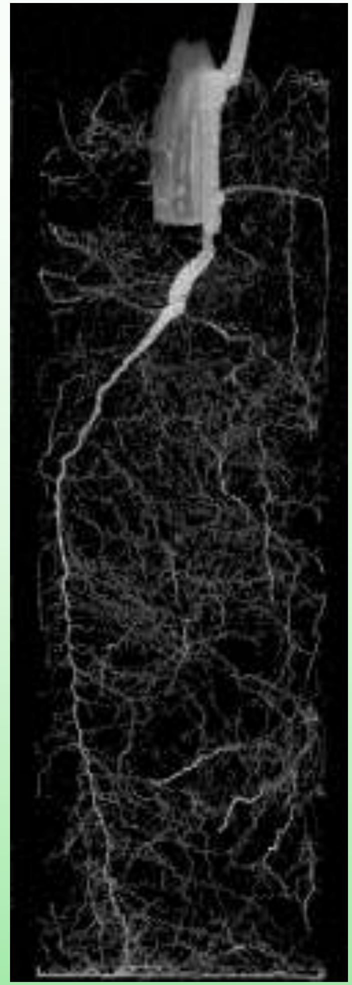
MRI root images collection

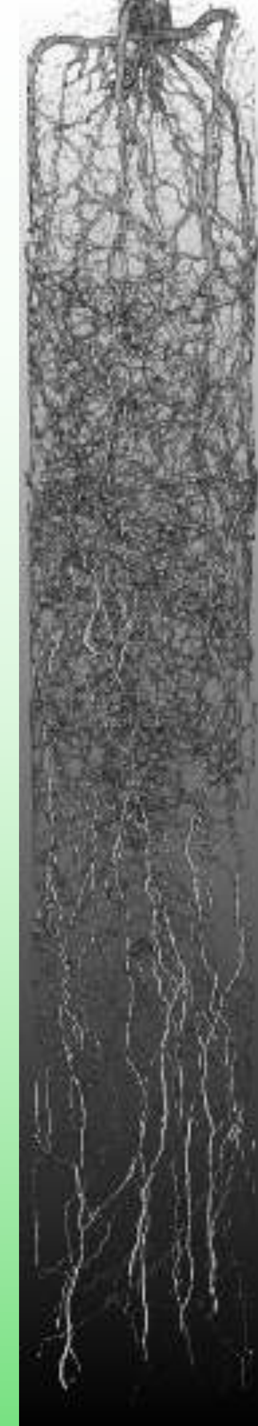
Arabidopsis

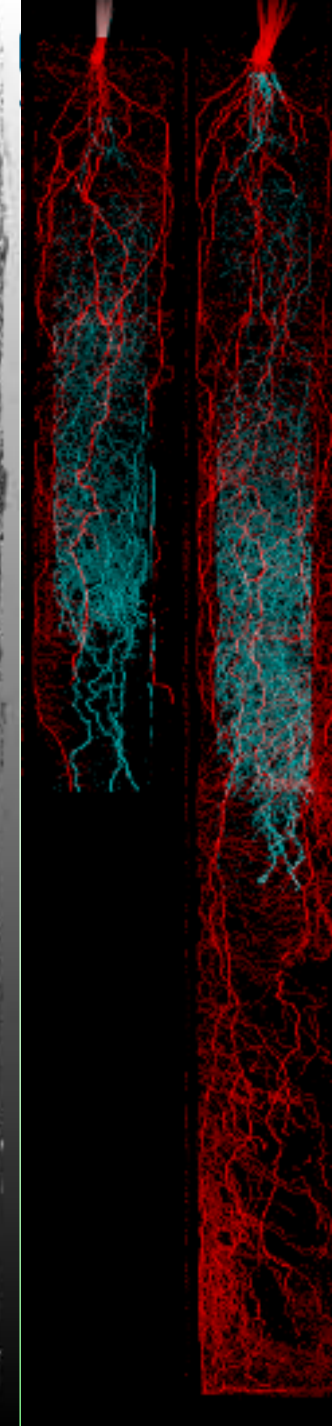
Brachypodium



Helianthus-Phaeseolus







Manihot E.
Zea M
Hordeum V.

Can we be satisfied?

NO……Most uptake done by laterals…..root hairs

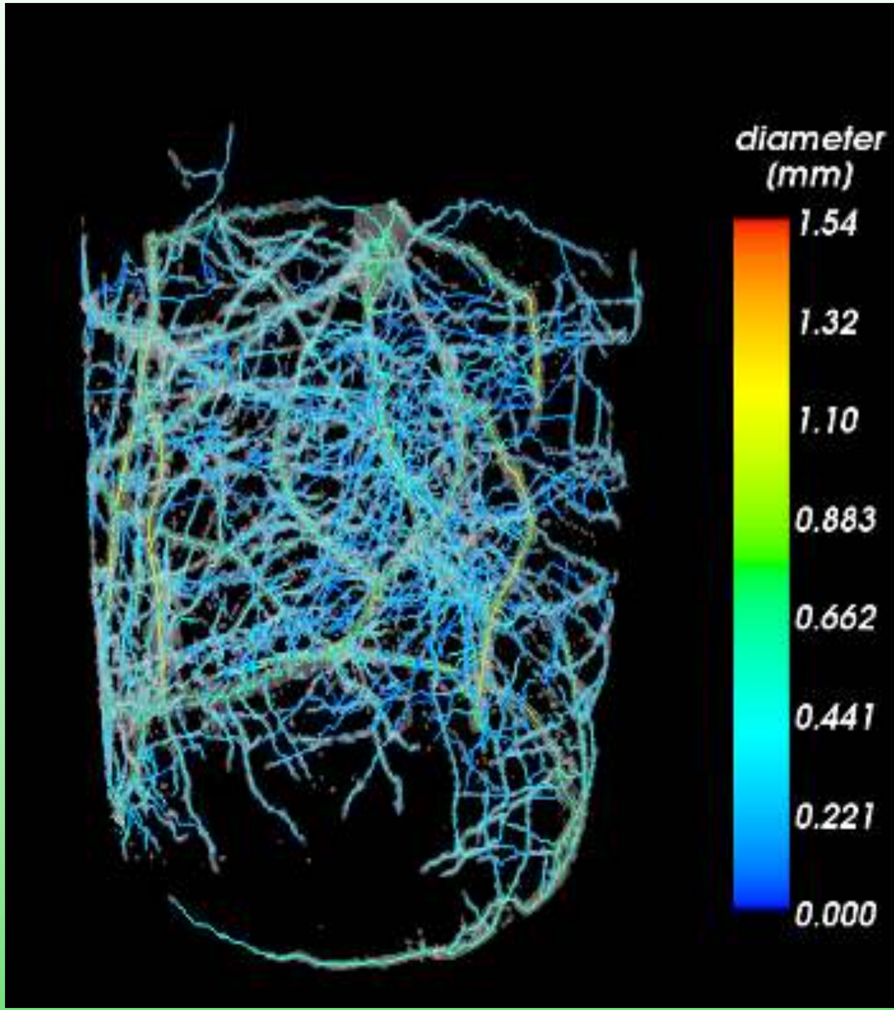
NO……Too slow for phenotyping (limited N)

YES….Combination with other tools

YES…. Dynamical studies

YES…. Right questions

Adapt measurement protocols



Roots and root water uptake

Current practices:

- Tracer studies (D_2O) with Neutron Tomography
  - Root conductivity for local segments
    - Non-standard

- Changes of local soil water content θ with time:
  - Time Domain Reflectrometry (TDR) and modelling
    - Root water uptake induces soil water flows
    - Fairly poor spatial resolution
    - Mediocre sensitivity
    - Modelling is rather complicated

Wish list

Technology should be as cheap as TDR.

Easy to use/calibrate

Require reduced modelling

Quantify root water uptake profiles in relation to θ.

Central hypothesis

When root water uptake (RWU) fluctuations are relatively fast redistributive soil water flows, being much slower, will show none of these fluctuations, which allows the quantification of the two processes.

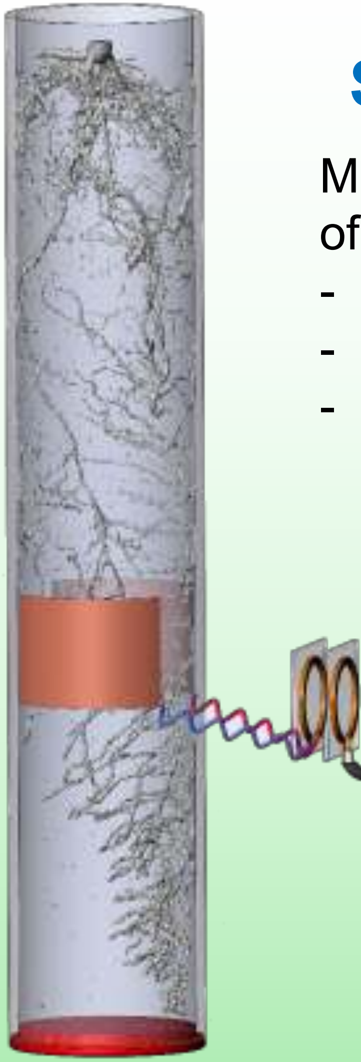
Requirements

Highly sensitive sensor for soil water content:

- Expected θ changes are very small
- First order perturbation should hold – soil-plant system more or less unchanged during measurement period

Root system can be treated as resistive electrical network:

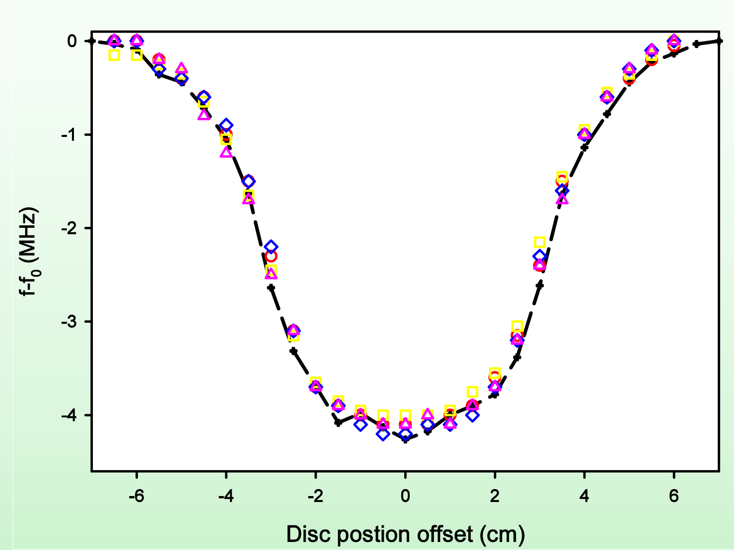
- Negligible growth
- Root capacitance is minimal

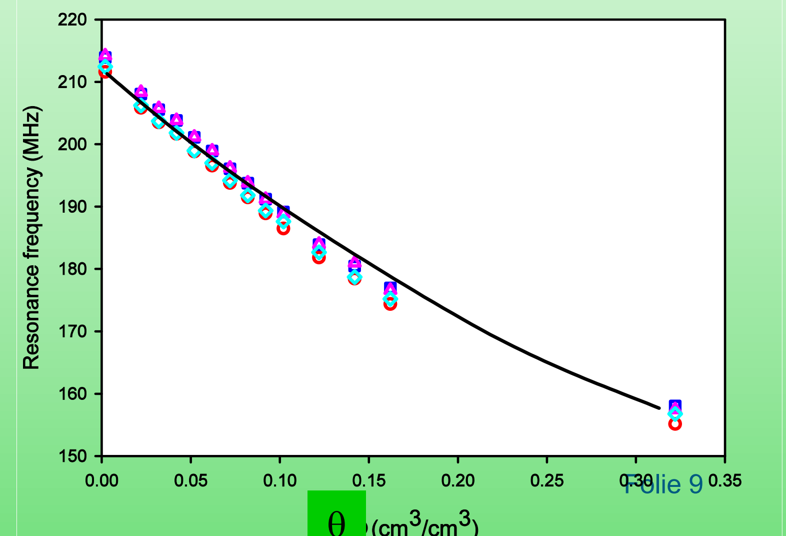


Soil Water Profiler (SWaP):

Measures local average (di)-electric permittivity by means of resonance frequencies.

- Sensitivity 0.00006 cm^3/cm^3
- ~ 3 µl/slice(=51.5ml)
-





Profiling of soil column – removing E-field effect

Generally – soil water content changes smooth, E-field distribution constant

Edges – Larger jumps in average permittivity → deviations

Non-constant PSF → Non-deterministic **deconvolution**

$$\theta(z) = K(f..\theta) \cdot \theta(z) \otimes \vec{E}(z)$$

$$\frac{\partial\theta(z,t)}{\partial t} = \frac{\partial K(f..\theta)\cdot\theta(z,t)\otimes\vec{E}(z)}{\partial t} = \frac{\partial K(f..\theta)\cdot\theta(z,t)}{\partial t} \otimes \vec{E}(z)$$

Depth and time profiles – Some examples

Final calibrations:

Θ of locally excavated soil vs SWaP

Addition of 20 μL of water to soil column

Summary

Sensor with accuracy of 0.002 cm^3/cm^3 in main section

Drops to 0.005 near edges

Sensor precision 0.00006 cm^3/cm^3

'Resolution' of 1cm after deconvolution

Integral over column (z) of $d\theta(z)/dt$ gives T_{act}, evapotranspiration

Root Water Uptake and Soil Water Flow

Root system analogy with stable resistive electrical network:

- No growth during measurement period, negligible capacitance
- Soil plant system stable (small h changes), 1st order perturbation app.

→ RWU profile independent of transpiration rate

$$\frac{\partial\Theta(z,t)}{\partial t} = \frac{\partial}{\partial z}\left[K(h(z,t))\left\{\frac{\partial h(z,t)}{\partial z} + 1\right\}\right] + K_{sx}(z)\cdot\Delta h(z,t)\cdot RLD(z) + \begin{cases} S_{eva}(z,t), z = 0 \\ 0, \quad z \neq 0 \end{cases}$$

$$\frac{\partial\Theta(z,t)}{\partial t} = rSWF(z,t) + fRWU(z)\cdot T_{act}(t) + \begin{cases} S_{eva}(z,t), z = 0 \\ 0, \quad z \neq 0 \end{cases}$$

$$\sum_z fRWU(z) = 1, \sum_z rSWF(z,t) = 0, \qquad RWU(z,t) = fRWU(z)\cdot T_{act}(t)$$

CAVEAT: When dθ(z)/dt = 0 flow may still exist!

Distinguish RWU(z,t) and rSWF(z,t)

Expose plant to somewhat rapid light fluctuations.
Determine $T_{act}(t)$ (correct for evaporation) and use as fit function of $d\theta/dt$ for each z:

$$\frac{\partial\theta(t)}{\partial t} = p_0 + p_1 t + fRWU \cdot \frac{T_{act}(t)}{V}$$

Is rSWF(t) non-periodic?

Effect of transpiration

Change light period

Forward simulation of Richards equation with predetermined sink – RWU(z,t)

Provide pF, K(h), q(t=0)

Vary fluctuation amplitude, period and K_s

Linear regression using RWU(z,t) model

Soil conductivity influence

Do we follow 1st order perturbation?

rSWF(z,t) for the most part non-periodic

Good correlation RLD(z) and fRWU(z) for wet conditions

Variations in fRWU are small
under moist conditions

Dryish conditions require short
measurement periods….

Further steps

Simple tool to measure effective rooting depth and RWU.

How do these correlate with RLD? → MRI..CT..excavate

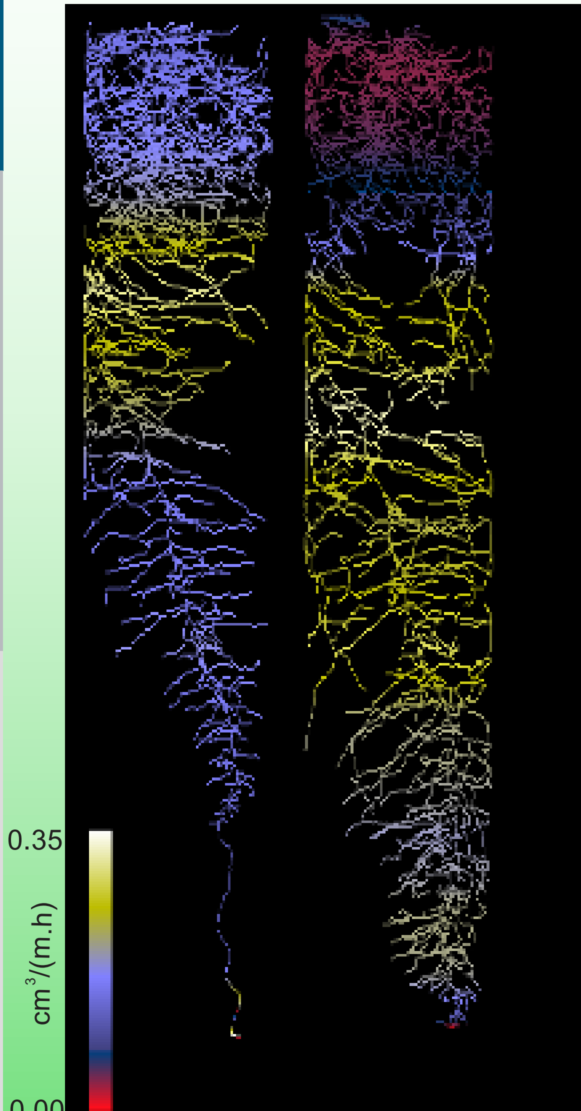
θ does not reflect soil water potential - pF curve

Roots see different environment….How do they handle it?

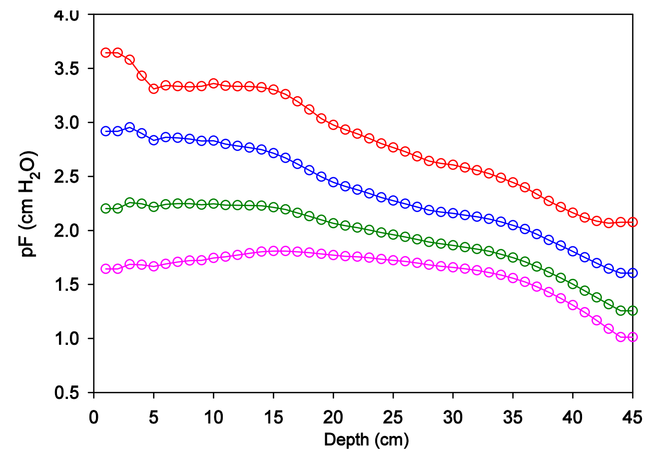
Generalized approach – Couvreur et al.:

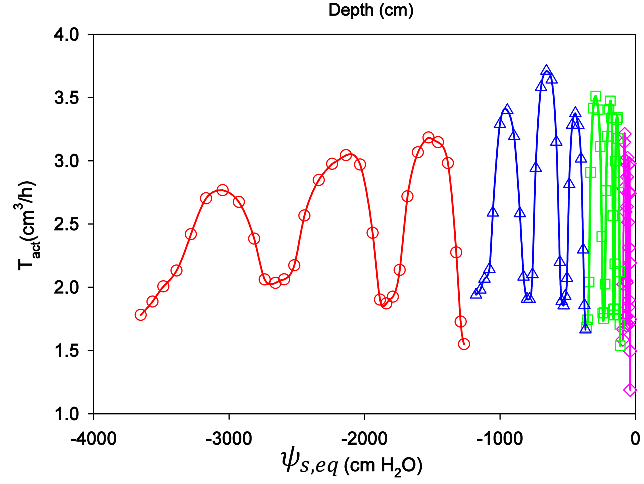
$$\psi_{s,eq} = \sum_{z=1}^{45} \psi_{rs,z} \cdot fRWU(z)$$

Root water uptake in relation to root system and soil water potential



$$\psi_{s,eq} = \sum_{z=1}^{45} \psi_{rs,z} \cdot fRWU(z)$$





Limitations

Temperature fluctuations – $\Delta T_{act}(t) > 0.15$ ml/h

Stable root conductivity during scan

Pot diameter – primarily ‘salty’ soils

Intermediate drought levels somewhat complicated

Conclusion

1- Developed very precise soil water content profiler

2- Combined with fluctuating plant transpiration RWU profiles can be measured and distinguished from soil water flows

No pF curve or RLD profile required.

3- Low cost equipment – Data analysis robust, relatively straightforward

4- When combined with RLD profile and pF (and soil conductivity) it can be used to obtain more detailed information on plant hydraulics

Plans for future:

Improved set up – LED lights coupled to SWaP

Combinatorial studies – e.g. gas exchange…stomatal conductance
- SWaP and gravimetrics
- SWaP and modelling

Anisohydric vs isohydric plants

→ Possible to use many SWaP's simultaneously

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