Towards the mechanistic understanding of plant-source water isotopic offsets

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A European vision for hydrological observations and experimentation

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Use of $\delta^{18}O$ and $\delta^{2}H$ to study plant water sources

Xylem water $\delta \approx \delta$ of the mix of sources accessed by roots

↓

Assumption → No isotopic fractionation during root water uptake

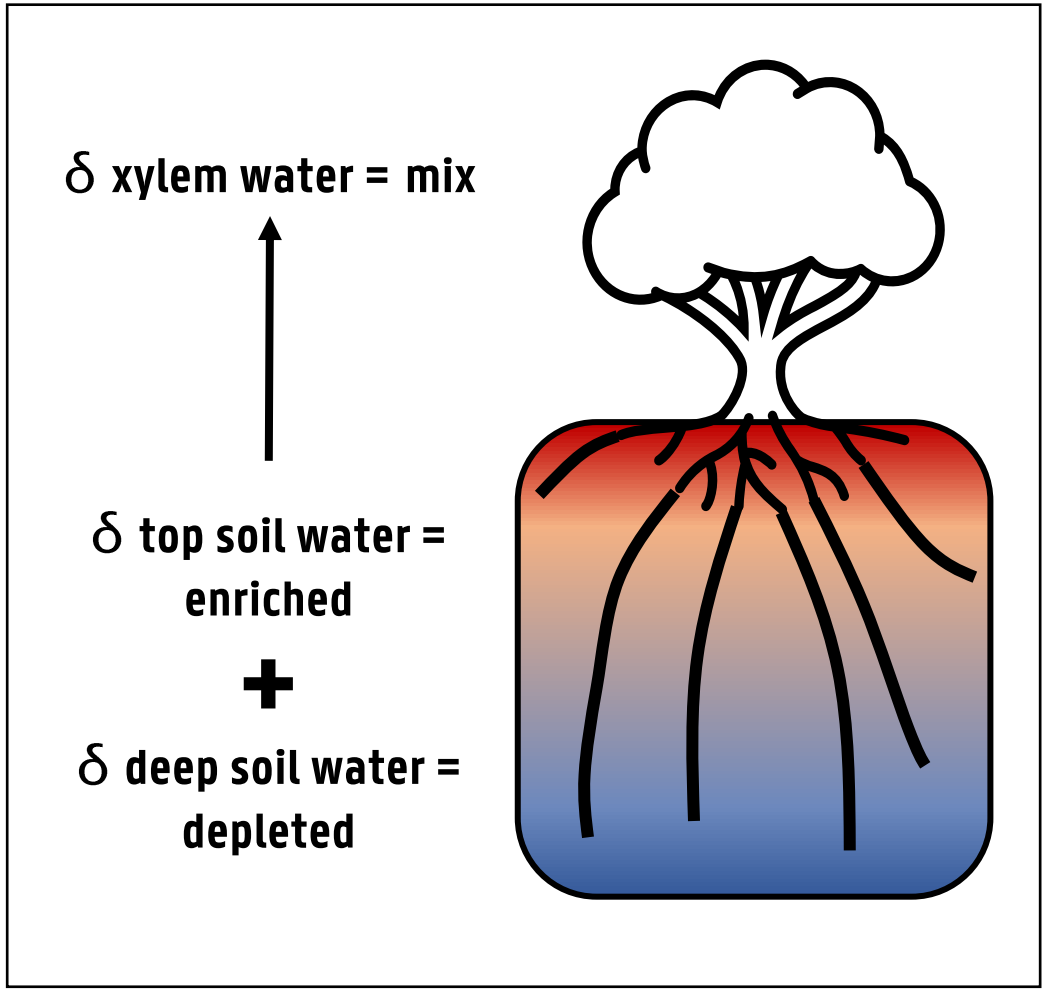
Ehleringer and Dawson, 1992

Dawson and Ehleringer, 1991

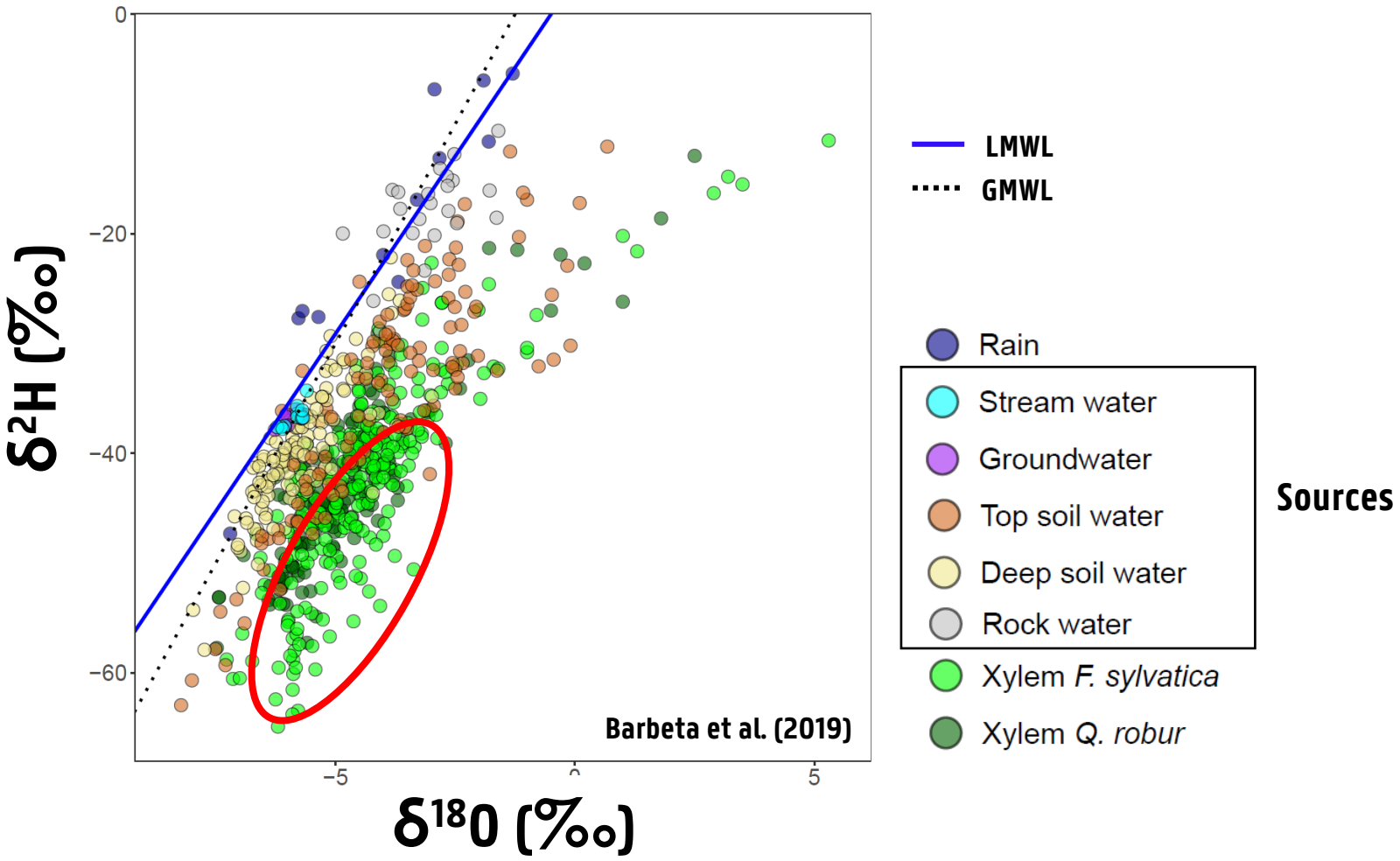
White et al. 1984

Wershaw et al. 1966

Gonfiantini et al. 1965

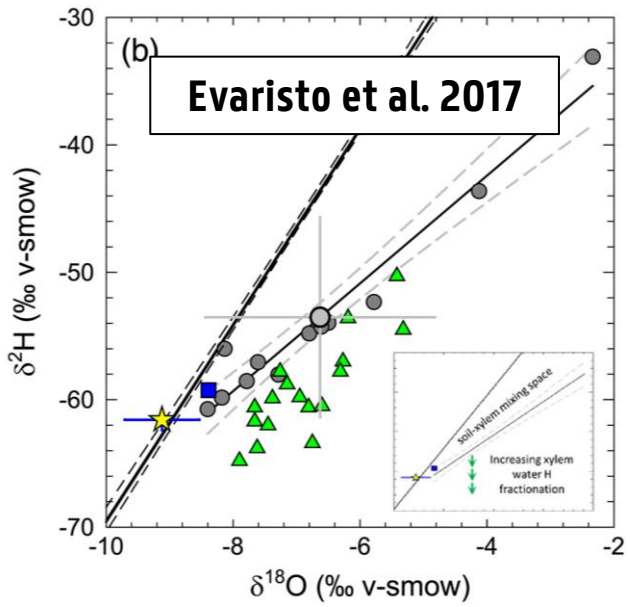


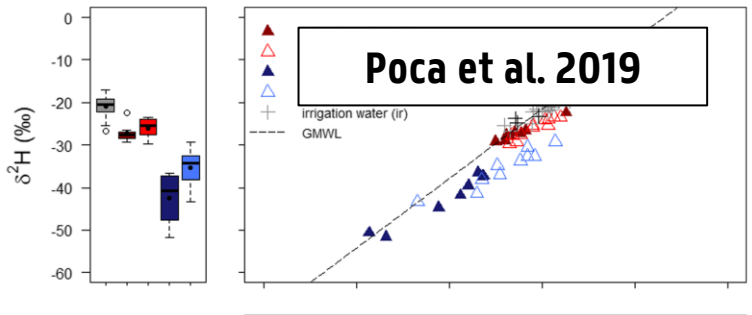
Is there fractionation during root water uptake?

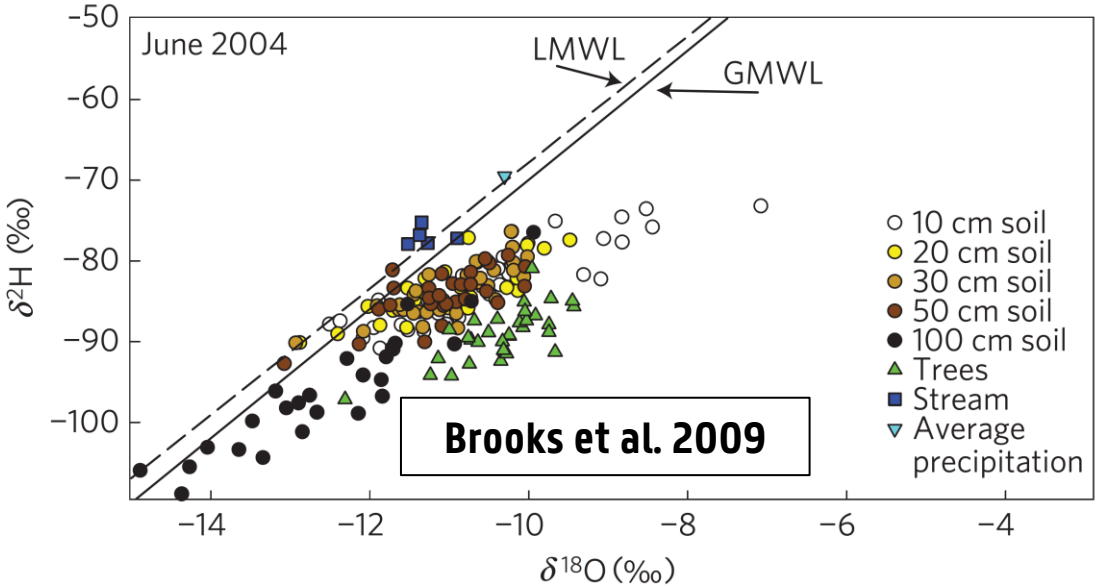


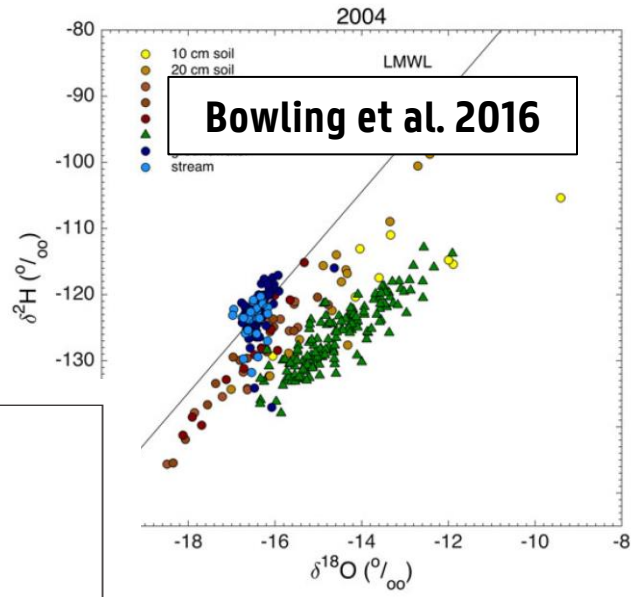
Isotopic offsets between xylem and source water δ^2H

Is there fractionation during root water uptake?



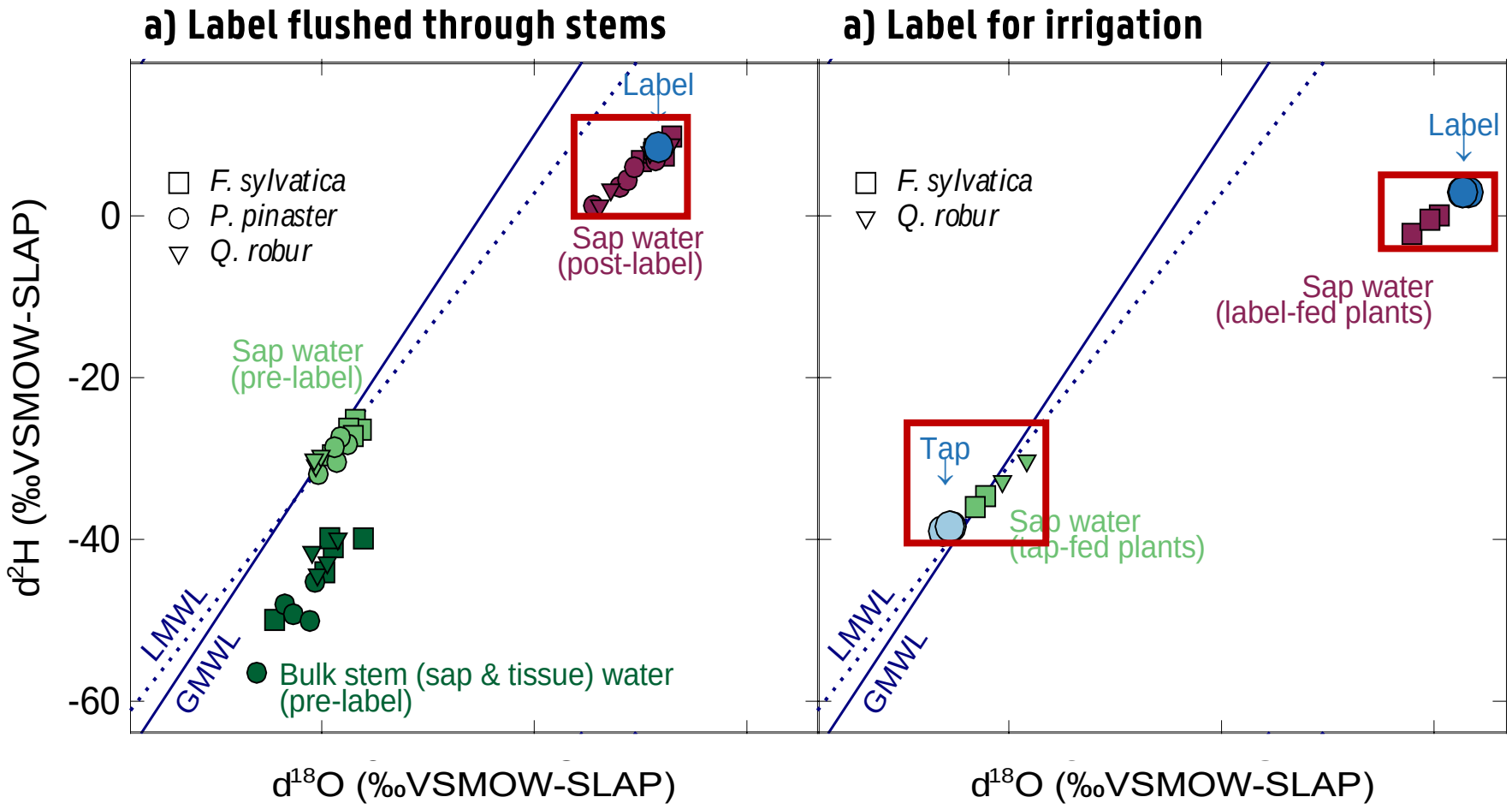


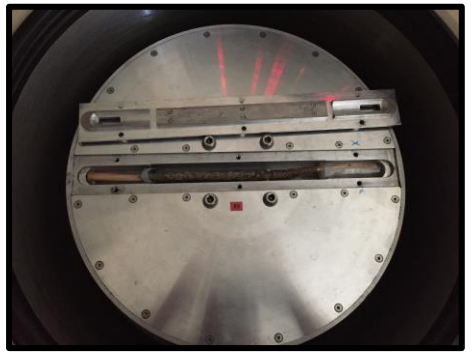




Isotopic offsets have been found in different ecosystems, plant species, and also, under controlled conditions

Is there fractionation during or after root water uptake?





Flow-rotor centrifuge

Barbeta et al. 2022

Xylem-source water isotopic offsets are <u>not observed</u> if we extract exclusively <u>xylem sap water</u>

Depleted xylem water δ^2H relative to the source:

A naturally occurring fractionation or a methodological artifact?

New Phytologist

Research

Evidence for distinct isotopic compositions of sap and tissue water in tree stems: consequences for plant water source identification

Adrià Barbeta[1,2], Régis Burlett[3], Paula Martín-Gómez[1], Bastien Fréjaville[1], Nicolas Devert[1], Lisa Wingate[1], Jean-Christophe Domec[1] and Jérôme Ogée[1]

PNAS

Stem water cryogenic extraction biases estimation in deuterium isotope composition of plant source water

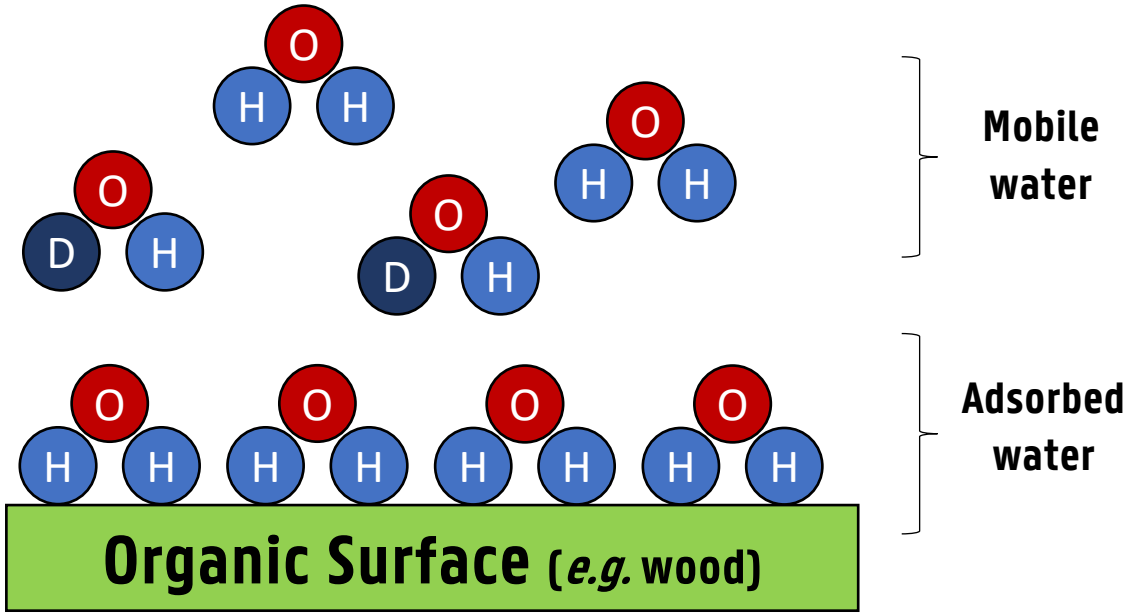
Yongle Chen[a,b], Brent R. Helliker[c], Xianhui Tang[a], Fang Li[a,b], Youping Zhou[d], and Xin Song[a,e,1]

Depleted xylem water δ^2H relative to the source:

A <u>naturally occurring fractionation</u> or a methodological artifact?

<u>Surface effects</u> or hydrogen exchanges with cellulose during CVD?

Isotopic equilibrium with water vapour differs between adsorbed water and free (mobile) water



Fibre saturation point: 30% water content

Based on Guo Chen et al., 2016, Lin and Horita 2018, Guo Chen et al., 2021…

Water adsorbed onto <u>particles is relatively more depleted</u> than mobile water

Depleted xylem water δ^2H relative to the source:

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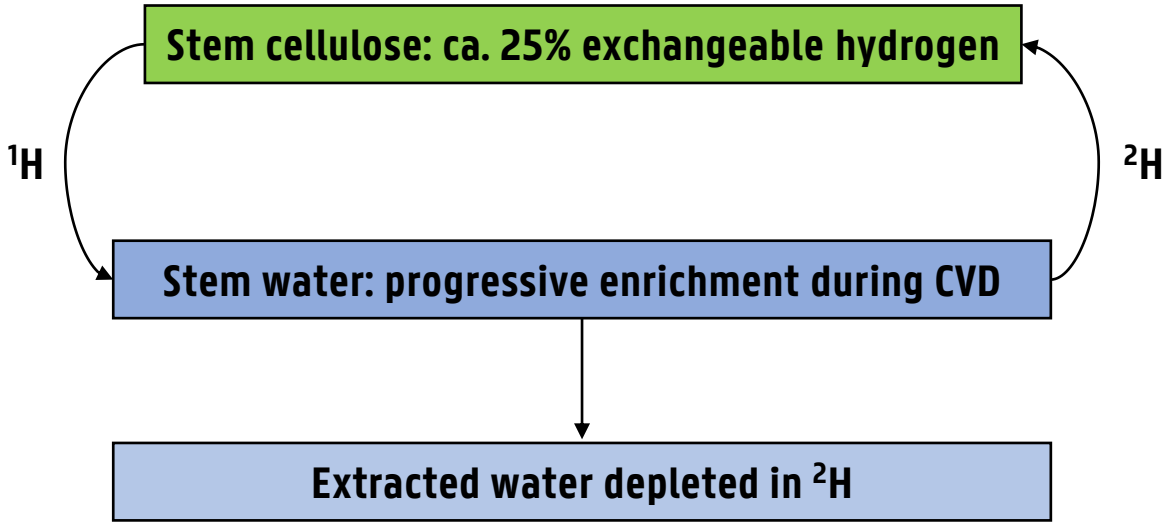
Surface effects or hydrogen exchanges with cellulose during CVD?

Yongle Chen et al., 2020, PNAS: Cryogenic vacuum distillation results in the depletion of extracted water

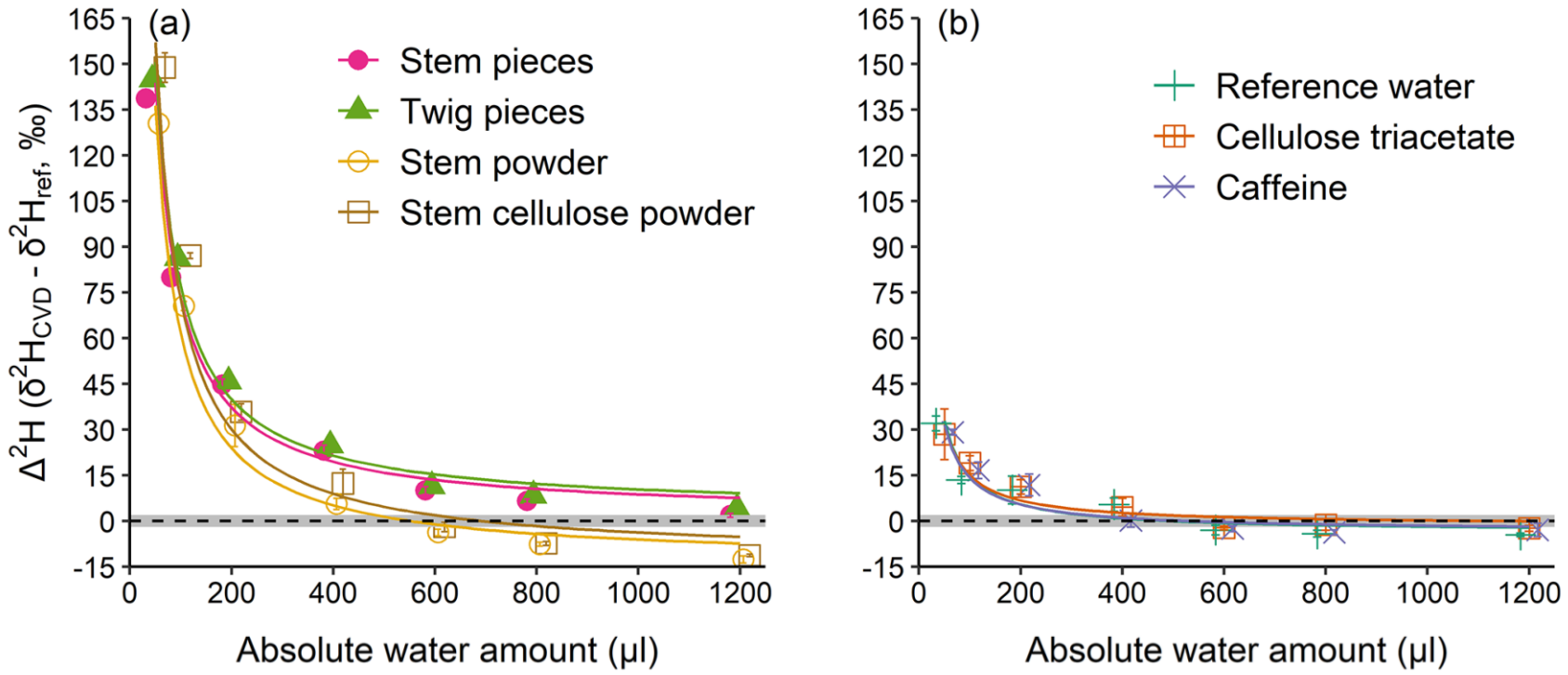


- Effect is stronger with relatively drier samples.

“On uncertainties in plant water isotopic composition following extraction by cryogenic vacuum distillation”.

Experiment: Rehydration with depleted reference water and subsequent CVD extraction of:

Material with exchangeable H | **Material without exchangeable H**



Diao et al. 2022, HESS

Numerical models to quantify the two processes (H exchange and surface adsorption) during a typical CVD experiment.

Jérôme Ogée et al. *unpublished results*

Aim:

- To evaluate which process is most likely responsible for the observed isotopic offsets between $\delta^2H_{stem,\ CVD}$ and δ^2H_{source}.

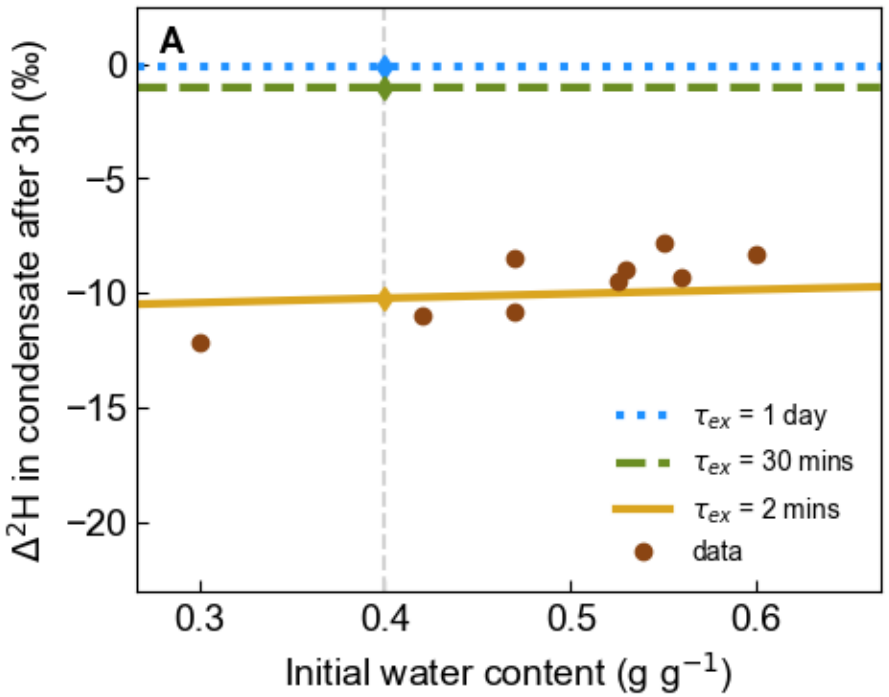
Methods: Two separate models.

- Isotopic model for H exchange during CVD extraction with different exchange rates and stem water contents.

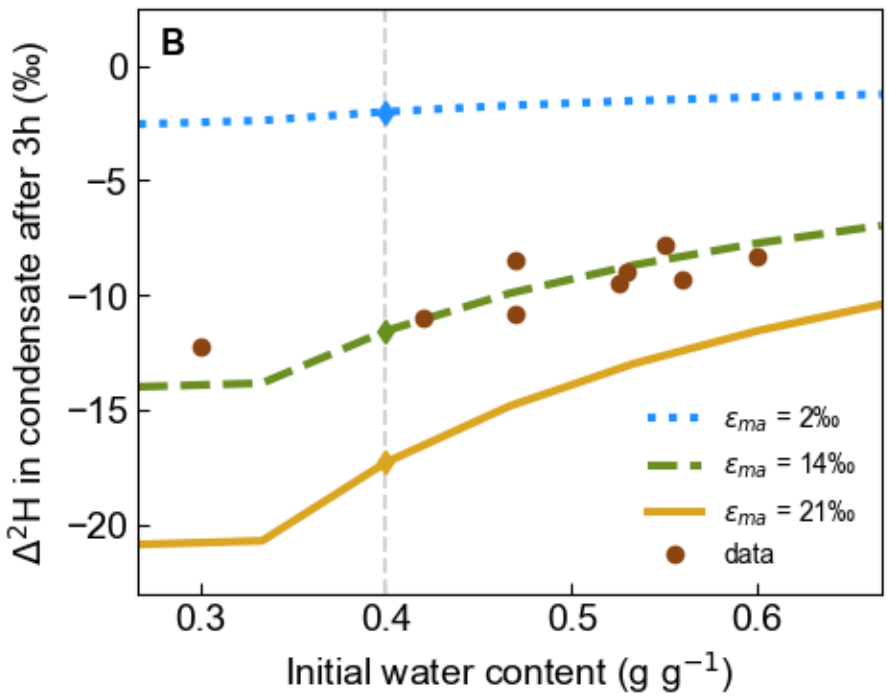
- Isotopic model accounting for surface effects and different water contents.

Both processes are compatible with observations in Chen et al. 2020

H exchange with cellulose



Surface effects



Jérôme Ogée et al. *unpublished results*

Take-home messages

There is no fractionation during root water uptake

Consensus, evidence from different approaches

CVD-extracted stem water is depleted in δ^2H

Consensus, evidence from different approaches

H exchange with cellulose during CVD (artifact)

Direct evidence, but the magnitude may be negligible

Other CVD-related artifacts for low water amounts

System-dependent (Diao et al., 2022)

Naturally occurring surface isotopic effects

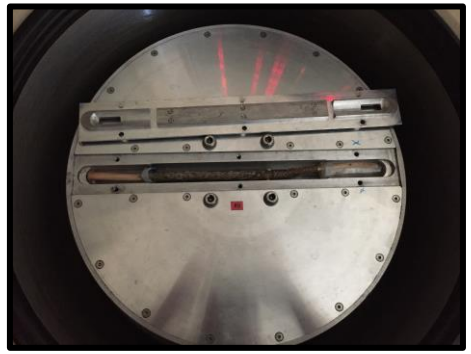
Direct evidence but the magnitude is hard to disentangle from H exchange artefacts

Unknown fractionation processes in stems

No evidence yet (*e.g.* aquaporins)

Towards the mechanistic understanding: ideas to move forward

- Performance of rehydration tests to set minimum absolute water contents in CVD systems.
- Meta-analysis of CVD-extracted water isotopic data with extraction conditions (time, pressure, initial water content, substrate…).
- Formal experimental test of surface isotopic effects in plant (woody) tissues.
- Use and development of unbiased techniques to extract water for plant water sourcing.



Flow-rotor centrifuge

Thank you very much

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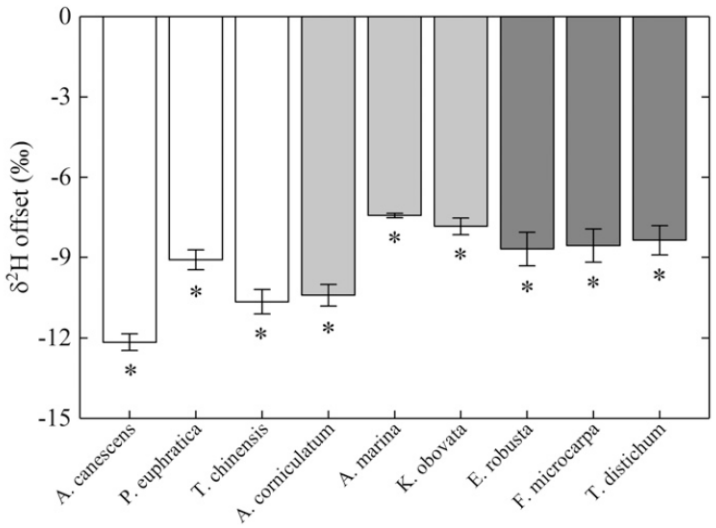
Experiment 2: rehydration experiment to test for isotopic heterogeneity in stem water.

Dry stems rehydrated for 24 hours → No surface effects at saturation (?) → CVD extraction →



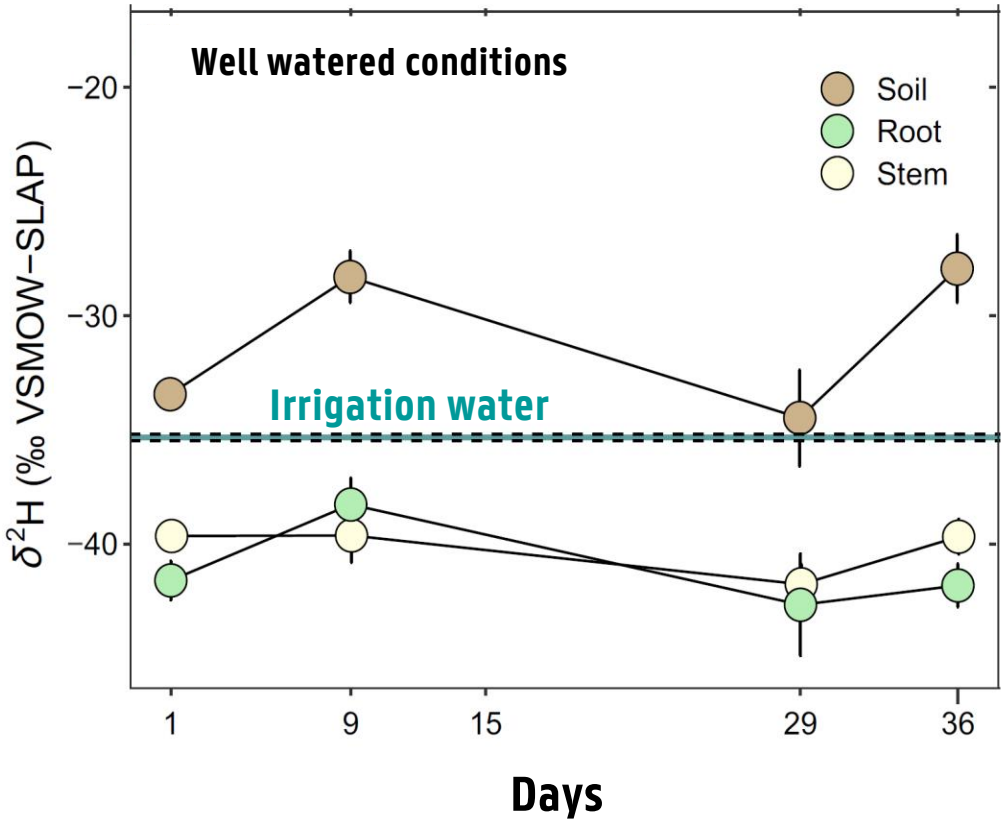
Conclusion: hypothesis of isotopic heterogeneity (surface effects) is rejected.

Is the 24 h-rehydration equivalent to water transport through living tissues of plants?

Is there fractionation during or after root water uptake?

A controlled experiment with potted plants

Barbeta et al. 2020



Xylem water	$R_X = R_S \times \alpha_U = R_P$
Soil water	$R_S = R_P / \alpha_U$
Irrigation water	R_P

α_U = fractionation factor caused by root water uptake

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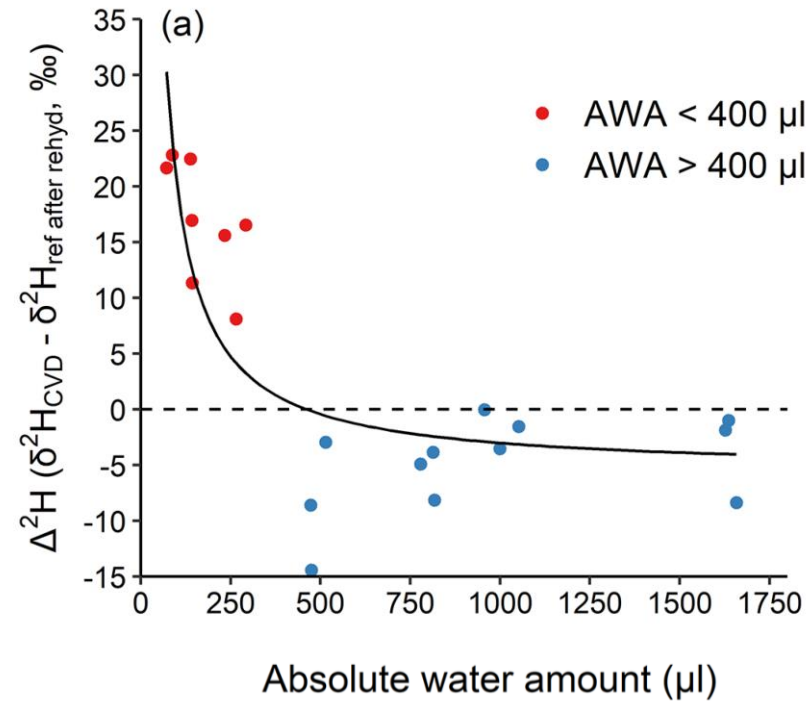
Experiment 2: Rehydration with depleted reference water and subsequent CVD extraction of:

Difference to reference water after rehydration



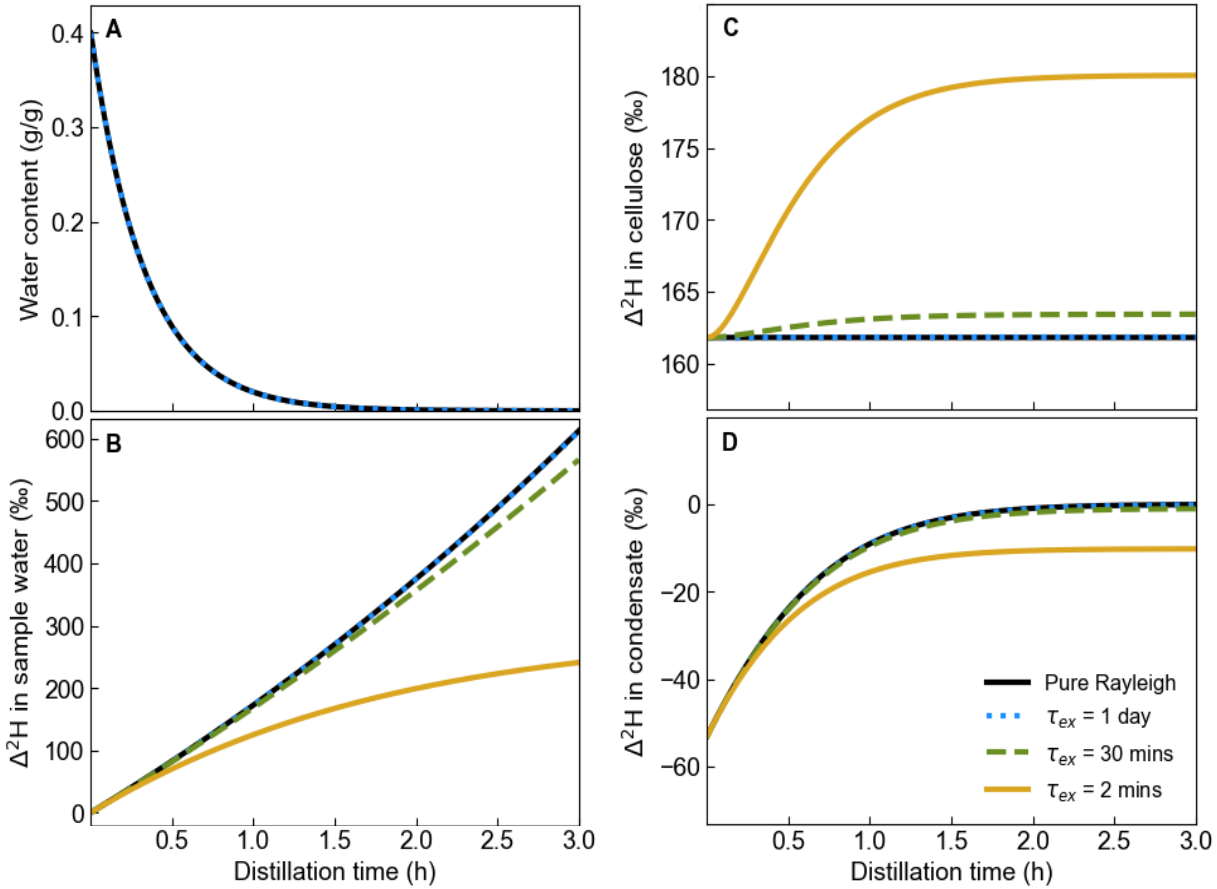
Δ^2H of materials with non-exchangeable H of similar magnitude.

Diao et al. 2022, HESS

A numerical model to quantify the two processes (H exchange and surface adsorption) during a typical CVD experiment.

Jérôme Ogée et al. *unpublished results*

Isotopic changes during a typical CVD



τ = time it takes for the exchangeable hydrogens to decrease until half its initial value