Intact Plant MRI: up and down during 40 years

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Introduction: Modern plant breeding needs to increase agricultural productivity under changing climate conditions while decreasing the ecological footprint. Therefore, there is a strong need to characterize plant genotypes in relation to dynamic environmental (stress) conditions based on photosynthesis, water use efficiency and plant performance. Xylem and phloem transport in plants (Fig. 1) are considered key traits for such phenotyping [1]. Several methods are available to measure parameters related to plant water status [1,2]. PFG-MRI propagator measurements are the most powerful, both for xylem and phloem flow.
Intact plant (mobile) MRI hardware and methods have been developed during the last 40 years that allow to measure long distance transport in relation to the study of photosynthesis and plant water status in an integrative way [1].

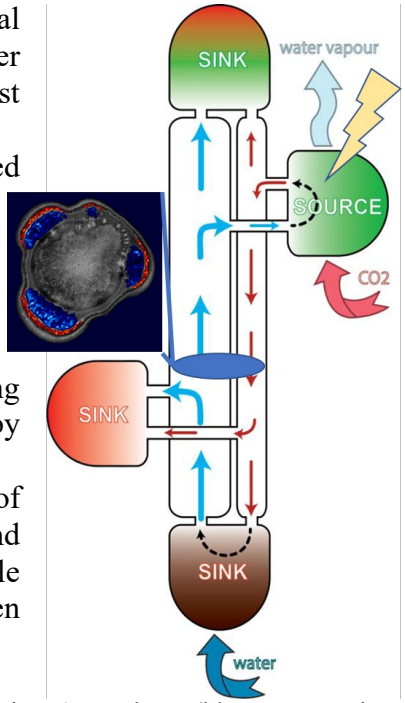

Fig. 1: Xylem (blue, connecting uptake and transpiration) and phloem (red, from source leaves to growing/storage tissues, the sinks) transport in plants. In the cross-sectional image of the stem xylem and phloem flow is overlaid on a proton-density image.

Methods: Propagator measurements in the stem of intact plants by PFG-STE-RARE. Exchange between flowing water and non-flowing water can (strongly) affect the results [3] and has been tested by varying big delta values.
Dedicated lab-based MRI systems (with control/monitoring of microclimate parameters, light intensity, temperature, humidity) and (low field) portable NMR/MRI systems for *in situ* use are available since then 80s [4,5] and have further been developed in the last ten years [6-8].

Results: Long distance flow has been studied as a function of light intensity, photoperiod, fruit pruning, drought stress (tomato plants) and developing strong sinks (tubers) in the root part (potato genotypes with different phloem area), flooding (anoxic root condition that limits sucrose uptake from phloem, Ricinus) reveals that xylem velocity and flux scales with transpiration, but phloem flux is regulated by varying the flow conducting area, not the velocity [9]. At the same time the sucrose content of phloem varied (at higher B_0 reflected in the T_2 of phloem sap), and thus the viscosity. This may stimulate exchange between flowing water and non-flowing water in companying cells. Since propagators and flow results were independent of big delta values (50-150 ms), flow conducting area and velocity were not affected by exchange [9].

Conclusion: MRI can be used for in depth plant phenotyping, eg based on transport traits. Phloem flux is limited by the phloem conducting area present in plants, and can inhibit photosynthesis under optimal photosynthetic conditions! Breeding should include optimizing maximum phloem conducting area in relation to optimizing photosynthesis efficiency. MRI can be of help.
MRI at higher field strengths (2 a 3 T or higher) allows to relate phloem flow characteristics and phloem sap sucrose content in relation to photosynthetic activity. Portable MRI becomes available for phenotyping *in situ*. Due to the low B_0 no info on phloem sucrose is available by such systems.

References: [1] Van As & van Duynhoven, J Magn Reson (2013). [2] Van As, J Exp Bot 2007. [3] Homan et al, Phys Chem E (2010). [4] Reinders et al, J Exp Bot (1988). [5] Van As et al, J. Exp Bot (1994). [6] Windt and Blümler, Acta Hort (2013). [7] Nagata et al, J Magn Reson (2016). [8] Sidi-Boulenouar et al, J Sensors & Sensor Systems (2018). [9] Prusova, PhD thesis Wageningen (2016).