Combining flow-MRI method and modeling approach to assess water fluxes in tomato plant architecture

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INTRODUCTION

Water and carbon status throughout growth and development are tightly controlled by the plants and are key components of their response to environmental stresses. Measuring and predicting resource availability and transport within intact plants is a challenge.

The objective of this study is to compare the flow-MRI measurements to the prediction of a functional-structural plant model in order to explore the relevance of this MRI method to analyze the plant responses to abiotic stresses and map the ressource availability.

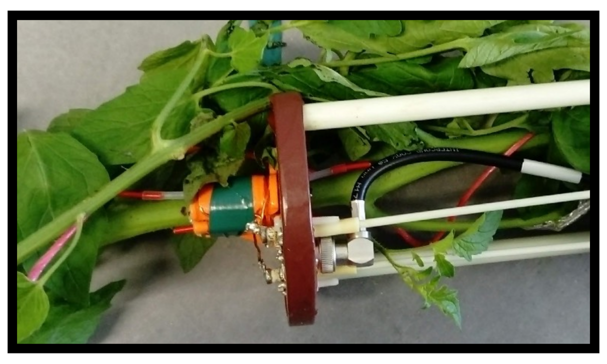
MATERIALS AND METHODS

Flow-MRI method

We used a novel flow-MRI method involving the slice selectivity in the context of a multi slice spin echo sequence [1]. Two pulse sequences measuring a slice inflow and outflow weighted are performed, allowing slow flow sensitive imaging. The experiments have been performed on a Agilent MRI scanner working at 9.4T. A ^1H MRI openable saddle-coil tuned at 400MHz has been designed to fit the stem of plants [2].

We applied this method to the main stem of a tomato plant (cv : WVA106), under the third truss. Histological measurements were performed after the MRI experiment.

Openable saddle-coil



Openable saddle-coil around the stem of a tomato plant

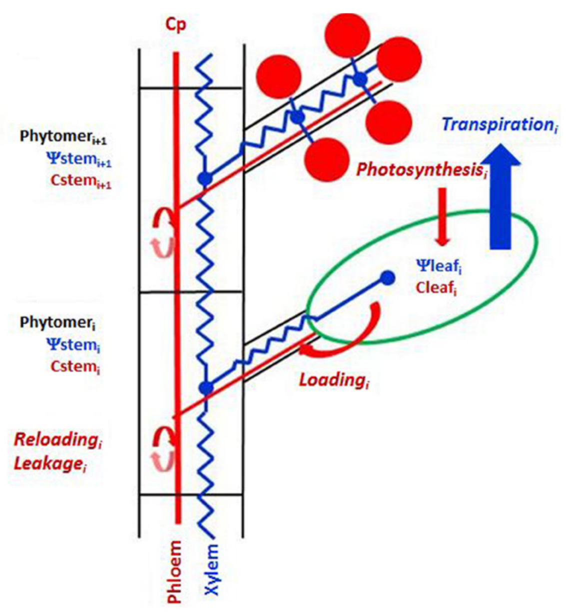
Agilent MRI scanner 9.4T

Environmental conditions

The plant is placed horizontally inside the MRI scanner. The experiments were performed during three consecutive days with no light (extended night conditions). The temperature in the MRI scanner is 20°C.

Plant model

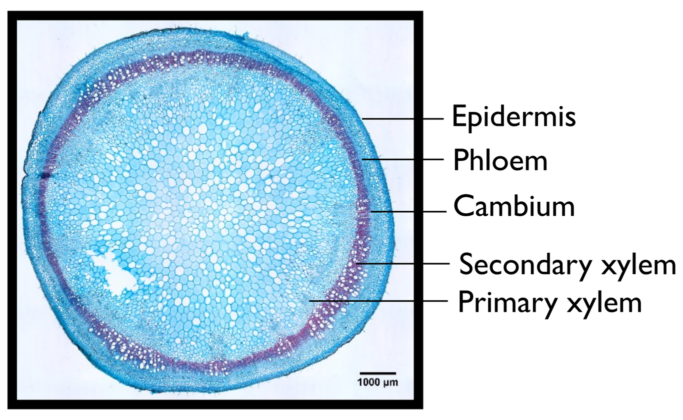
We ran a bio physiological functional-structural plant model [3] until the computed plant achieved the same architecture as the investigated plant. Then, the MRI environmental conditions were reproduced in order to analyze the fluxes predicted under the third truss.



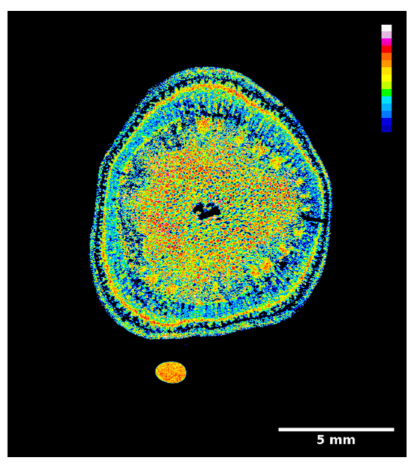
Schematic representation of how the model describes the network of source and sink organs as well the transport of resources within this network [3]

RESULTS

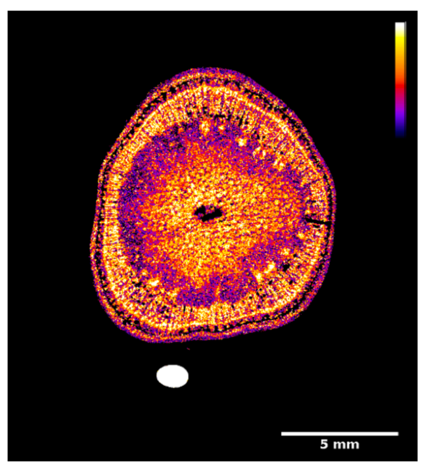
Flow-MRI measurements



Histological slice of the main stem. FASGA coloration (Safranine + Toludine blue)

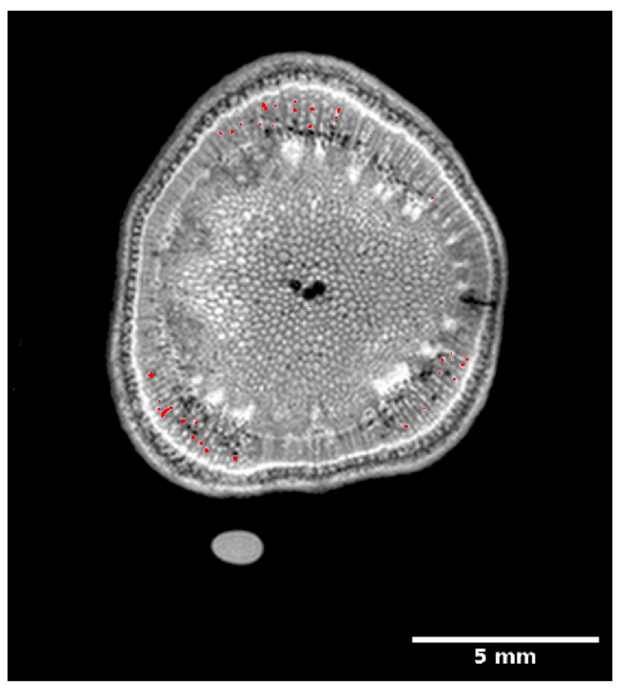


M0 parametric image



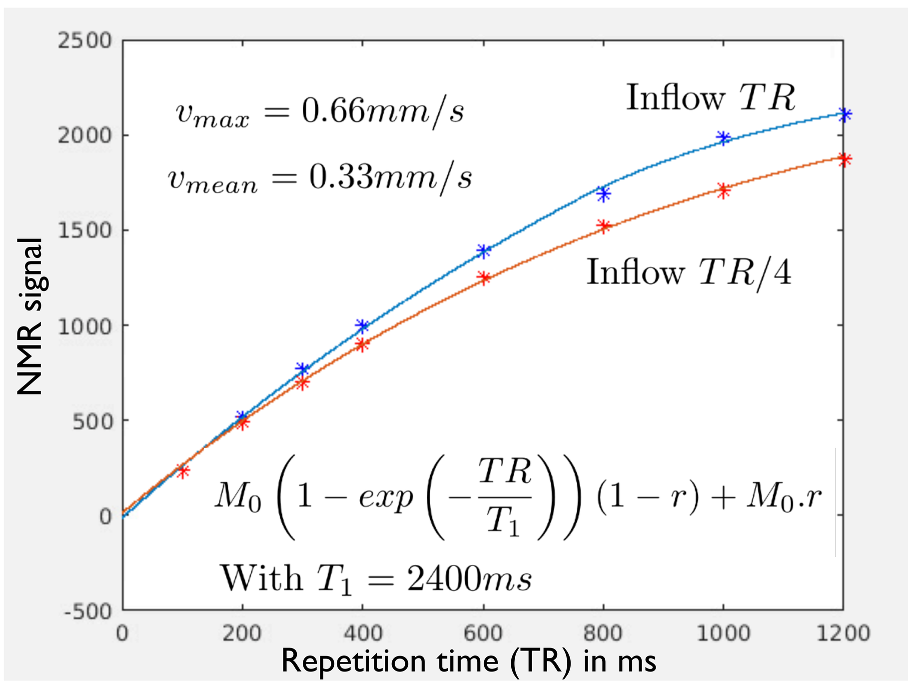
Long T2 parametric image

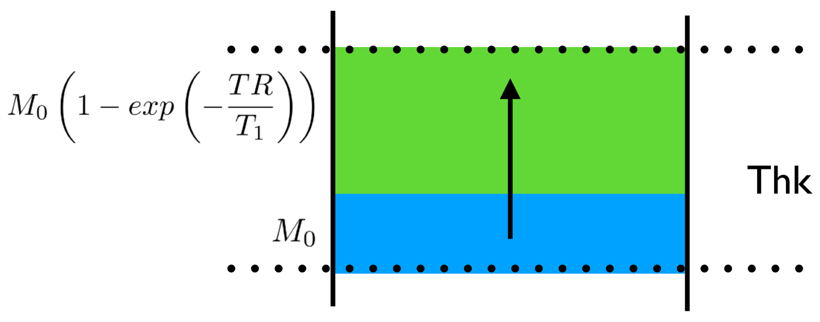
TR = 10 s

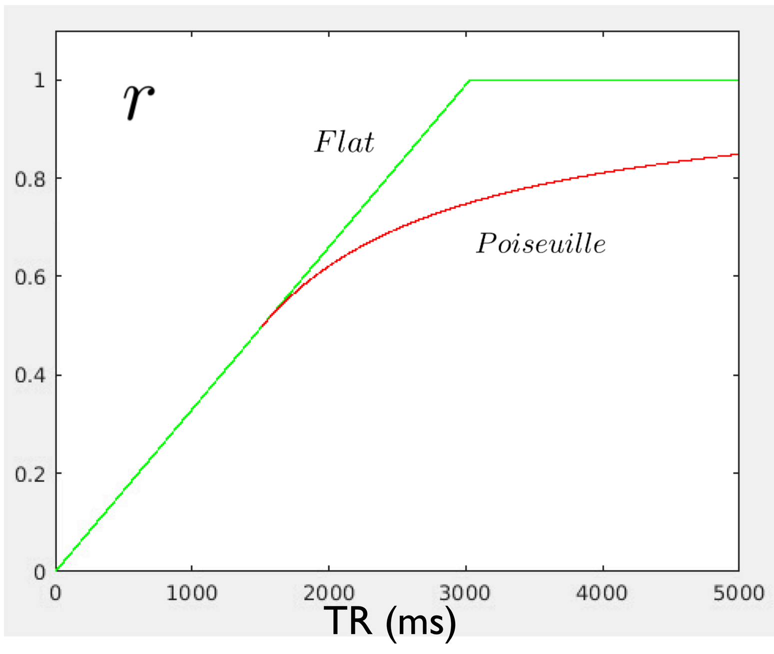


Inflow MRI image. TR = 1200 ms. Thk = 0.5 mm. TE = 12 ms.

The red areas represent the active vessels during flow-MRI measurements.







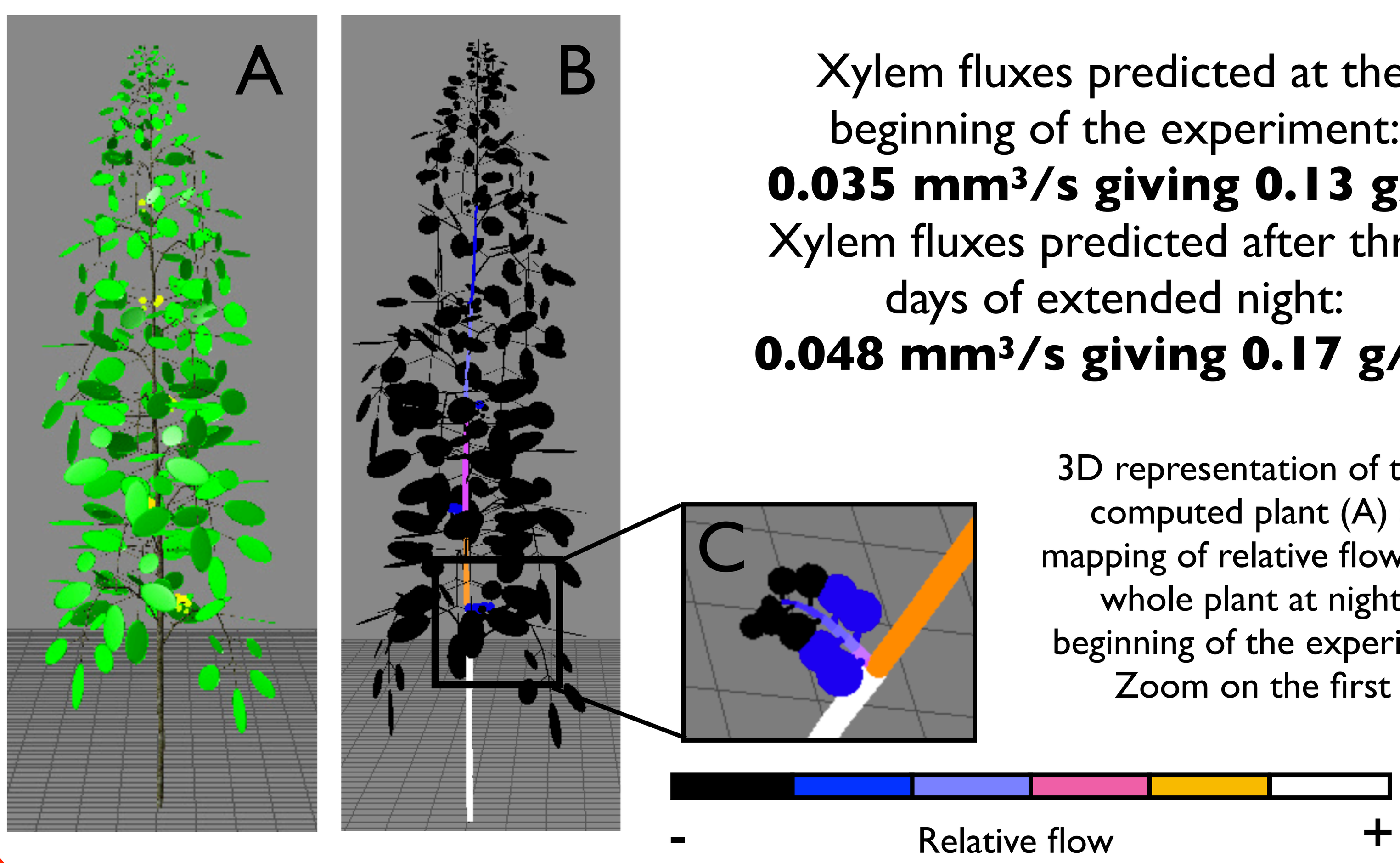
Active surface = 0.23 mm² and v = 0.33 mm/s

Xylem fluxes = 0.076 mm³/s giving 0.27 g/h

Model predictions

Model predictions of xylem fluxes in the MRI conditions, on a virtual plant with the same aerial architecture as the measured plant, and at the same position on the stem : under the third truss.

The assumption made by the model at night is that the fluxes are only due to fruit activity and that the leaves do not transpire.



Xylem fluxes predicted at the beginning of the experiment:

0.035 mm³/s giving 0.13 g/h

Xylem fluxes predicted after three days of extended night:

0.048 mm³/s giving 0.17 g/h

3D representation of the whole computed plant (A) and 3D mapping of relative flow (B) in the whole plant at night at the beginning of the experiment. (C) Zoom on the first truss.

CONCLUSION AND PERSPECTIVES

The flow-MRI method allows us to measure water fluxes in slow flow conditions. The measurements are in agreement with the predictions of the plant model in the same environmental conditions.

These results confirm that this method will be a useful tool to analyse plant responses to abiotic stresses and will help to improve the plant model.

Perspectives

- Add some echoes to increase the SNR and have better chances to see phloem fluxes.
- A new ^1H MRI probe as been designed to fit the fruit pedicel plants which will allow us to measure the fluxes going to the fruit.
- The acquisition of a new vertical MRI scanner 3T will allow us to make measurements in better environmental conditions and during longer time periods.

Helmholtz coil designed for the fruit pedicel

REFERENCES

[1] : Buy S., Le Floch S., Tang N., Sidiboulenouar R., Zanca M., Canadas P., Nativel E., Cardoso M., Alibert E., Dupont G., Ambard D., Maurel C., Verdeil J.-L., Bertin N., Goze-Bac C., Coillot C. 2018. Flip-flop method: A new T1-weighted flow- MRI for plants studies. PLoS ONE 13(3): e0194845. doi: 10.1371

[2] : Coillot C., Sidiboulenouar R., Nativel E., Zanca M., Alibert E., Cardoso M., Saintmartin G., Noristani H., Lonjon N., Lecorre M., Perrin F. and Goze-Bac C., Signal modeling of an MRI ribbon solenoid coil dedicated to spinal cord injury investigations, J. Sens. Sens. Syst., 5, pp. 137–145, (2016).

[3] : Baldazzi V., Pinet A., Vercambre G., Bénard C, Biais B., Génard M. 2013. In-silico analysis of water and carbon relations under stress conditions. A multi-scale perspective centered on fruit. Front. Plant Sci., doi: 10.3389

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