FROM SOIL-ROOT HYDRAULIC ARCHITECTURES TO MACROSCOPIC REPRESENTATIONS OF HYDRAULICS IN LAND SURFACE MODELS

JAN VANDERBORGHT, **VALENTIN COUVREUR**, FELICIEN MEUNIER, MARTIN BOUDA, ANDREA SCHNEPF, AND MATHIEU JAVAUX

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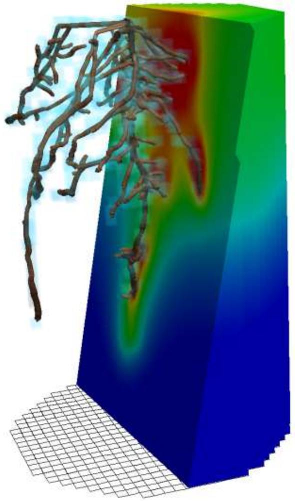
PHYSICALLY BASED ROOT WATER UPTAKE MODELS

Functional structural plant models:

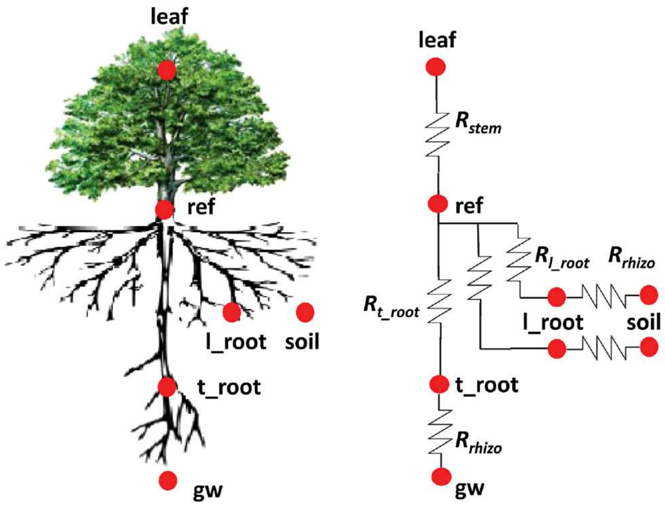
- Full 3-D root system architecture
- Root segment hydraulic properties
- Solved by matrix inversion



Doussan et al., Ann. Bot., 1998
R-SWMS: Javaux et al., 2008
OpenSimRoot: Postma et al., 2017
Marshal: Meunier et al., 2020

Parallel root models:

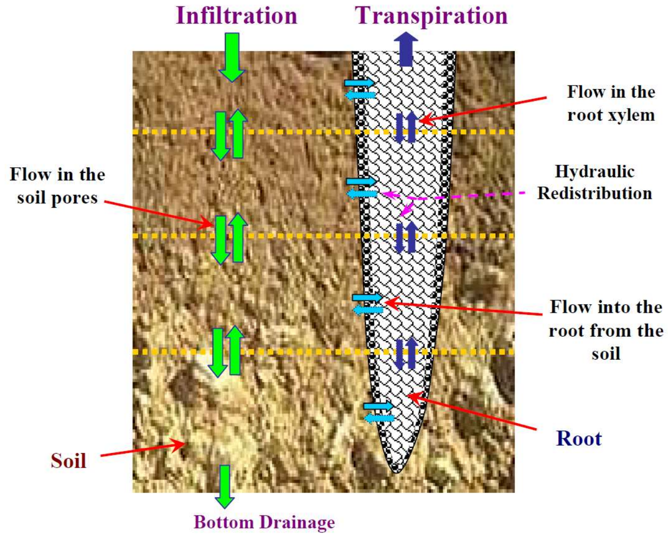
- Single network branching point
- Effective hydraulic resistances
- Analytical solution available



Manoli et al., AdvWR 2015
Nimah & Hanks, SSSAProc, 1973
CLM: Kennedy et al., 2019
CLM: Sulis et al., 2019

Big root models:

- Root segments in series only
- Effective hydraulic resistances
- Coupled soil-root diff. equations



Amenu and Kumar, HESS 2008
CLM: Zhu et al., 2017
E3SM: Bisht and Riley, 2019

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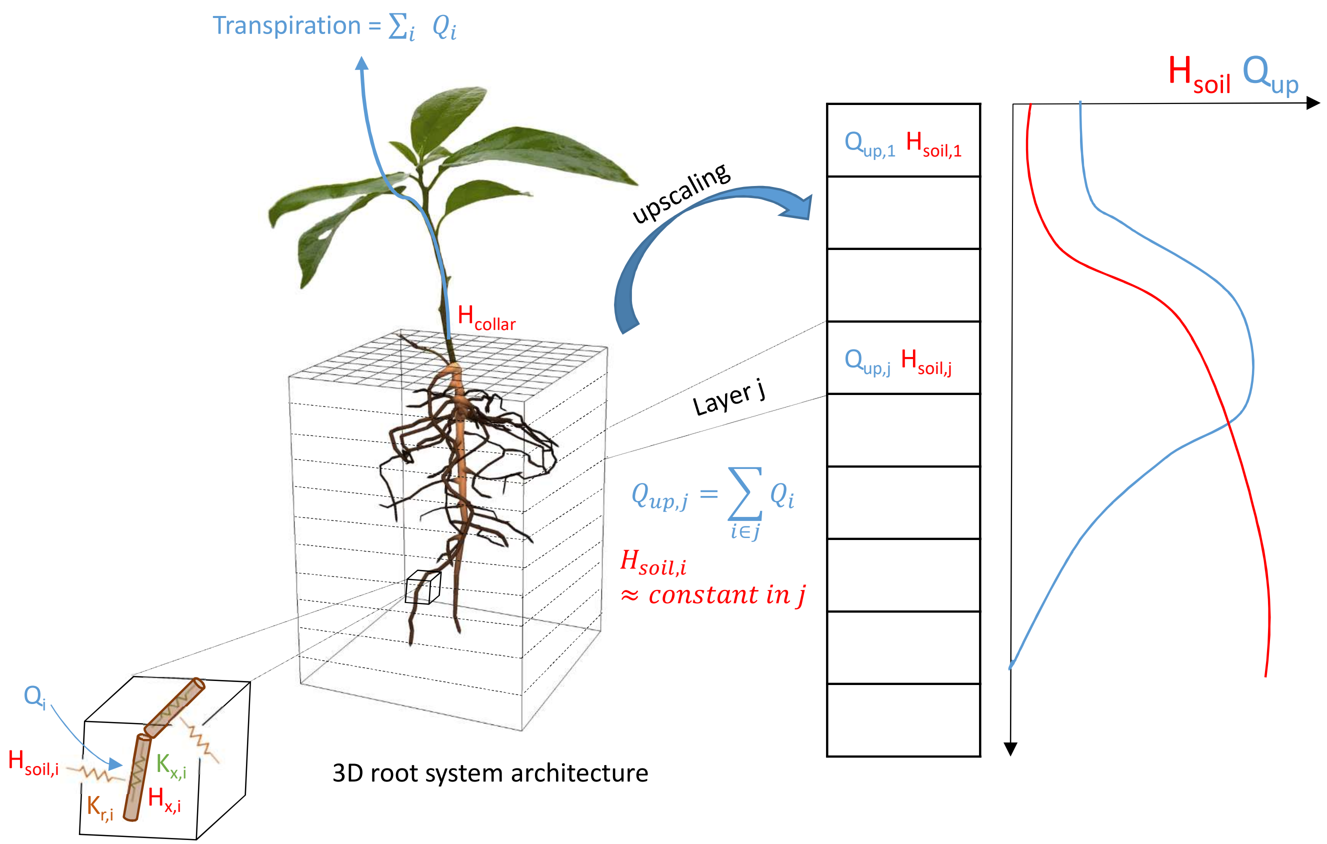
3D hydraulic root system **Upscaled 1D root water uptake model**



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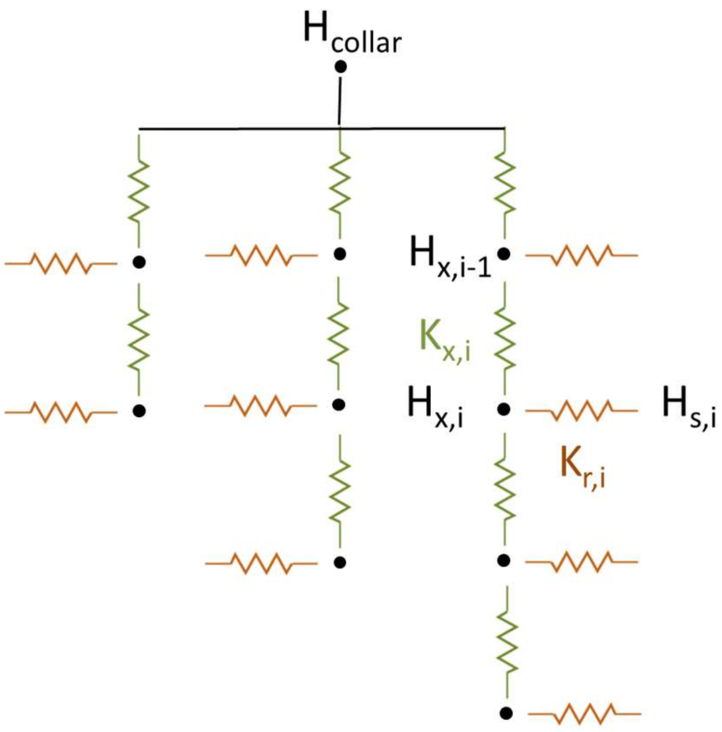
DISCRETE GENERAL ROOT NETWORK MODEL



K_r: radial root segment conductance
K_x: axial root segment conductance
H_x: xylem water potential

$$Q_i = K_{r,i}\left(H_{s,i} - H_{x,i}\right)$$

$$J_{x,i} = K_{x,i}\left(H_{x,i} - H_{x,i-1}\right)$$

General equation for flow in a root network:

$$\left[\mathbf{IM} \cdot diag(\mathbf{K}) \cdot \mathbf{IM}^{\mathrm{T}}\right] \begin{bmatrix} H_{collar} \\ \mathbf{H}_{\mathbf{x}} \\ \mathbf{H}_{\mathbf{soil}} \end{bmatrix} = \begin{bmatrix} -T \\ \mathbf{0} \\ \mathbf{Q} \end{bmatrix}$$

Doussan et al., Ann Bot 1998

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ROOT HYDRAULICS: THE CASE OF UNIFORM WATER POTENTIALS

Ohm's analogy (van den Honert, 1948)

$$T_{act} = K_{rs}\left(H_{eff} - H_{collar}\right)$$

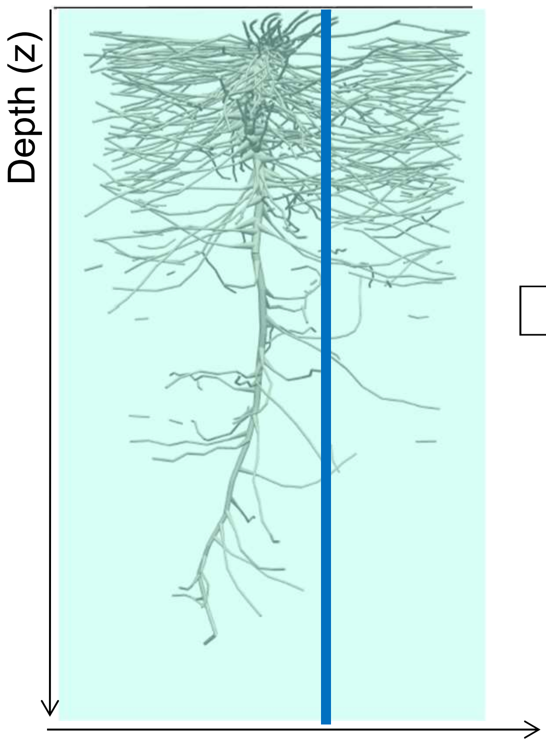
T_{act}: actual transpiration rate [m³/s]

K_{rs}: root system conductance

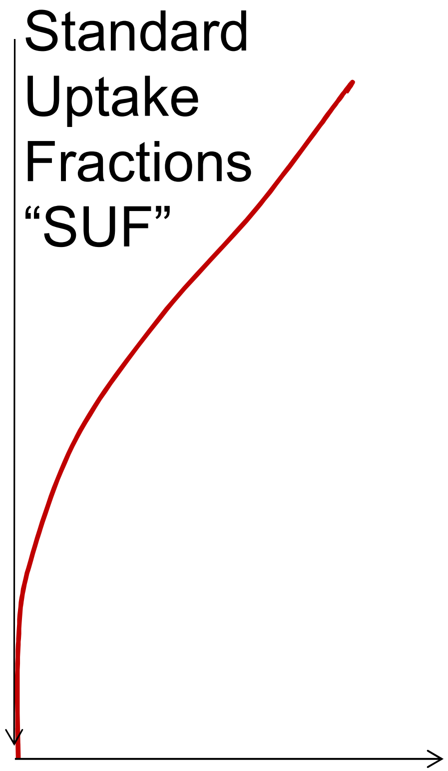
H_{eff}: representative **soil water potential**

H_{collar}: water potential at plant collar

$$Q(z) = T_{act}SUF(z)$$



Soil water potential H_s [MPa]
per depth (z)



Partitioning of uptake Q/T_{act} [-]
per depth (z)

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ROOT HYDRAULICS: NON-UNIFORM SOIL WATER POTENTIALS

What is H_{eff}, the representative soil water potential, when H_s is non-uniform?

$$T_{act} = K_{rs}\left(H_{eff} - H_{collar}\right)$$

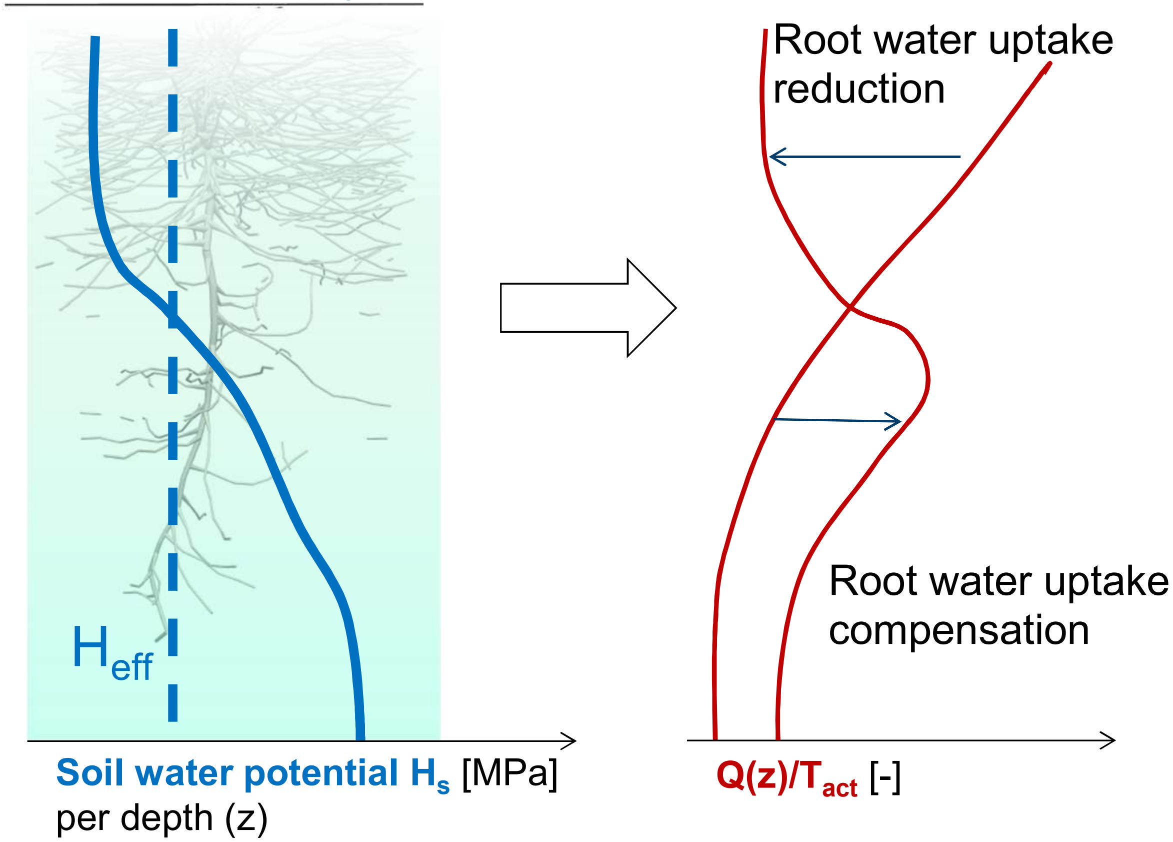
Still holds at the condition that…

$$H_{eff} = \sum_{z} SUF(z) H_s(z)$$

Proxy for reduction & compensation…

$$Q(z) = T_{act} SUF(z)$$

$$+K_{comp}\left(H_s - H_{eff}\right) SUF(z)$$



$valid\ if\ large\ xylem\ hydraulic\ condictivities\ (Couvreur\ et\ al., 2012, HESS)$

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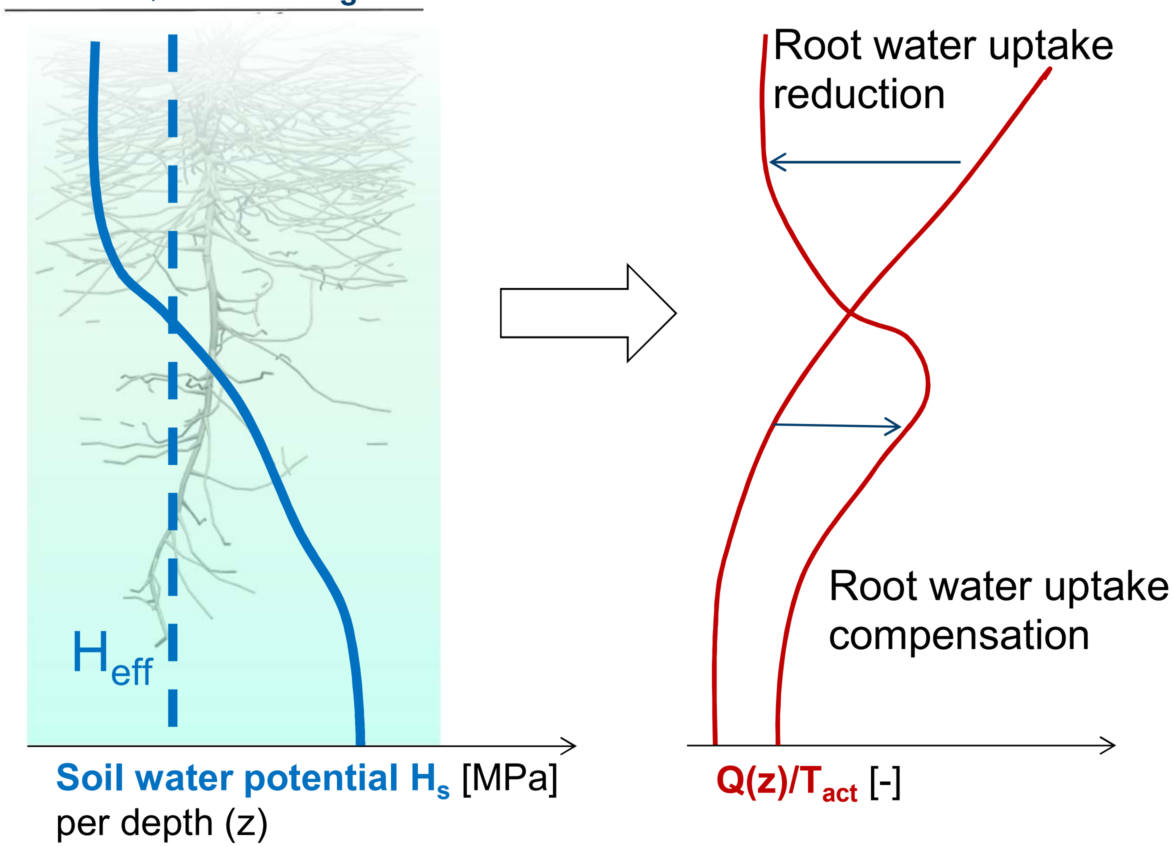
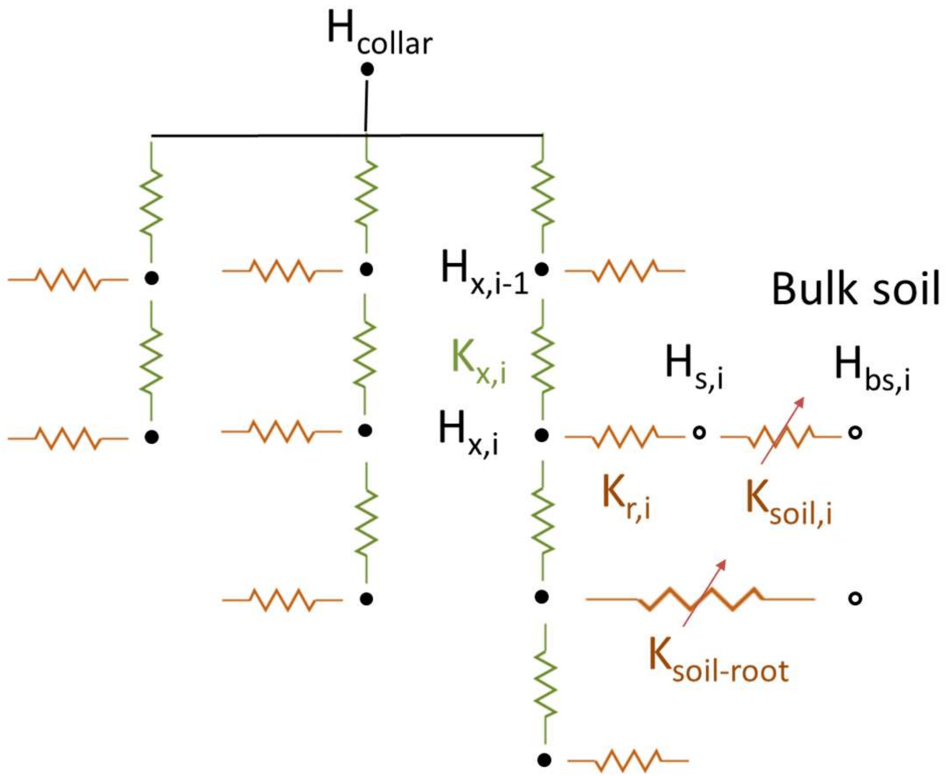


$$exact\ if\ null\ xylem\ hydraulic\ resistance\ (Couvreur\ et\ al., 2012, HESS)$$

NON-LINEAR SOIL ROOT NETWORK MODEL



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General equation for flow in a root network:

$$\left[\mathbf{IM} \cdot diag(\mathbf{K}) \cdot \mathbf{IM}^{\mathbf{T}}\right] \begin{bmatrix} H_{collar} \\ \mathbf{H_x} \\ \mathbf{H_{soil}} \end{bmatrix} = \begin{bmatrix} -T \\ \mathbf{0} \\ \mathbf{Q} \end{bmatrix}$$

How to upscale?

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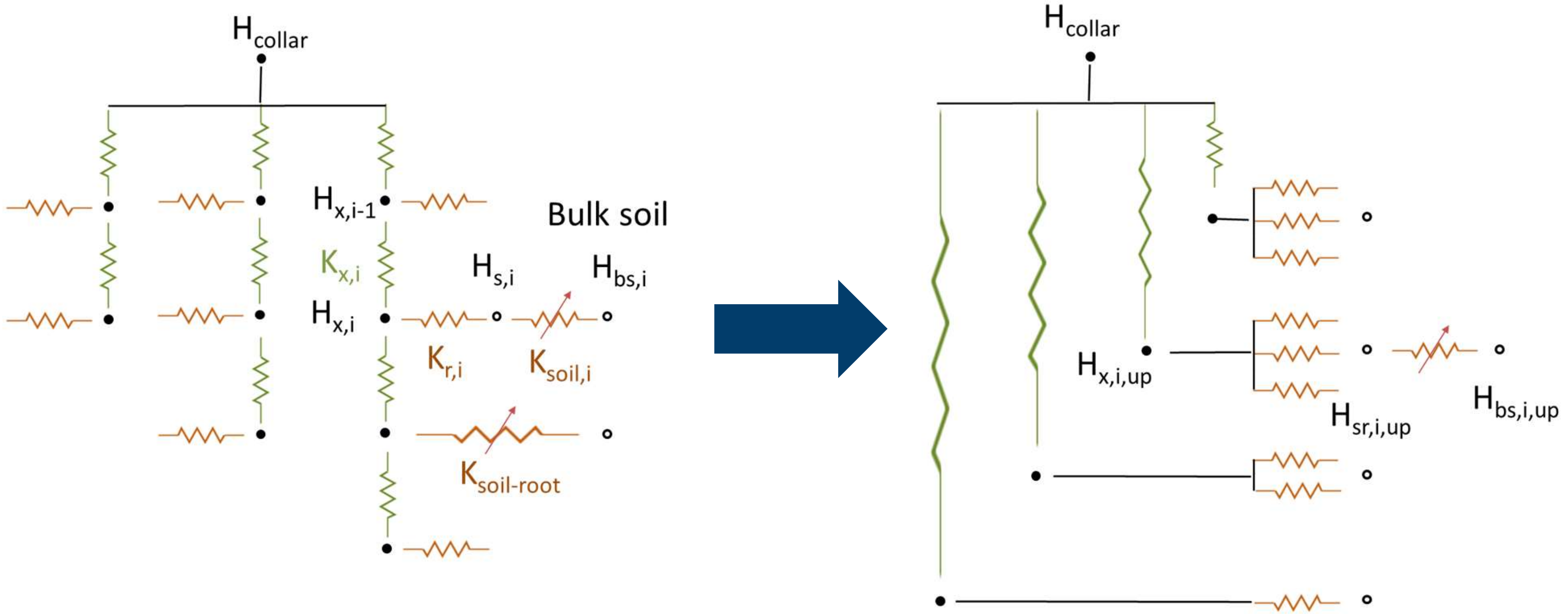
UPSCALING TO 1D PARALLEL ROOT MODEL



1. Assume H_{bs}, H_{sr} are constant within a soil layer
2. Calculate the average xylem potential, $H_{x,up}$, and the uptake Q in a soil layer for a given $H_{sr,up}$ in that soil layer using the ***upscaled linear model***.
3. Update $H_{s,r}$ for the calculated uptake Q, $H_{x,up}$, and the soil water potential H_{bs} using the ***non-linear $K_{soilroot}(H_x,H_{bs})$ function*** for each soil layer
4. Check the new $H_{s,r}$ and if different, update and return to 2.

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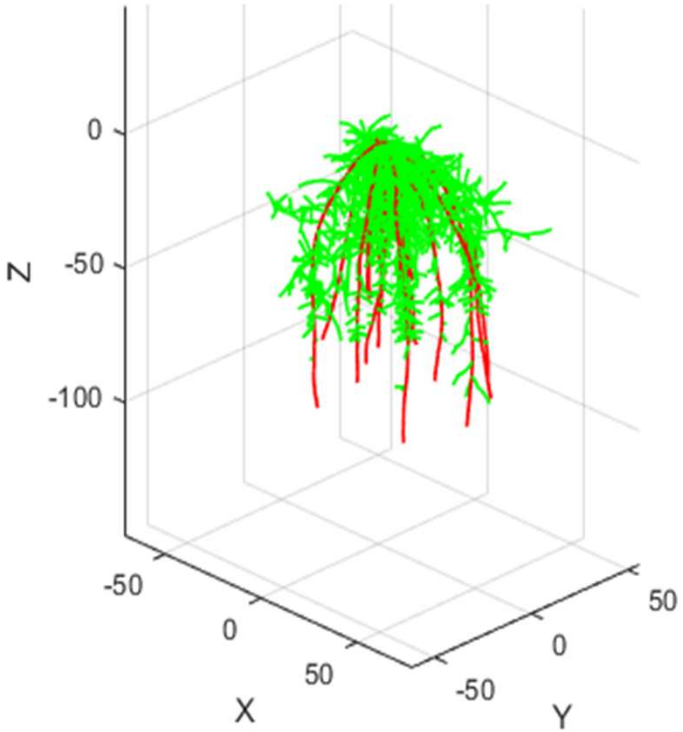
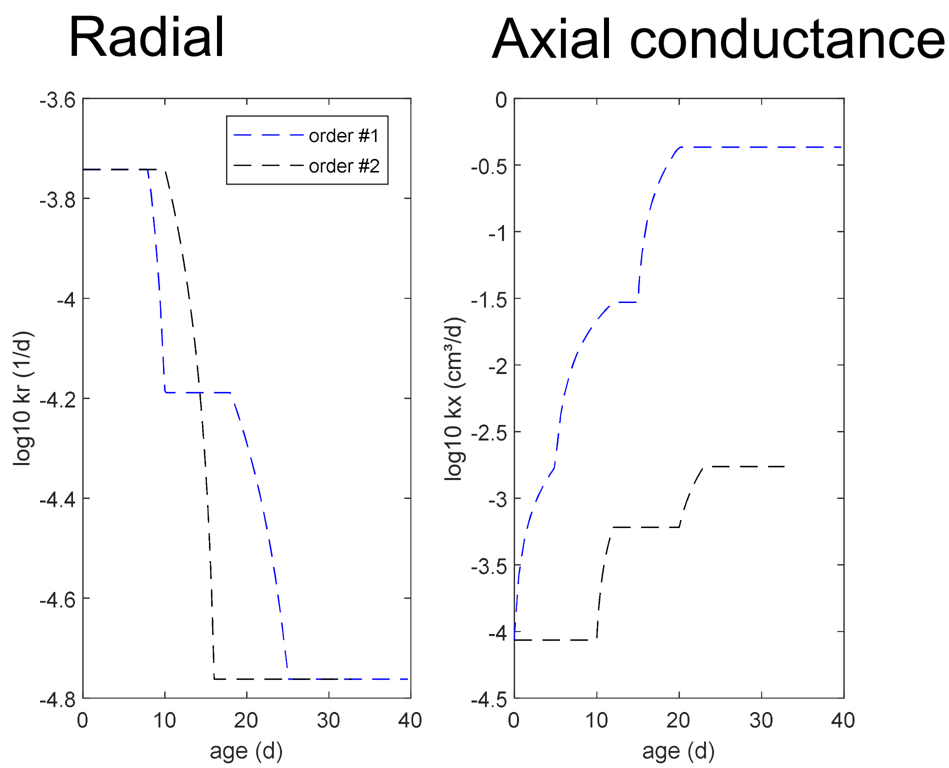
DEMONSTRATION

Root architecture and root segment properties

Maize





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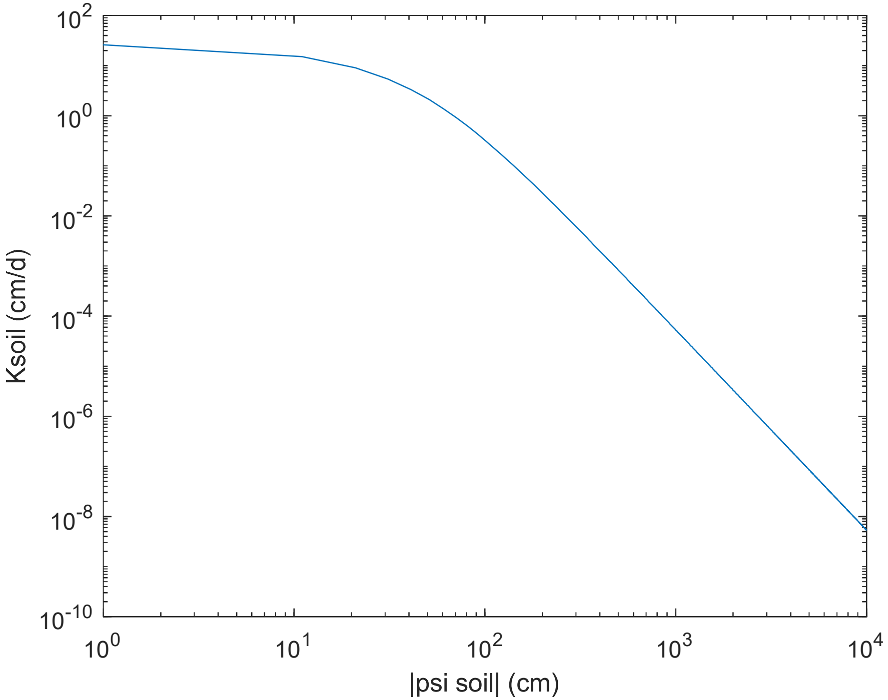
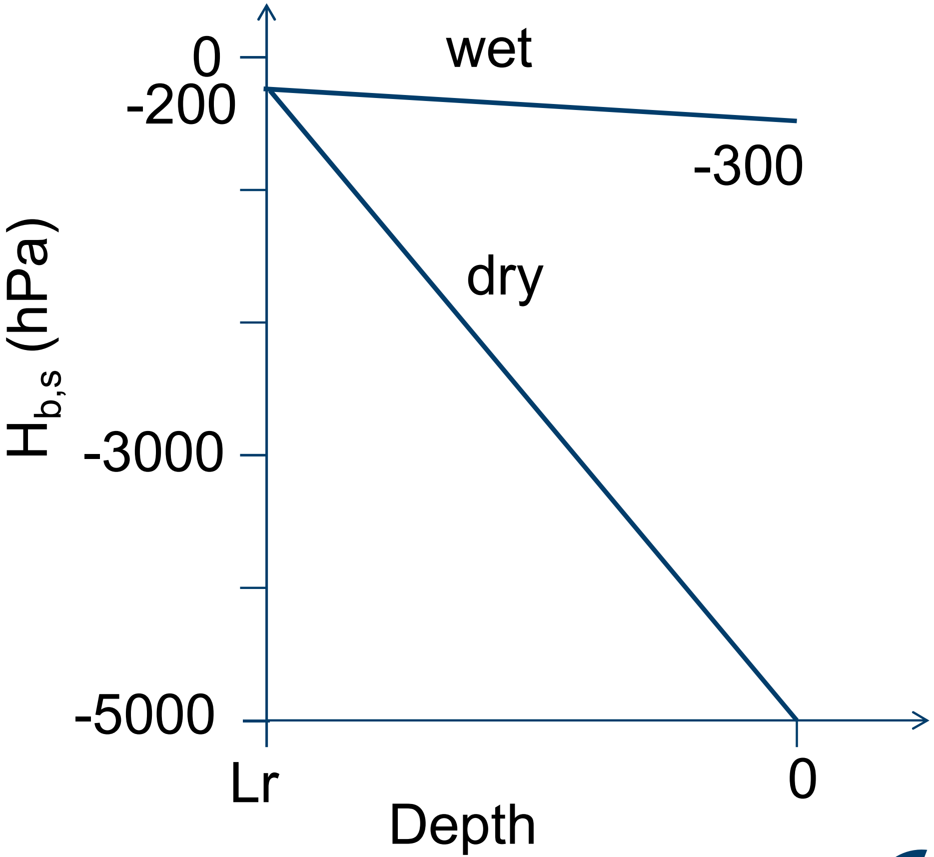
DEMONSTRATION

Soil hydraulic properties and soil water potential distribution

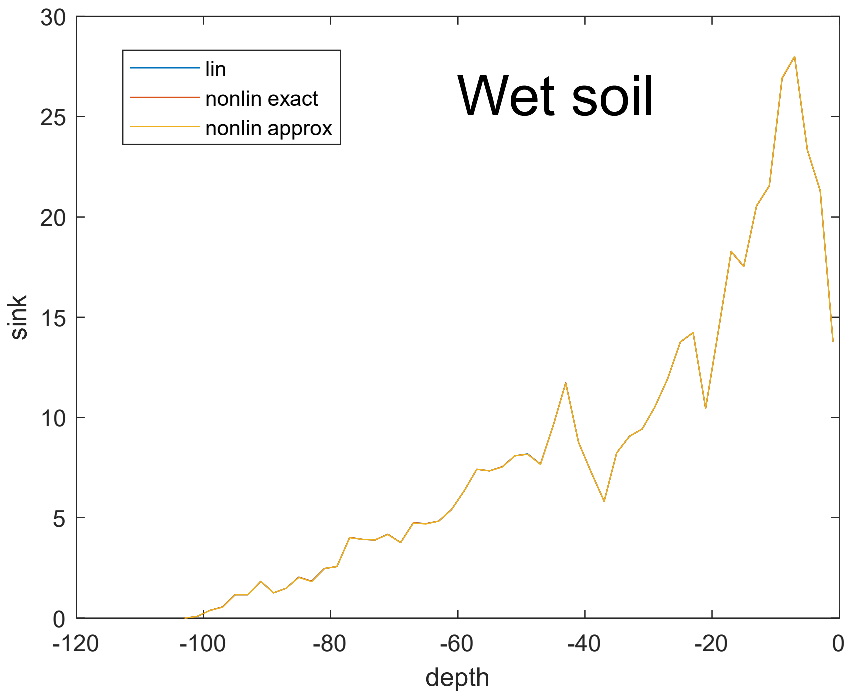




H_{collar} = -8000 hPa

DEMONSTRATION

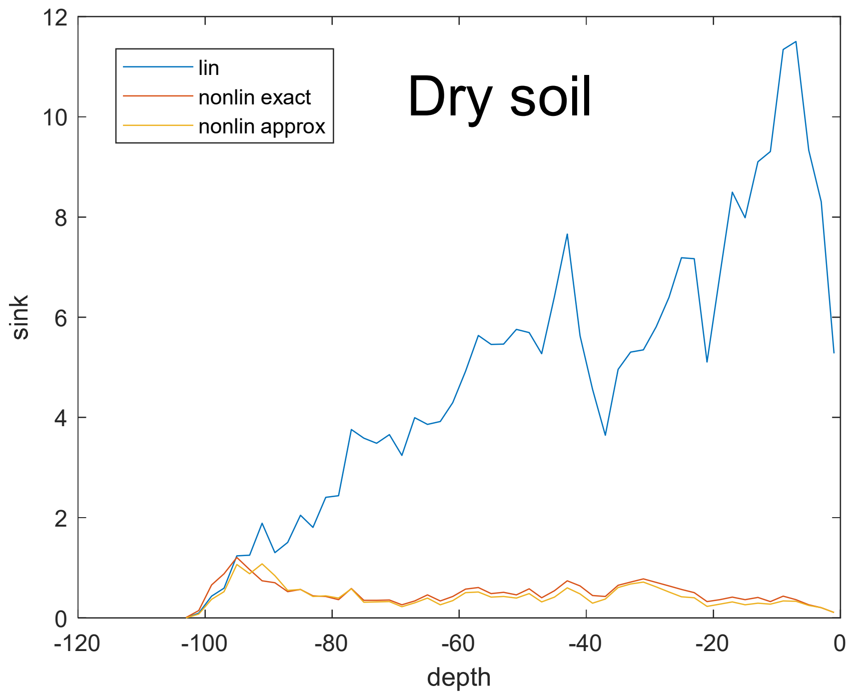
Simulated uptake



T_{lin} = 7.916 mm d^{-1}

T_{nonlin_exact} = 7.913 mm d^{-1}

T_{nonlin_1D} = 7.915 mm d^{-1}



T_{lin} = 4.474 mm d^{-1}

T_{nonlin_exact} = 0.45 mm d^{-1}

T_{nonlin_1D} = 0.40 mm d^{-1}

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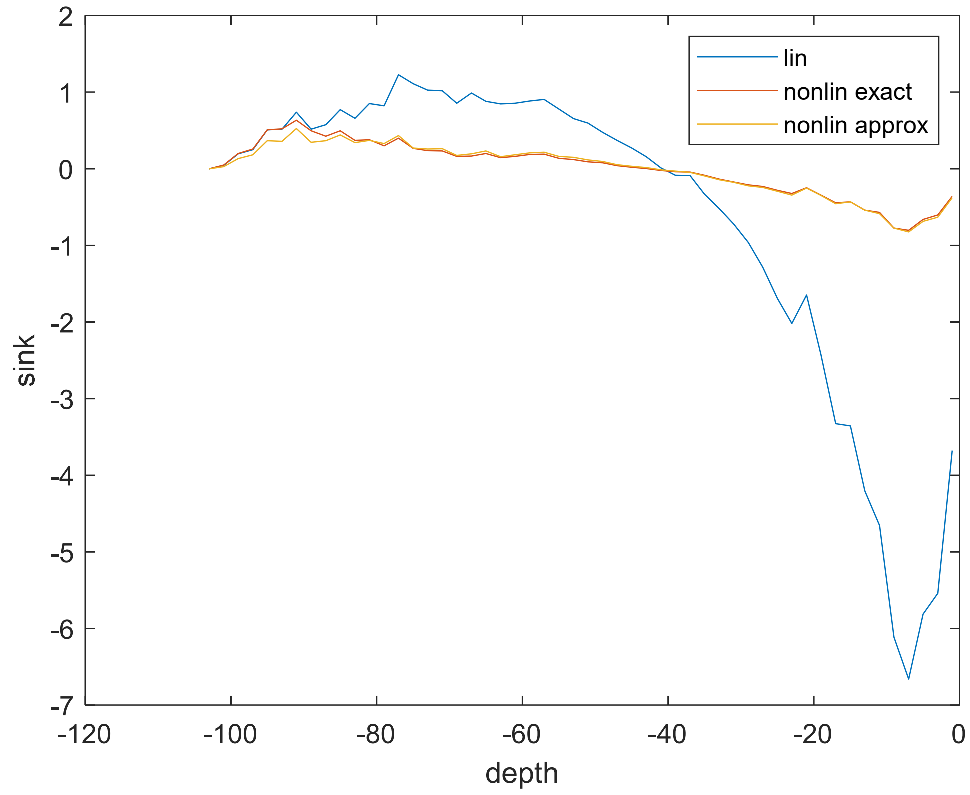
DEMONSTRATION

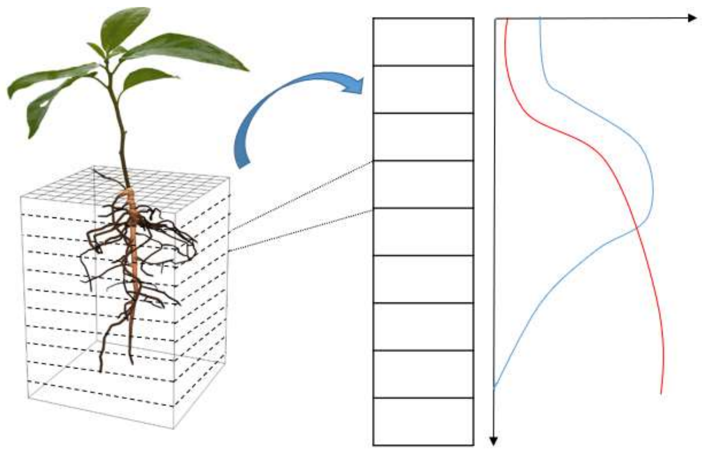
Redistribution for less negative H_{collar}

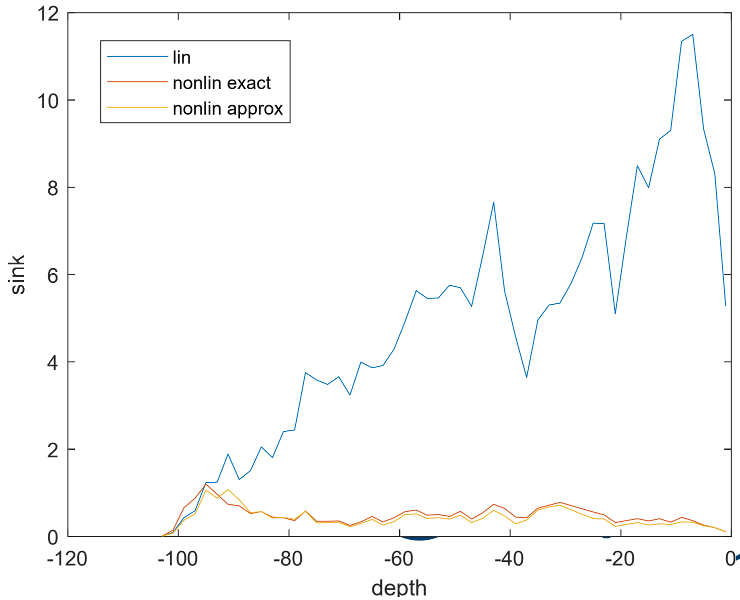
- H_{collar} = -3000 hPa
- Dry soil ($H_{soil,eff}$ ≈ -3000 hPa)



CONCLUSIONS

- Mathematical upscaling procedure to derive a 1D root water uptake model from a 3D root system model works well
- Upscaling of the non-linear soil-root model can be done in 1D assuming a single representative xylem hydraulic head per depth and iterating in 1D for non-linear soil hydraulics
- Neglecting the non-linear soil root conductance leads to:
  - a strong overestimation of uptake from dry soil layers
  - a strong overestimation of water redistribution into dry soil layers





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THANK YOU FOR YOUR ATTENTION! ☺

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