Sensor development for the plant sciences: technology drive, biology pull

Carel W. Windt

Non-invasive sensing of plant water status?

Measurement speed
Ease of use

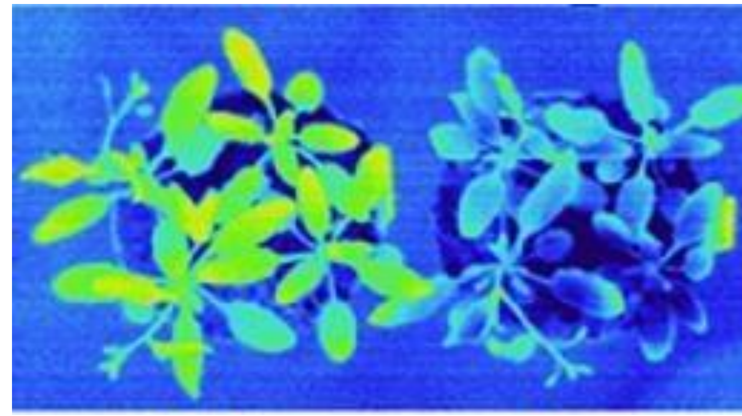
- Active thermography
- Cavity resonance
- Portable NMR
- Mobile MRI

Information content
Sensor proximity
Accuracy

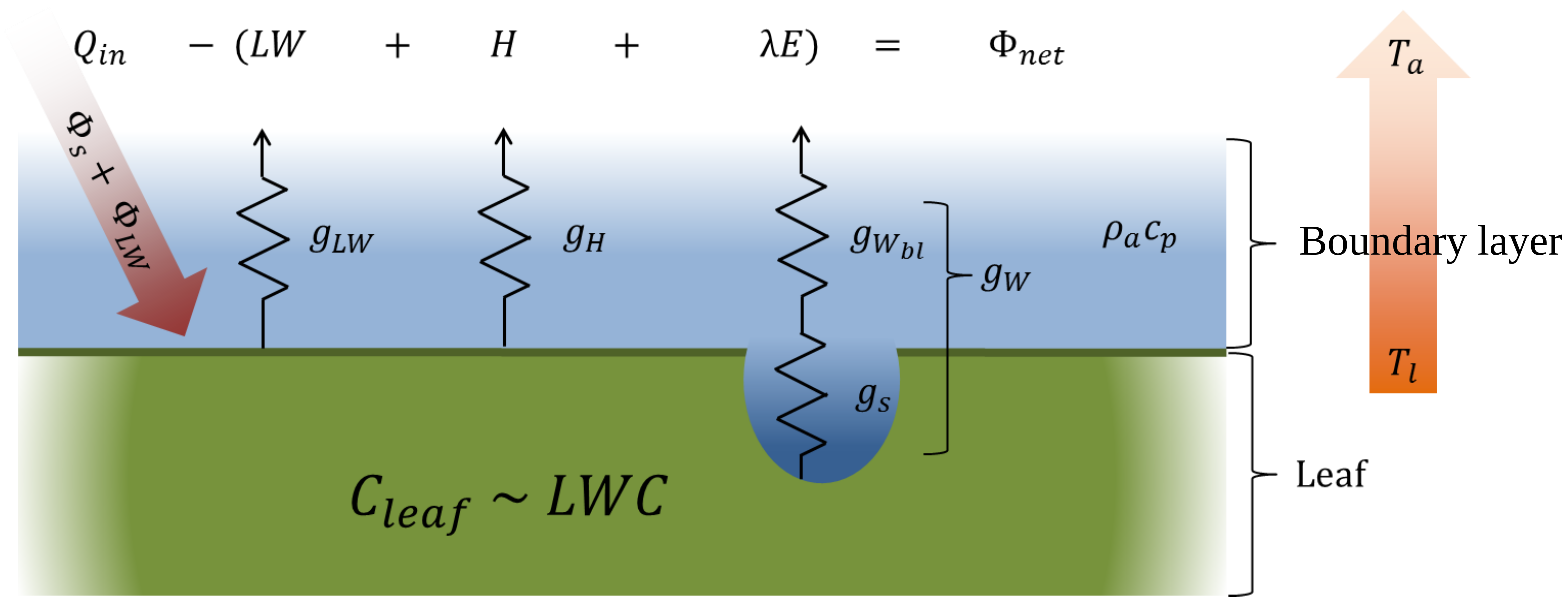
Infrared thermography: easy method to measure transpiration?

$T_{leaf} - T_{air}$ ~ rate of transpiration?

oversimplification



Kuromori et al. PNAS 107 (2010).

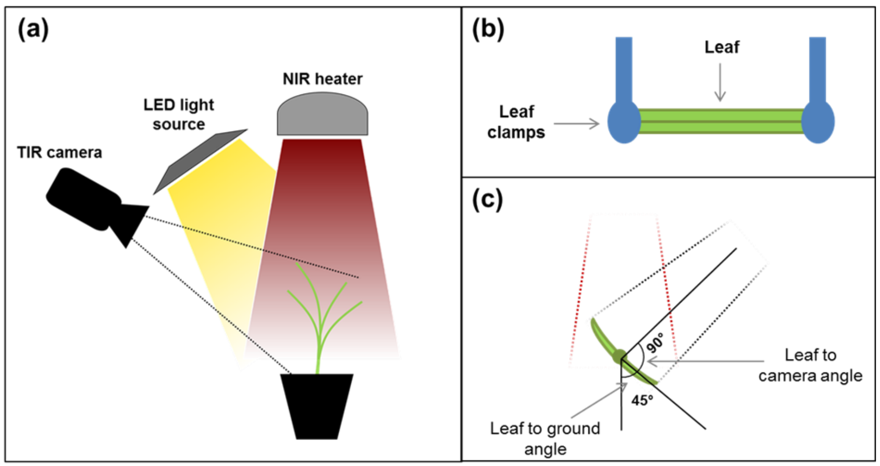


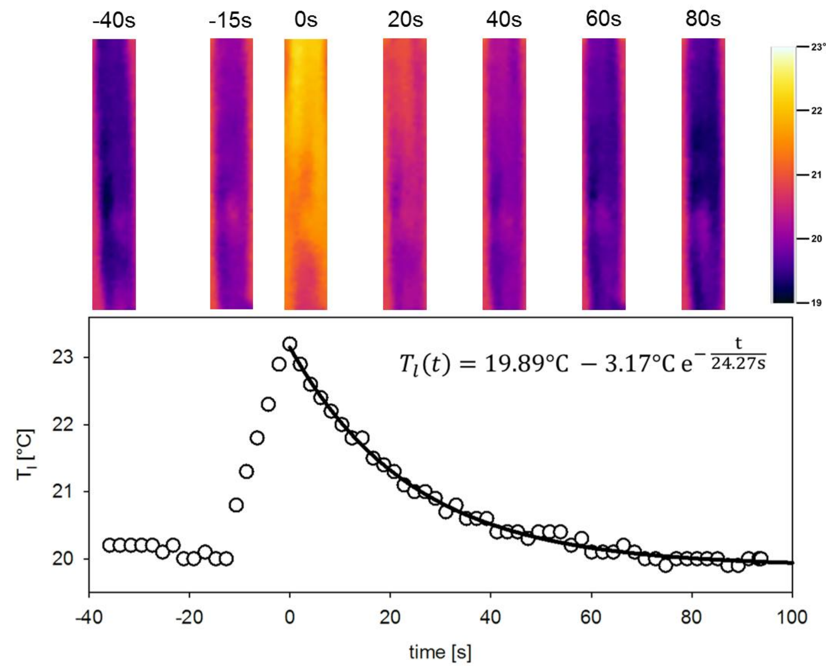
g_{LW}: infrared radiation

g_H: sensible heat

C_{leaf}: leaf heat capacitance ~ leaf water content

Measuring time constants with an active thermography approach

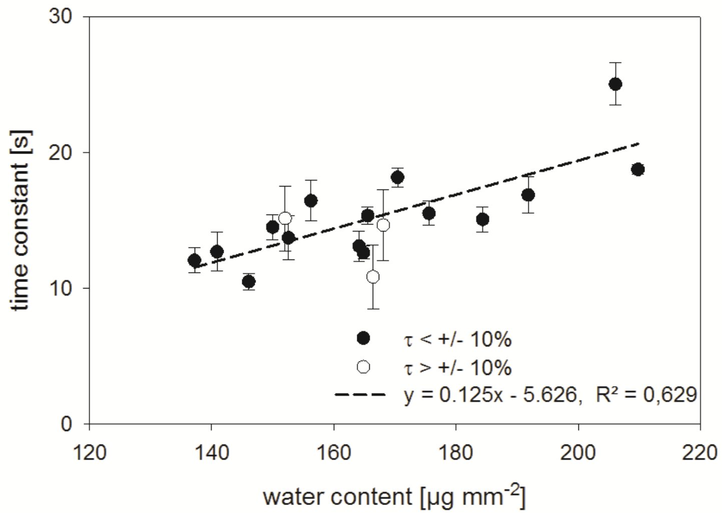


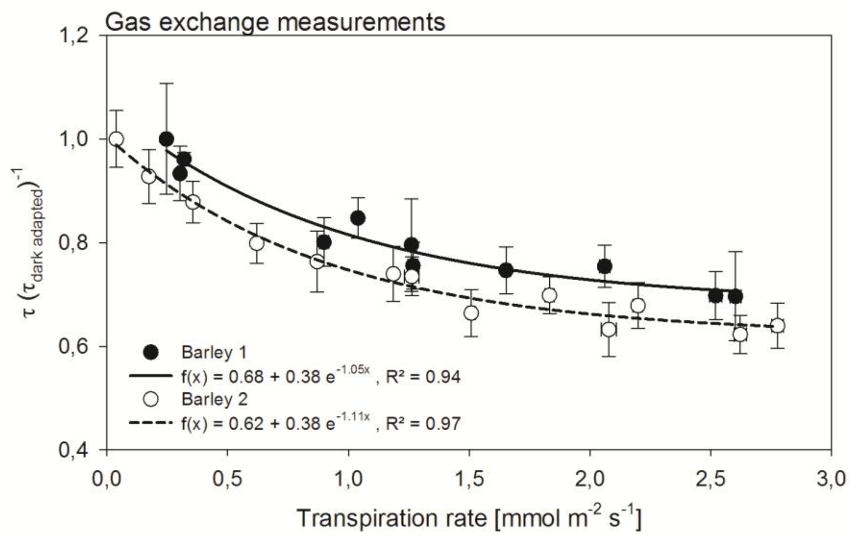


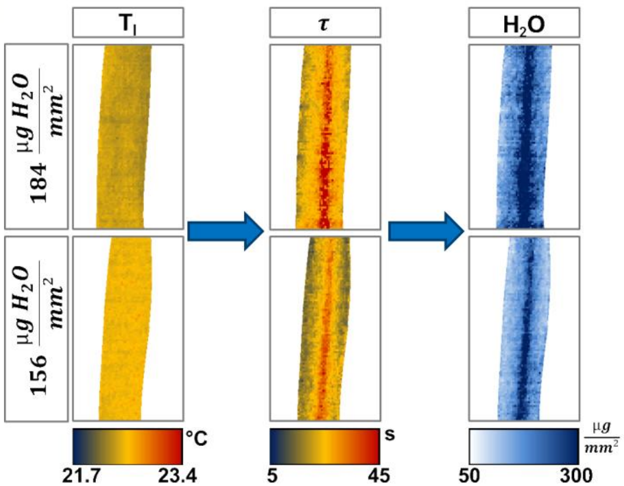
$$\tau \sim \left(\frac{C}{A}\right)_{leaf} \sim LWC$$

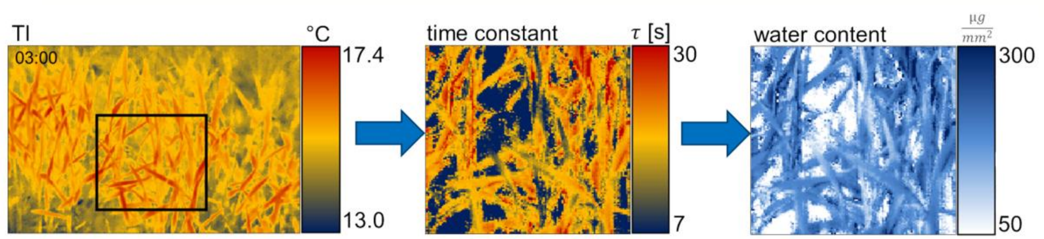
Albrecht et al., submitted

Measuring time constants with an active thermography approach

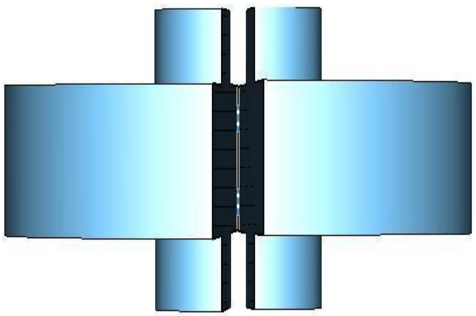


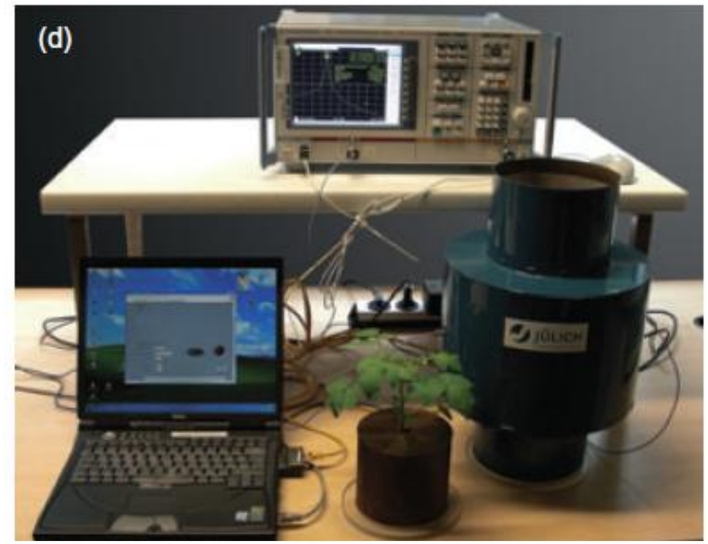


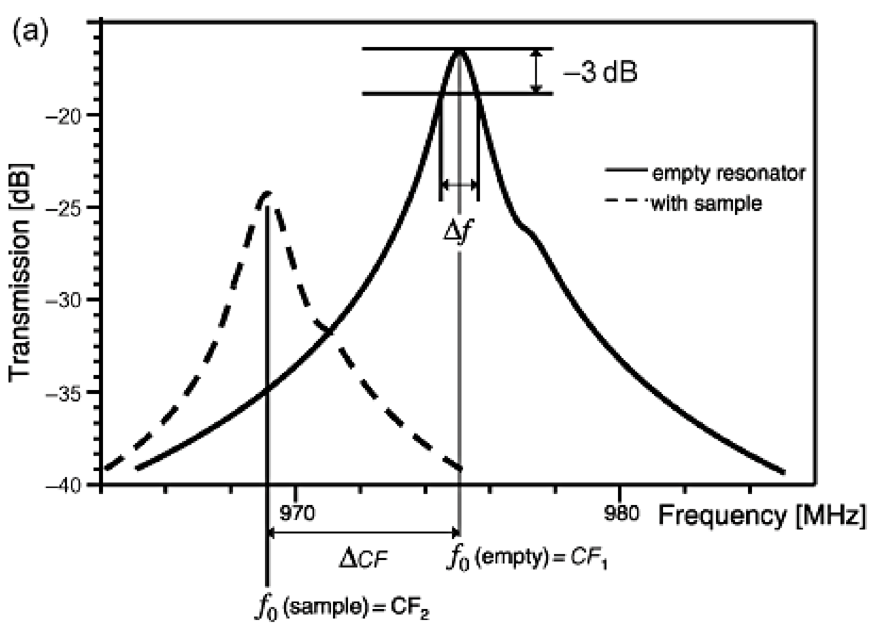


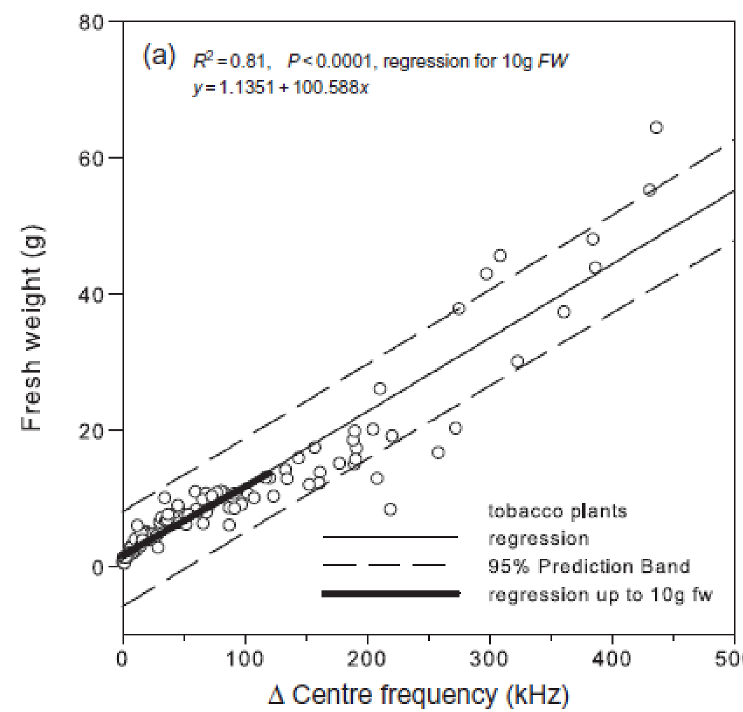


Cavity resonance for biomass measurements



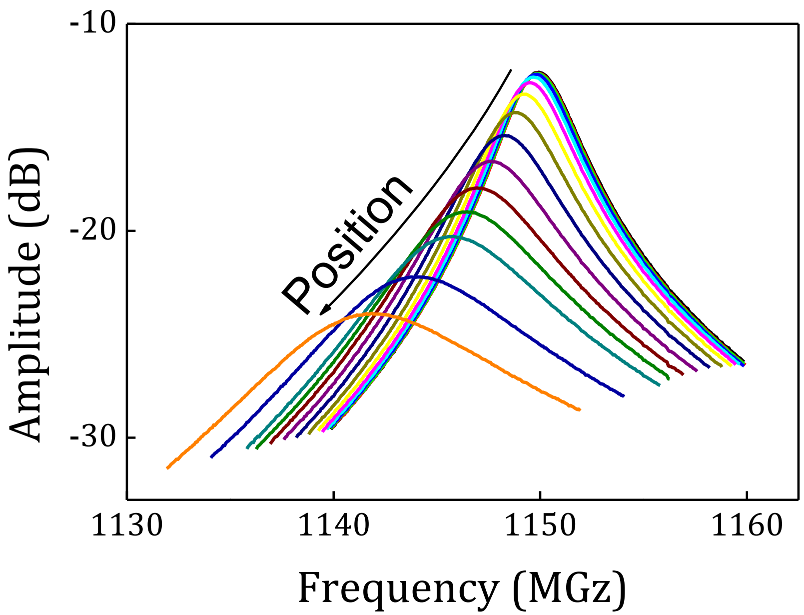


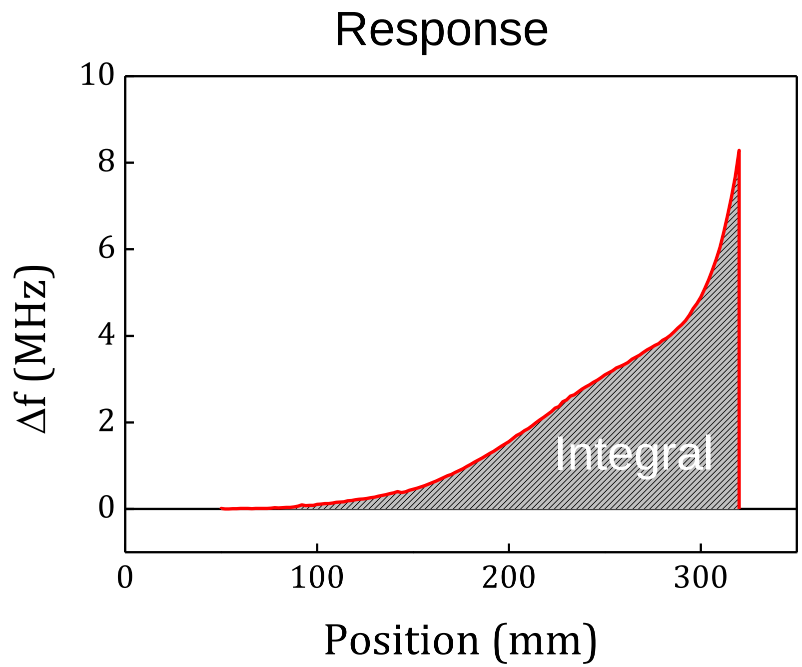


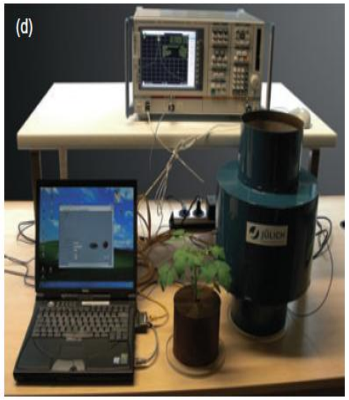


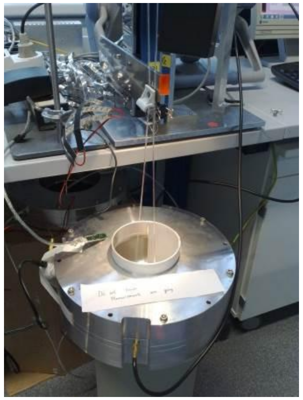
Menzel et al., 2009

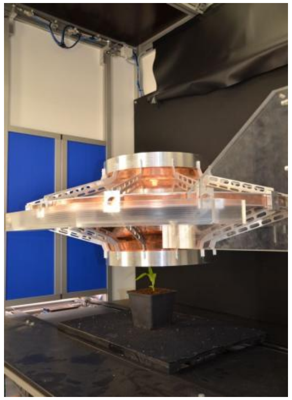
Redevelopment of the concept for use in a scanning mode and for plants of various size



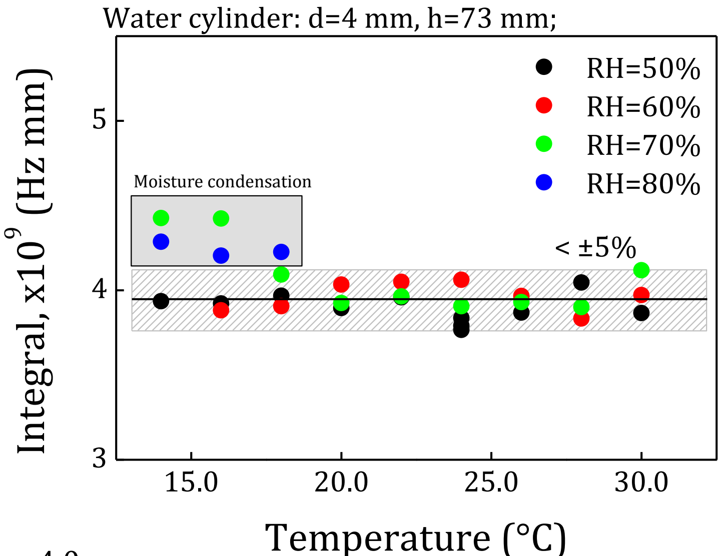


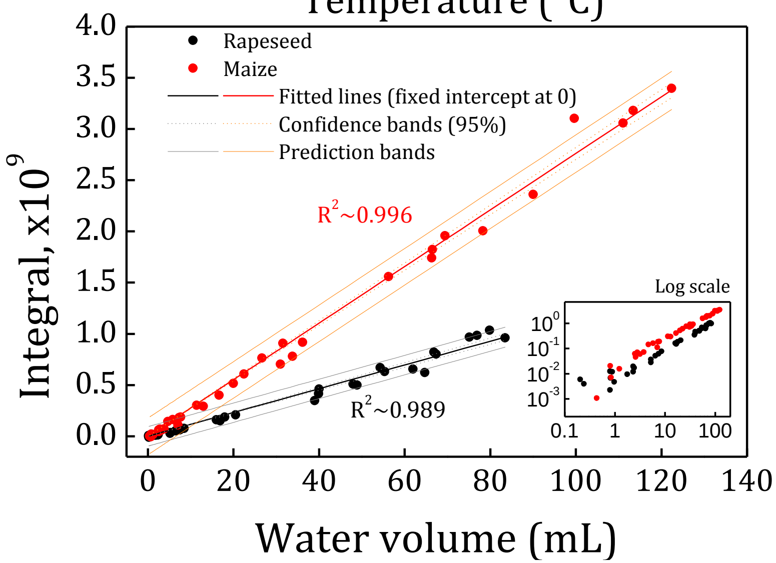


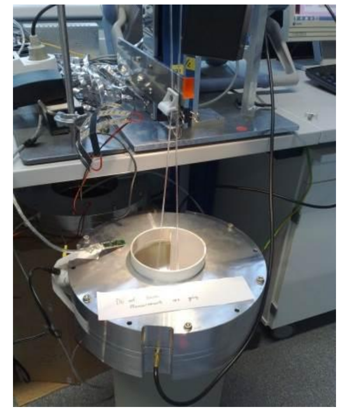


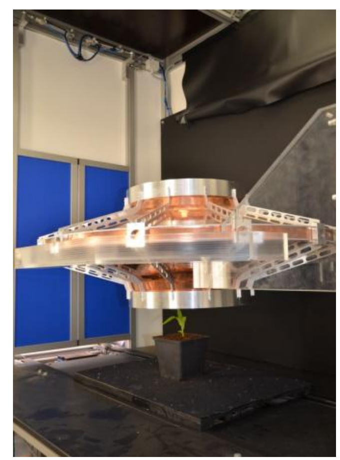


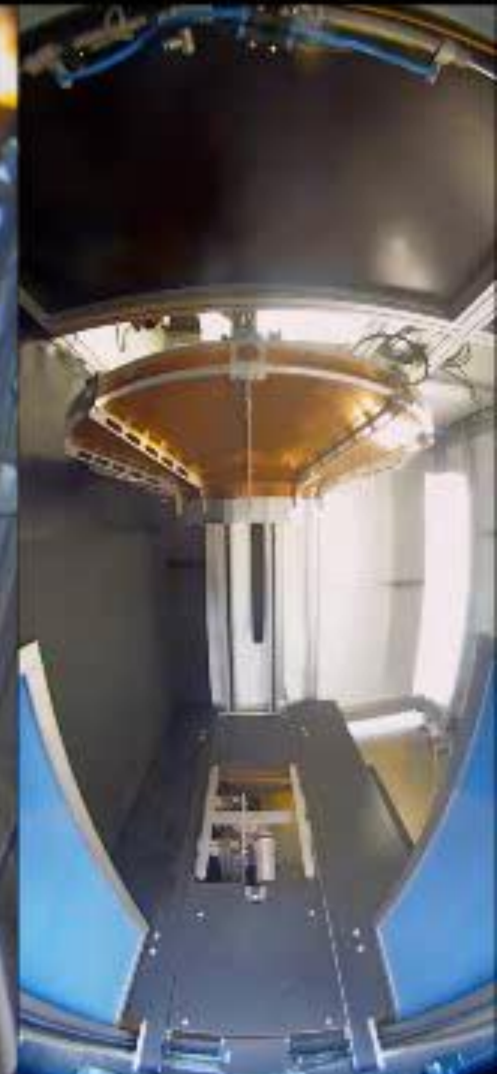
Calibration and dependency on environmental factors



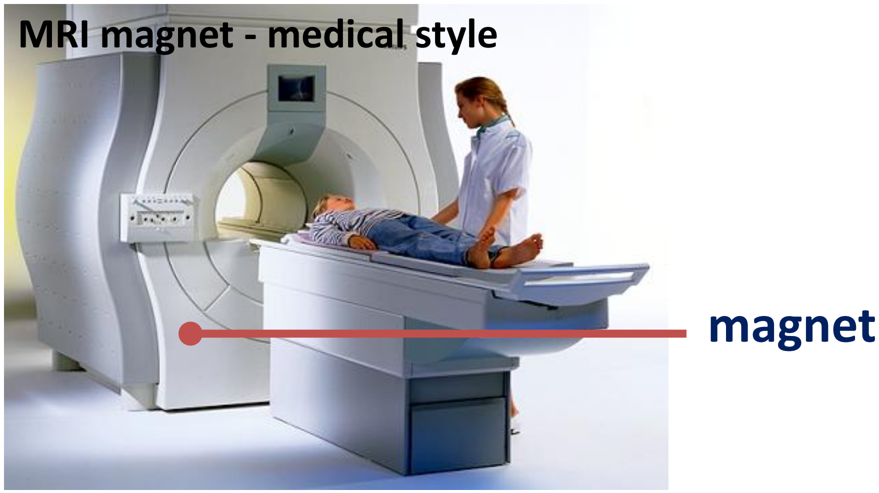


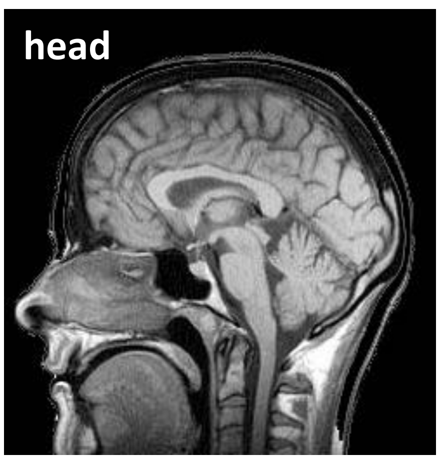


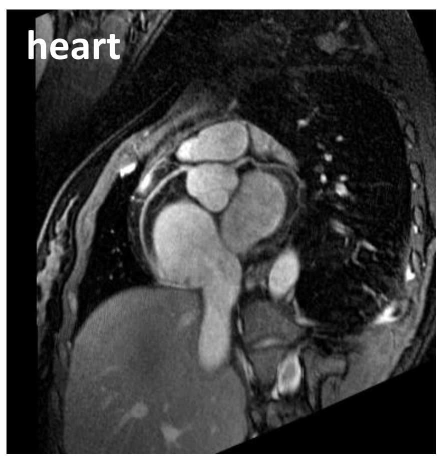




Medical MRI







Nuclear Magnetic Resonance imaging

=

NMR

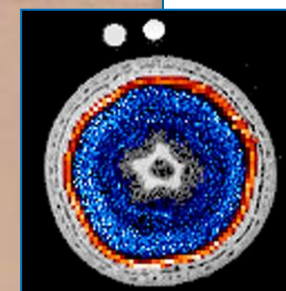
=

MRI

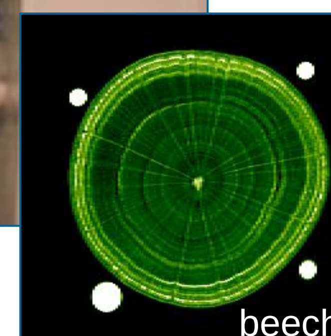
Making NMR mobile: the magnet is key

4.7T supercon
310mm bore
objects < 17cm Ø

MRI = (N)MR Imaging

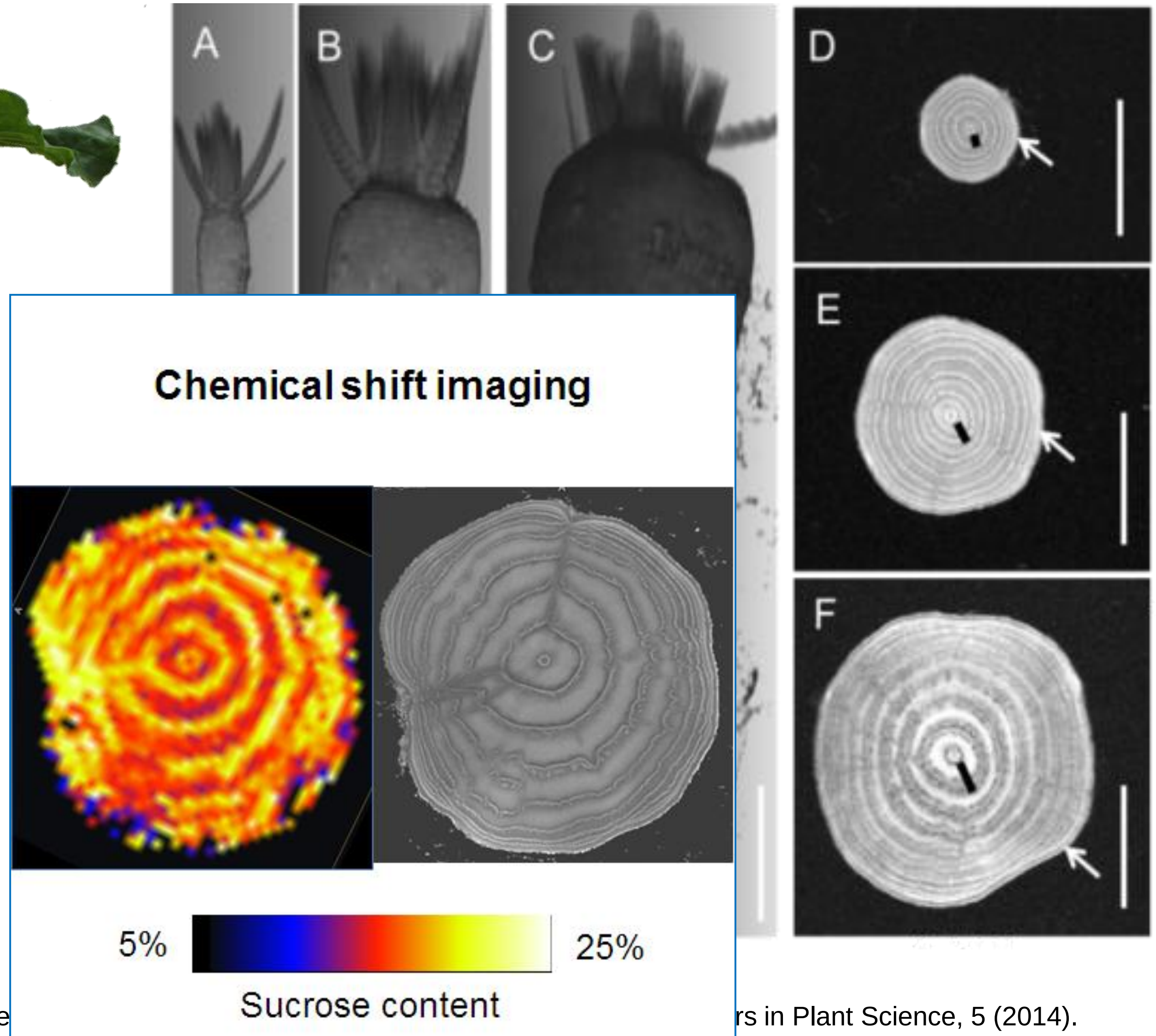


poplar



1.5T supercon
490mm gap
objects < 38 cm Ø
< 4.50m tall

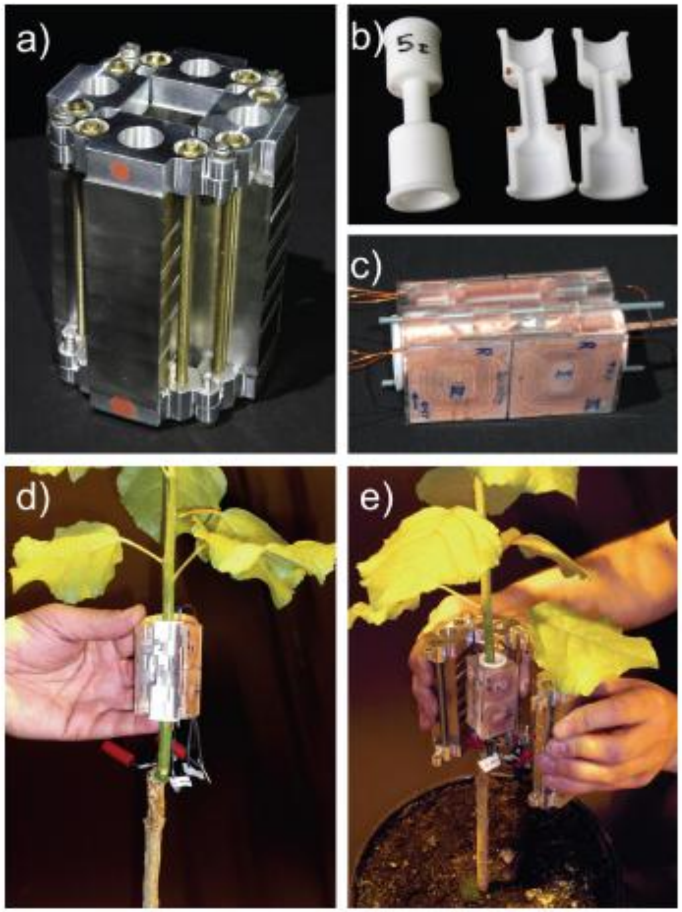
Automation of MRI measurements

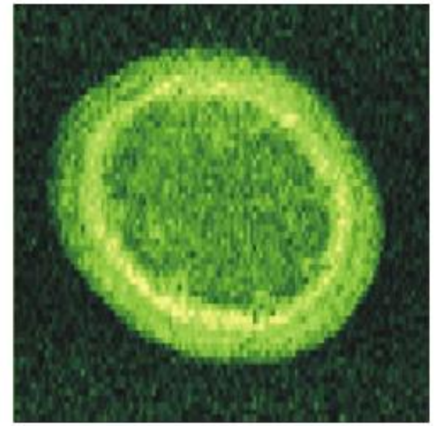


Also see … rs in Plant Science, 5 (2014).

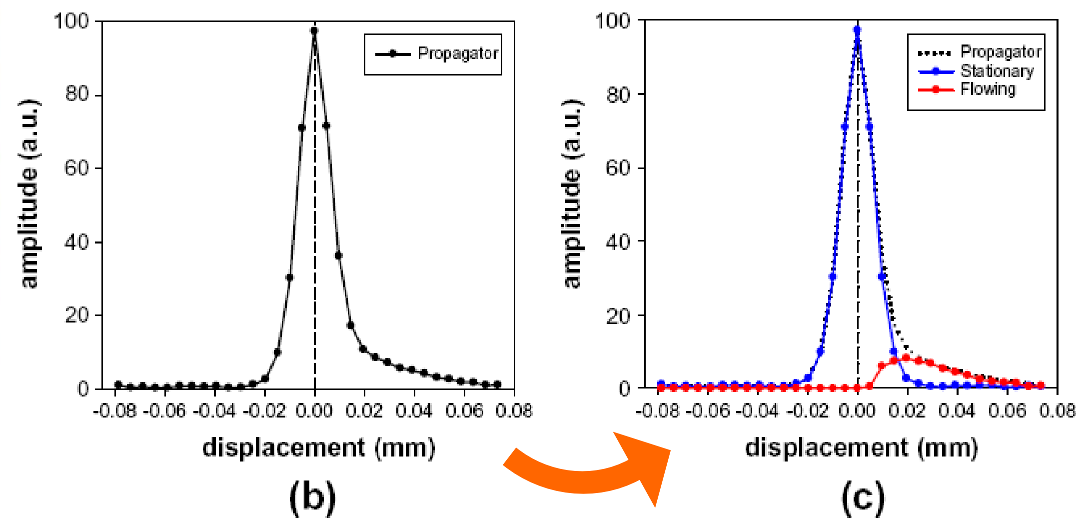
Also see: Metzner, Van Dusschoten, Bühler, Schurr & Jahnke, Frontiers in Plant Science, 5 (2014).

Sensorifying MRI and NMR: first prototypes





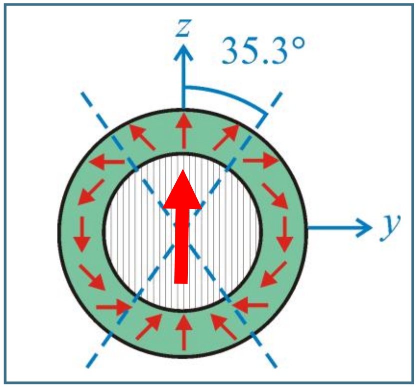
velocity spectrum



Windt C.W., Soltner H., Dusschoten D.v. & Blümler P. (2011) JMR, 208, 27-33.

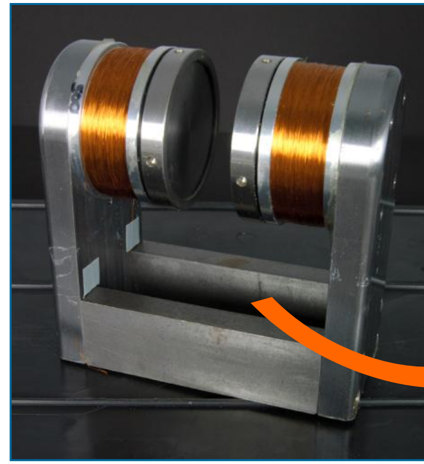
Openable Halbach: Tree scanner

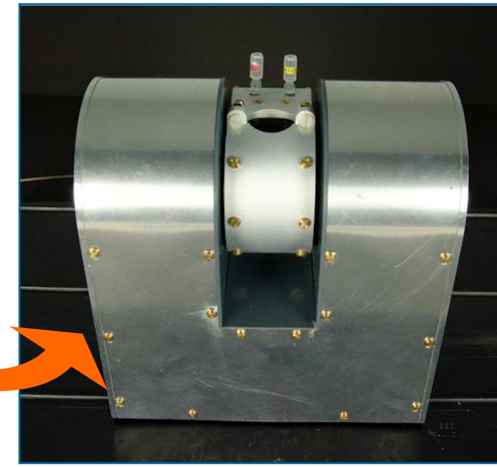
magnet ~ 200Kg
objects < 80mm Ø



Windt & Blümler (2015) Tree Phys, tpu105.

C-shaped magnets: robust, temperature stable



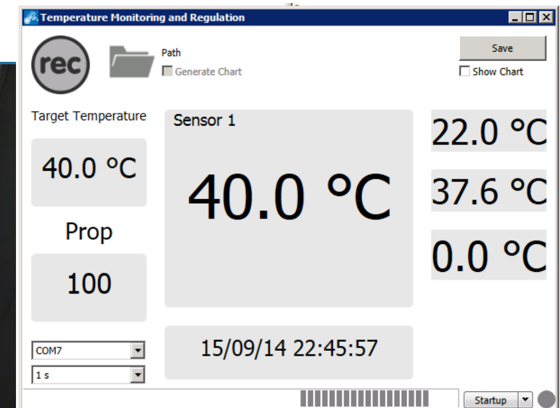


Temperature stabilized

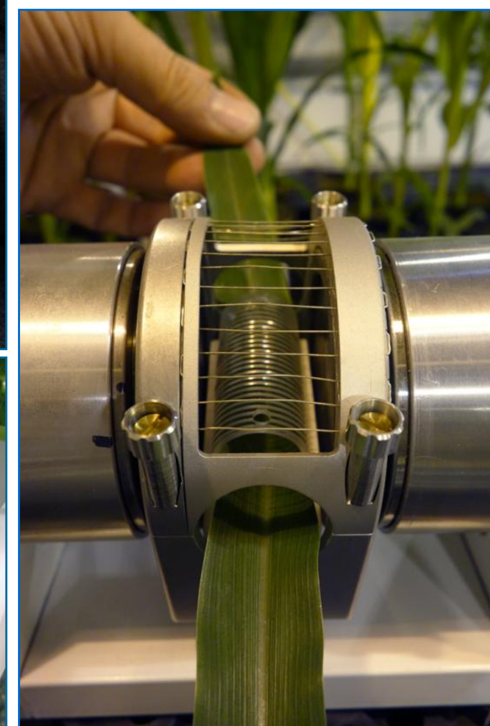
Temperature stable

Spectrometer and probe housing

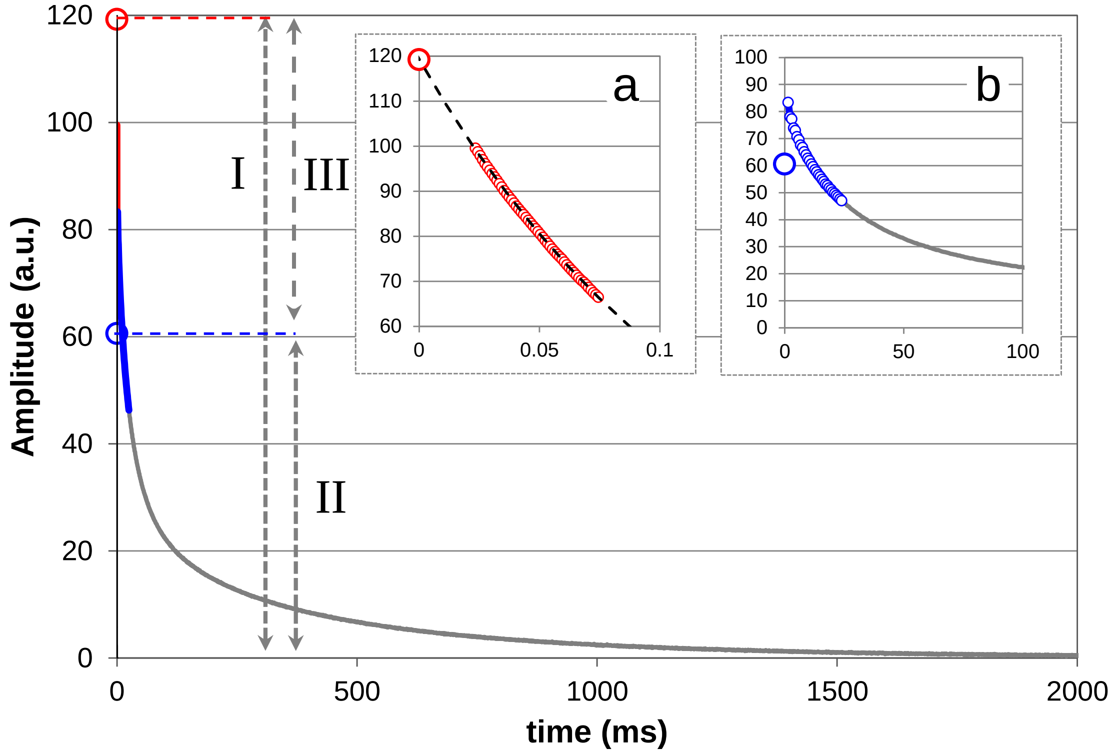
Johannes Kochs



Mansour Yaacoubi



Sensor-like usage: measurement principle



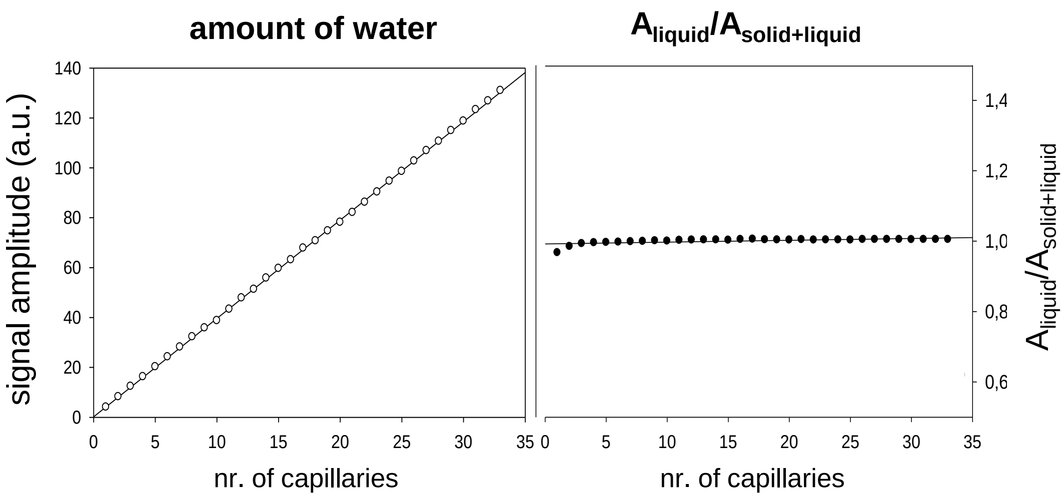
Example (FID-CPMG) curve: mature bean pod

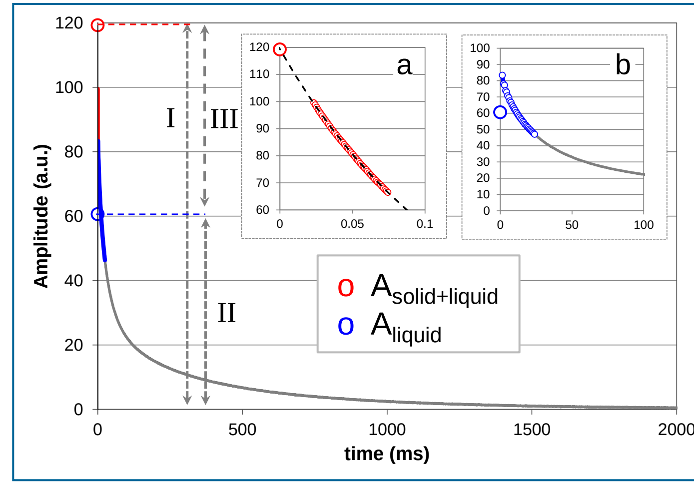
I: total proton density: liquids + solids

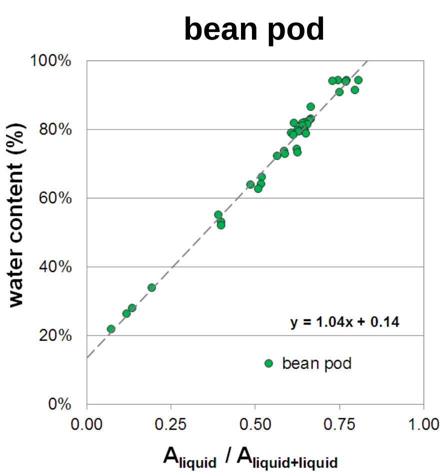
II: proton density liquids

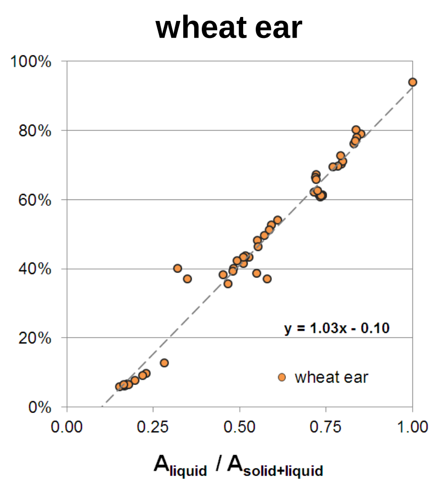
III: proton density solids

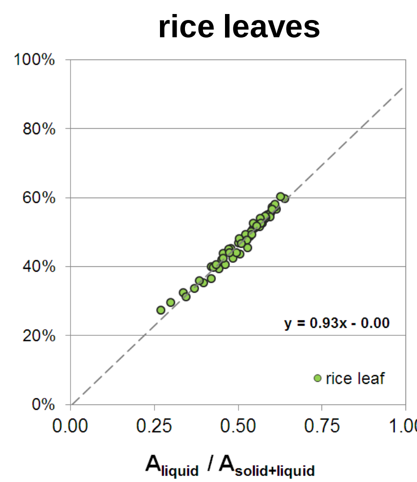
Quantitative and linear?

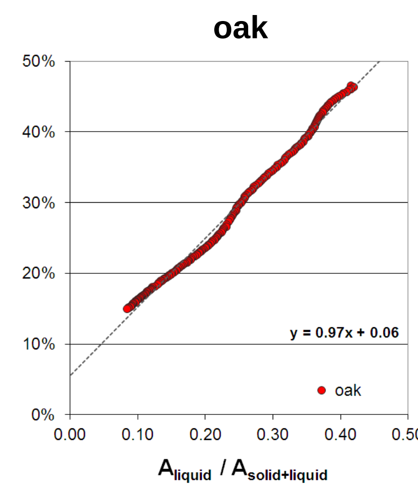




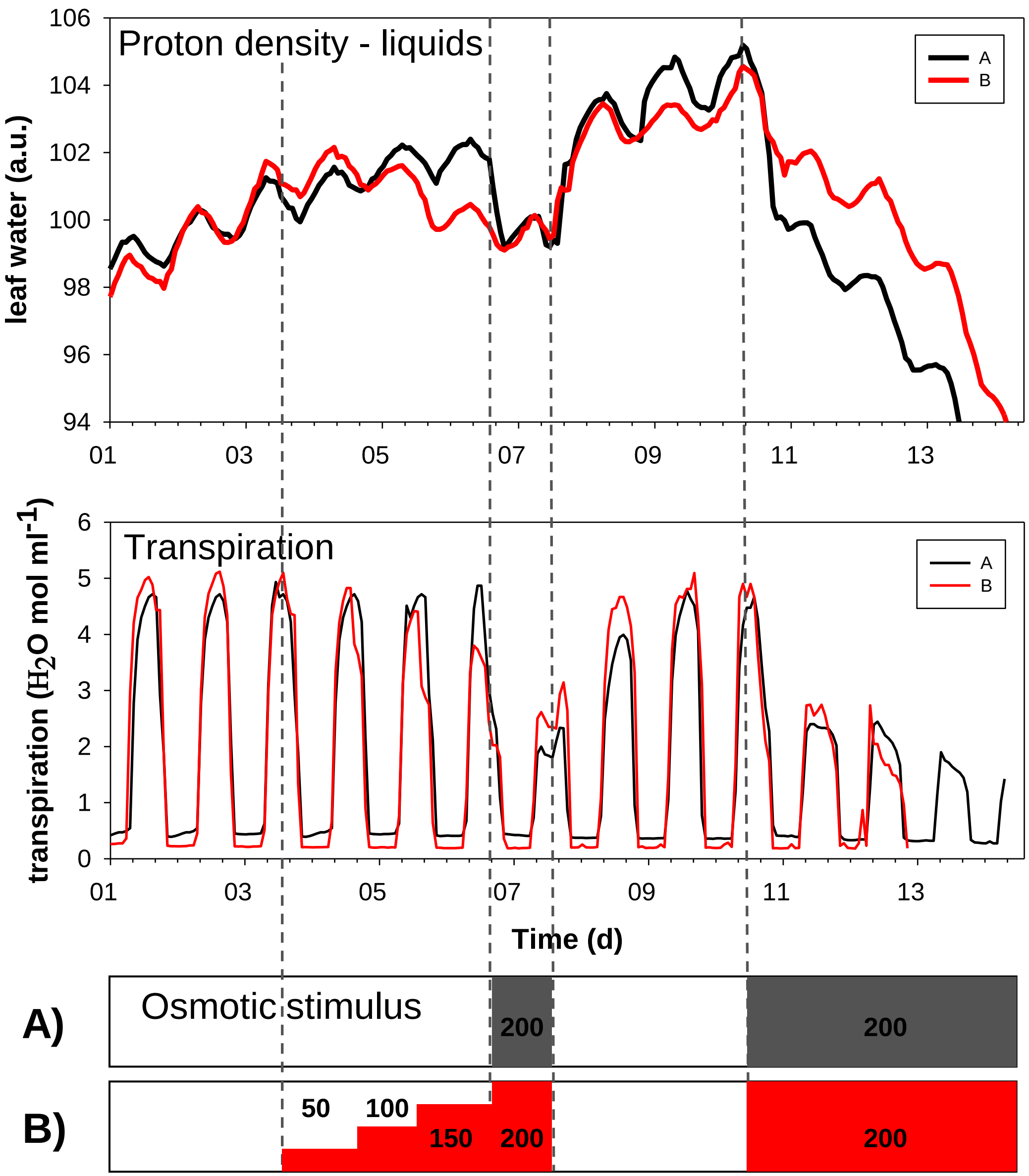








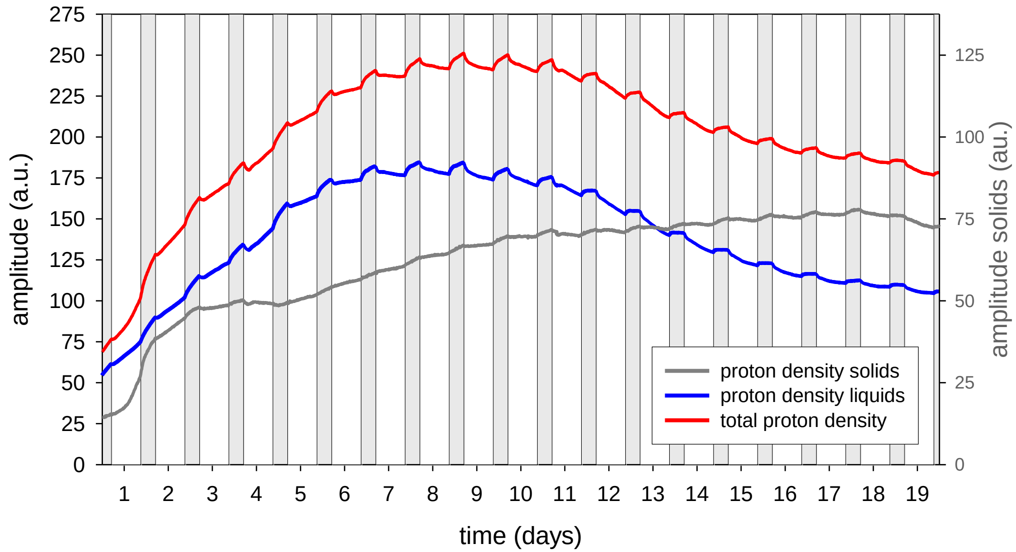
Leaf water status: stress response rice

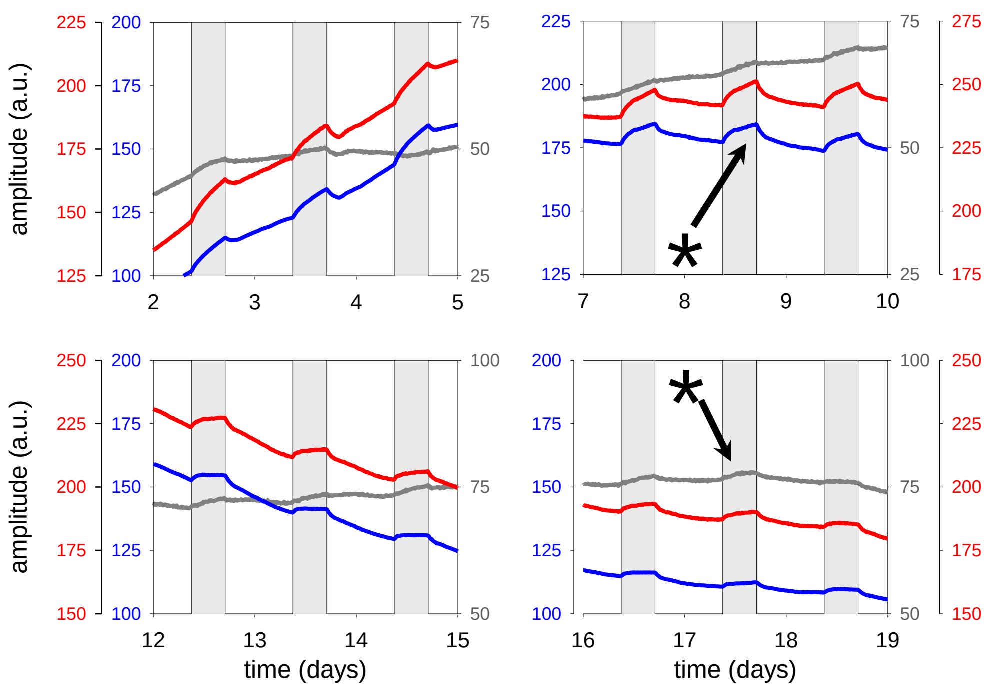


Treatments (PEG gr/l)

Work: Moritz Nabel

Fruit growth and seed filling: bean pod





- fully automated
- remotely operated
- time resolution up to 1s (10min typical)
- data evaluation fast, robust & simple

Acknowledgments

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DPPN

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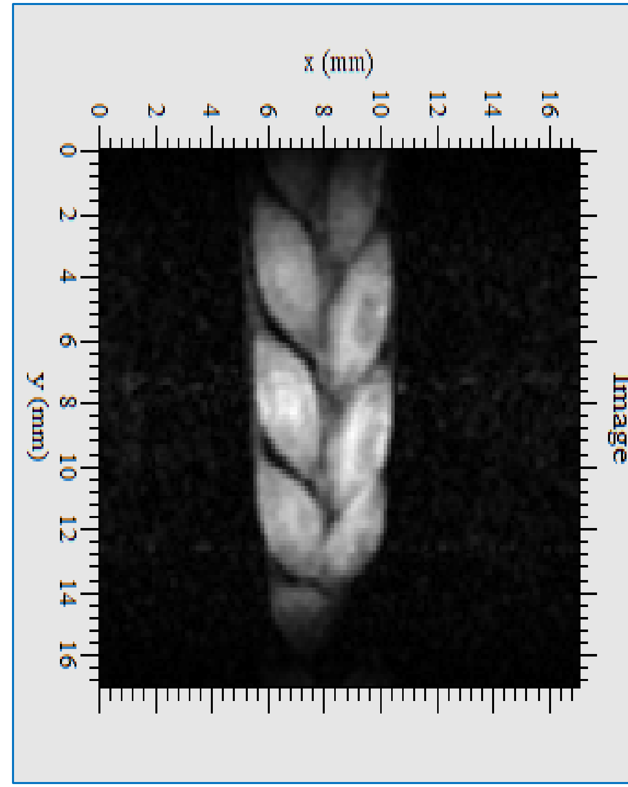
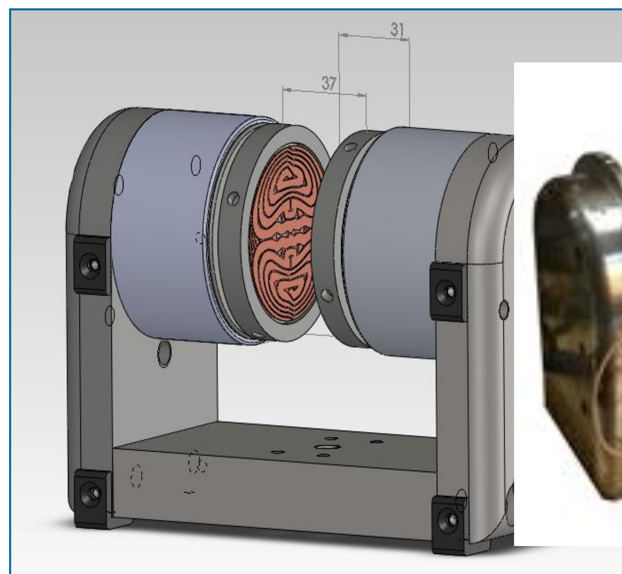
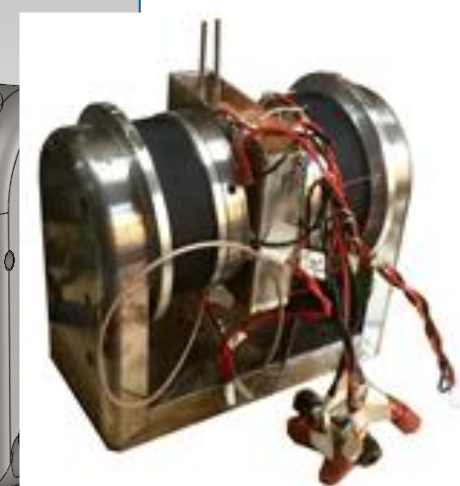
Bundesministerium für Bildung und Forschung

Thank you for your attention

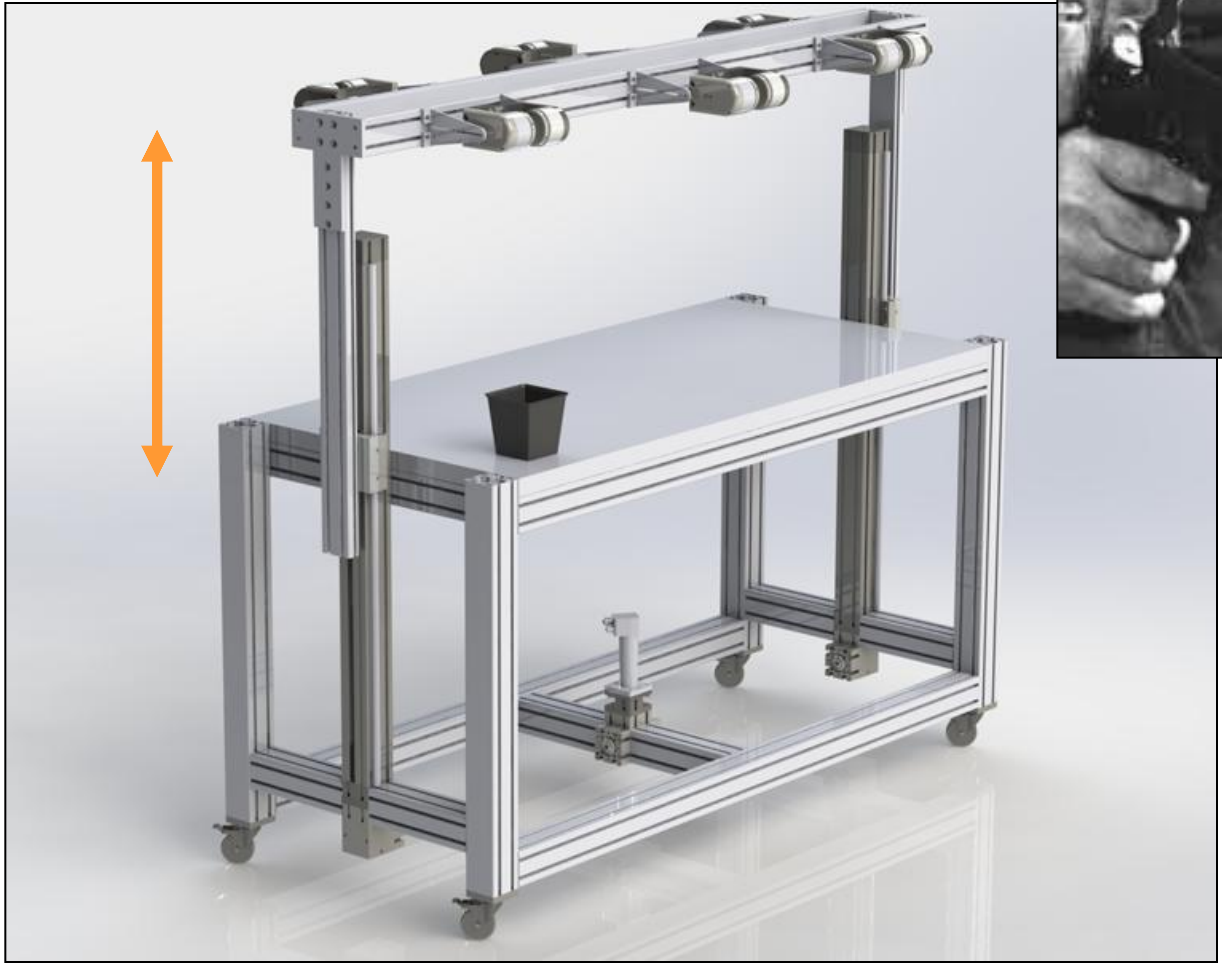
Mapping water content







Outlook: NMR-multiplex



NMR-MULTIPLEX (3D construction and image: Alexander Putz)