Extending the Concept of Soil Water Characteristic to Derive Xylem Water Characteristics of Trees

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Preface

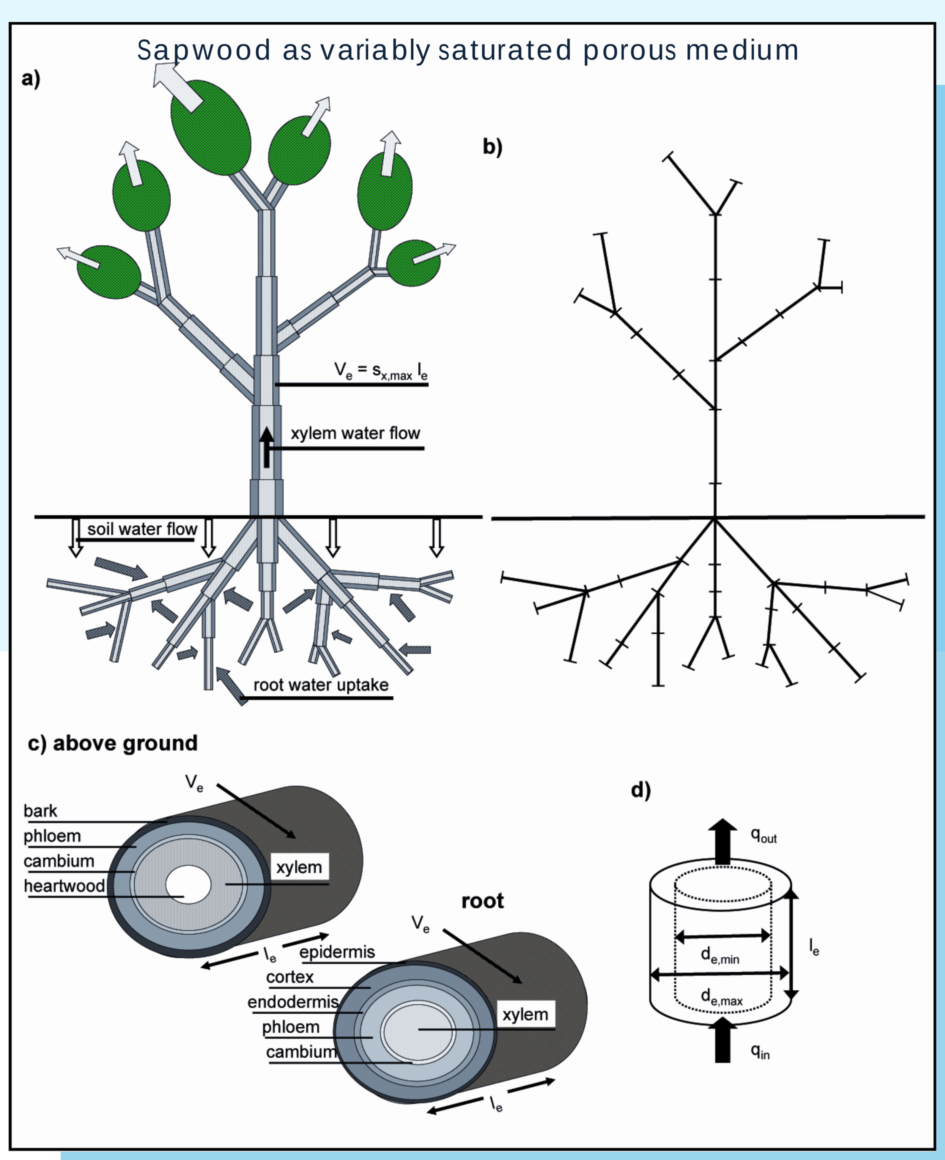
The application of Richards equation to simulate xylem water flow of trees based on three-dimensional graphs representing tree architecture needs water characteristic curves of the xylem porous medium.

A general concept to derive xylem water characteristic curves is presented. The concept is based on ideas to describe soil water retention and unsaturated hydraulic conductivity curves.

The elastic modulus of the xylem is used to determine the xylem water content at the air entry value and to define the relationship between xylem water content and xylem potential.

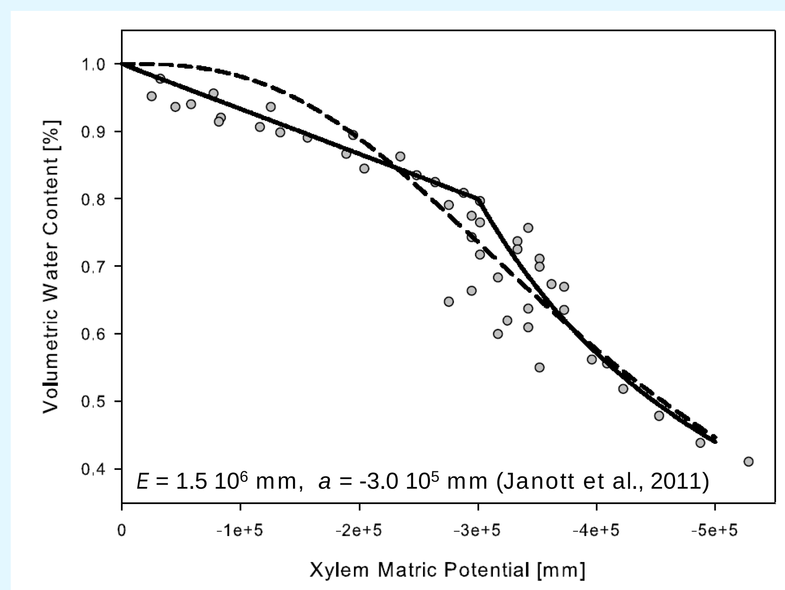
A capillary bundle approach is applied to calculate relative xylem conductivity.

Examples of xylem water characteristic are given for beech trees. Advantages and shortcomings of the newly derived concept to simulate sap flow in individual trees are discussed.



Results

Xylem Water Retention Curve:
Measured values are taken from European beech (Oertli, 1993).
New extended Brooks and Corey parameterization (black line) compared to van Genuchten parameterization (dashed line)



The elastic modulus E [mm] gives the slope of the retention curve $\theta_x(\psi_x)$ above the air entry value a[mm]:

$$\frac{1}{V_e}\frac{dV_e}{d\psi_x} = \frac{d\theta_x}{d\psi_x} = \frac{1}{E} \qquad \theta_{x,a} = \epsilon_x + \frac{a}{E}$$

Exponential part of the curve analogous to Brooks and Corey curve below the air entry value a[mm] with $\theta_{x,a} = \theta_x(a)$:

$$\theta_x(\psi_x) = \begin{cases} \theta_{x,a}\left(\frac{\psi_x}{a}\right)^{-\lambda}, & \text{if } \psi_x < a \\ (\epsilon_x - \theta_{x,a})\left(\frac{a-\psi_x}{a}\right) + \theta_{x,a}, & \text{else} \end{cases}$$

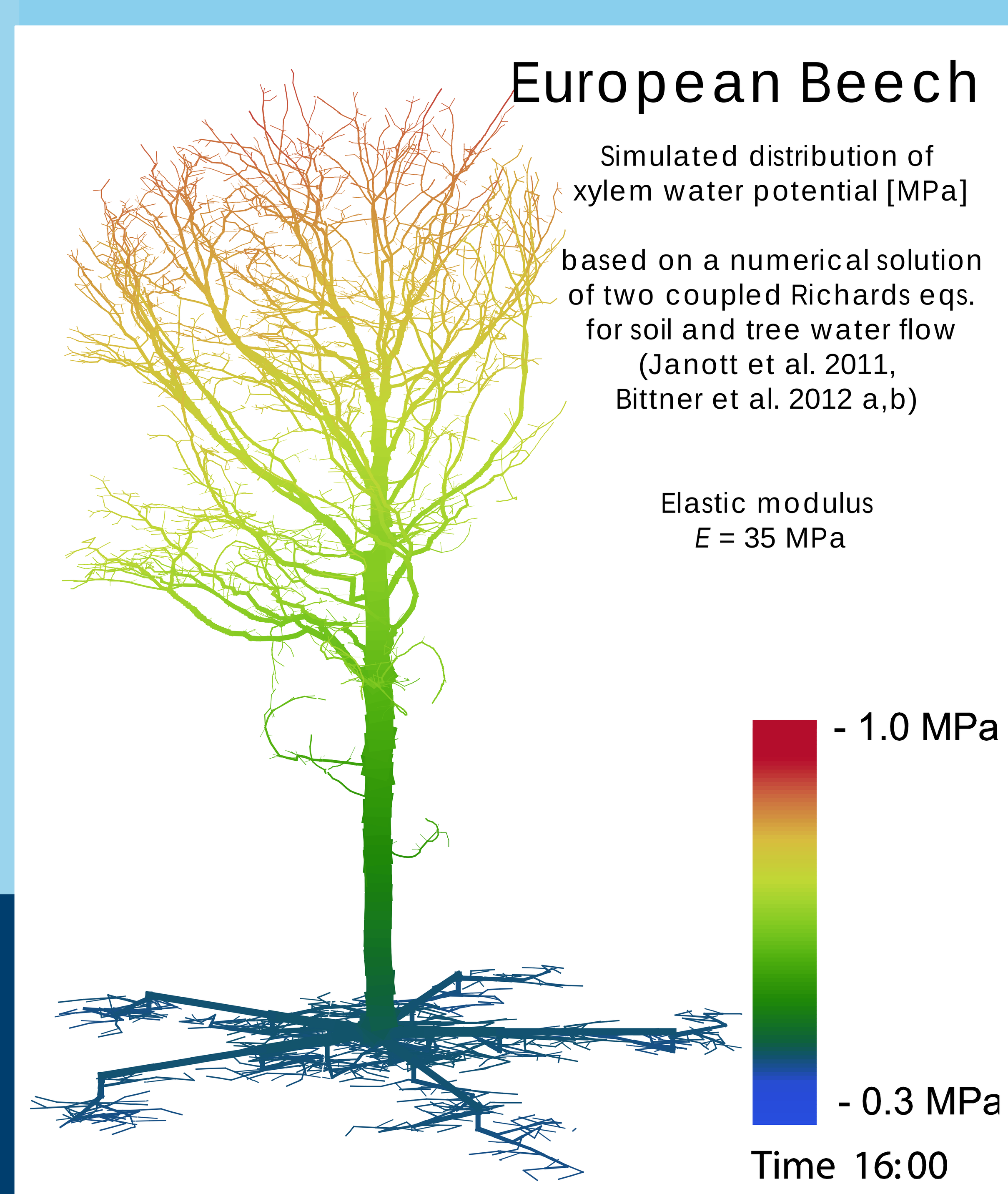
Defining the linear part of the curve:

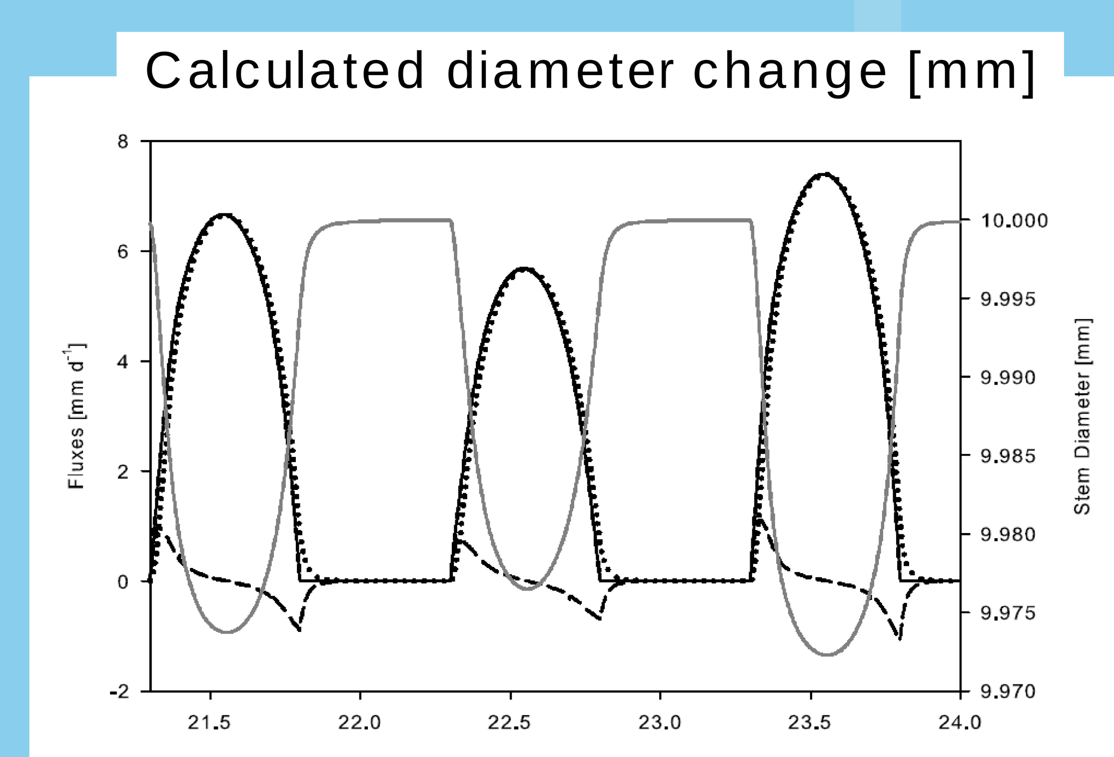
$$\epsilon_x(z) = \frac{s_{x,max}(z)\; l_e}{s_{e,max}(z)\; l_e} = \frac{s_{x,max}(z)}{s_{e,max}(z)}$$

Xylem porosity ϵ_x[-] based on maximal cylinder element and xylem volumes $V_{e,max}$ and $V_{x,max}$ [mm³], respectively maximal xylem cross sections $s_{e,max}$ and $s_{x,max}$ [mm²]

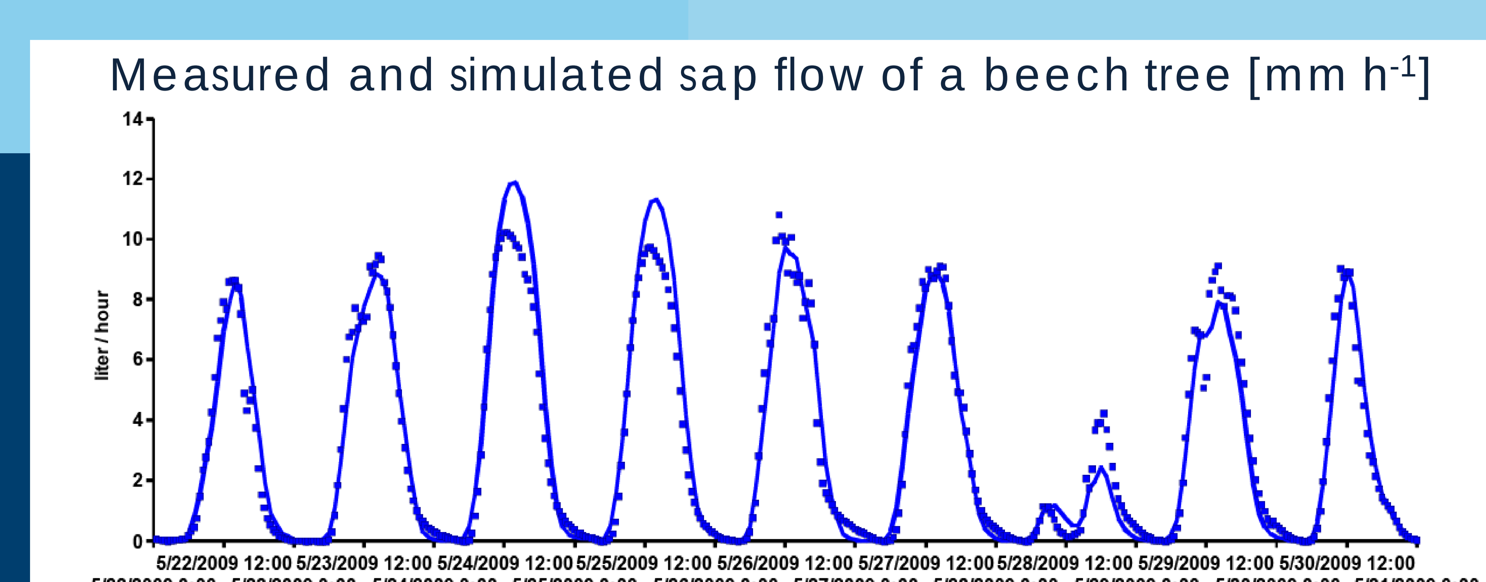
$$\theta_{x,a}(z) = \frac{s_{x,a}(z)}{s_{e,max}(z)}$$

Xylem volumetric water content $\theta_{x,a}$[-] at air entry value a [mm] (when cavitation occurs)





Scenario of young beech tree: Simulated diurnal course of transpiration $[mm\ d^{-1}]$ (solid line), of xylem water flux at the root collar $[mm\ d^{-1}]$ (dotted line), of change rate of xylem water content $[mm\ d^{-1}]$ (dashed line) and of stem diameter $[mm]$ (grey line) during three days.



Conclusions

If tree sapwood is considered as variably saturated medium, its water retention characteristics can be described by a curve consisting of an exponential and a linear part.
The exponential part represents volumetric water contents for xylem potentials when cavitation occurs, i.e. below the air entry value (cf. Brooks and Corey curve).
The linear part for xylem potentials above the air entry value gives water contents in the saturated range between maximal and minimal sapwood extension.

The slope of the linear part is inversely related to the elastic modulus E of the sapwood.

The radial elastic modulus E_r of wood (axis normal to the growth rings) could possibly be a good proxy to estimate values for E.

Data tables on wood elastic moduli derived from compression tests are available for many commercially important trees (e.g. Kretschmann, 1999)

Longitudinal elastic modulus E_L from bending (Living Tree)

Ash	
Black	7.2 GPa
White	9.0 GPa
Beech	
American	9.5 GPa
European	10.4 GPa
Elm	8.1 GPa
Oak	9.3 GPa
Pine	8.6 GPa
Spruce	6.9 GPa

e.g. Kretschmann (1999)

References

Bittner S. et al. (2012a) J. Geophys Res 117, G1, G01037
Bittner S. et al. (2012b) Agric Forest Meteor 158-159:80-89
Hentschel R. et al. (2013) Agric Forest Meteor 182-183:31-42
Janott M. et al. (2011) Plant Soil 341:233-256
Kretschmann D.E. (1999) in: Wood Handbook, USDA Forest Service
Oertli J. (1993) in: Water Transport in Plants Under Climatic Stress

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