SWAP 50 years: advances in modelling soil-water-atmosphere-plant interactions

Marius Heinen[1], Martin Mulder[1], Jos van Dam[2], Ruud Bartholomeus[2,3], Quirijn de Jong van Lier[4], Janine de Wit[3], Allard de Wit[1], Mirjam Hack – ten Broeke[1]

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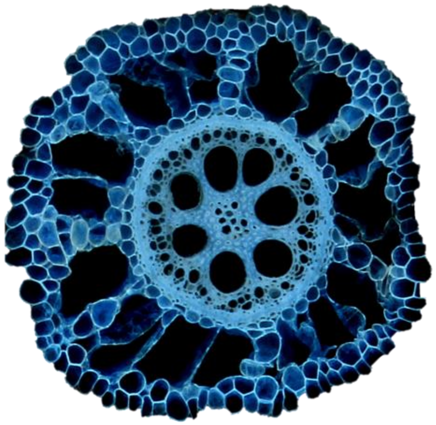

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KWR Watercycle Research Institute

cena Centro de Energia Nuclear na Agricultura

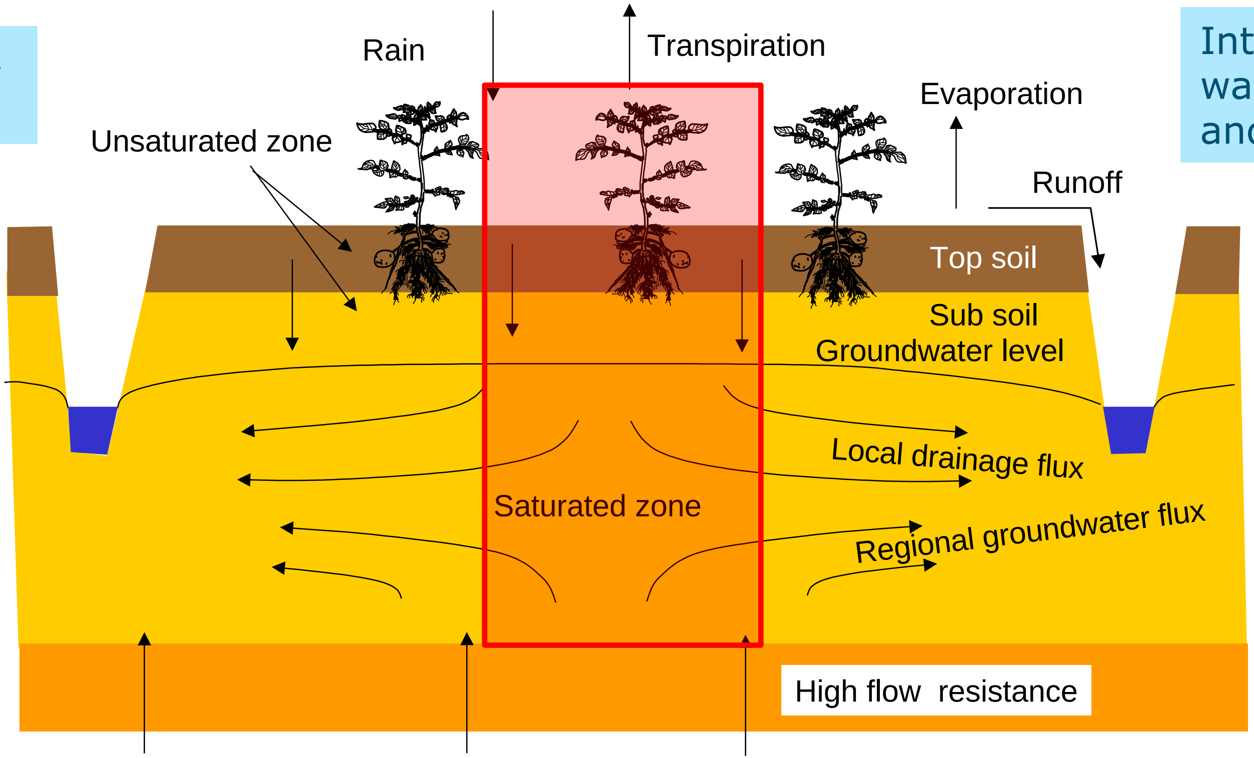
USP Campus "Luiz de Queiroz"

Contents

- Introduction
- Overview developments in past 15 years
    - Root water uptake: drought and oxygen stress
- Developments in the future

SWAP model domain

Biosphere, field scale



Interaction of soil, water, solute, heat and vegetation

Time scale: minutes to years

Users are: researchers, students and engineers

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It started in 1974

VOL. 10, NO. 6 WATER RESOURCES RESEARCH DECEMBER 1974

Field Test of a Modified Numerical Model for Water Uptake by Root Systems

R. A. FEDDES,[1] E. BRESLER, AND S. P. NEUMAN

Department of Soil Physics, Institute of Soils and Water, Volcani Center, Bet Dagan, Israel

Data obtained from careful water balance studies on water uptake by the roots of red cabbage are compared with results obtained from a modified numerical model of Nimah and Hanks. In the modified model the air dry moisture content at the soil surface may vary with time depending on meteorological conditions. The maximum possible rate of evapotranspiration is calculated by considering both meteorological conditions and crop properties. Data are quoted to suggest that the coefficient of the root sink may sometimes vary exponentially with depth. A period of 7 weeks was simulated, and the calculated weekly moisture profiles did not agree completely with those measured in the field. On the other hand, the calculated cumulative rates of evaporation and transpiration were in excellent agreement with the field data. When the original model was used without the suggested modifications, the agreement of these rates with the field data was not as good, an indication that some of these modifications actually improve the predictive capabilities of the model.

1: On leave from Institute for Land and Water Management Research, Wageningen, the Netherlands

Key words then and still current

- Soil water balance
- Water uptake by roots
- ET demand: meteorological conditions and crop properties
- **Soil – vegetation – atmosphere transfer processes**
- Numerical simulation model
- Old names: SWATR, SWATRE, SWACROP
- Since 1997: **SWAP: Soil Water – Atmosphere – Plant**

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Previous overview in 2008: major items discussed

- Numerical, mass-conservative solution of 1D Richards equation
- Evapotranspiration
- Interactions with groundwater and surface water
- Macropore flow
- Case studies
- Vision on the future

Advances of Modeling Water Flow in Variably Saturated Soils with SWAP

Jos C. van Dam,* Piet Groenendijk, Rob F.A. Hendriks, and Joop G. Kroes

Vadose Zone Journal 7(2): 640-653; https://doi.org/10.2136/vzj2007.0060

SWAP manual (2017)

- Theory and user manual
- SWAP version 4
- https://swap.wur.nl
- Freely available (open source; GNU GPL license 2.1)
- Manual included
    - https://edepot.wur.nl/416321

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SWAP 50 years

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Soil water balance

ABSTRACT

This paper highlights the evolution and impact of the SWAP model (Soil – Water – Atmosphere – Plant), which was initiated by R.A. Feddes and colleagues fifty years ago, in 1974. Since then, the SWAP model has played a crucial role in the advancement of agrohydrology. This paper highlights some major advances that have been made, especially focussing on the last fifteen years. The domain of the SWAP model deals with the simulation of the soil water balance in both unsaturated and saturated conditions. The model solves the Richards equation using the water retention and hydraulic conductivity functions as described by the Van Genuchten – Mualem equations. Bimodal extensions of the Van Genuchten - Mualem relationships have been implemented, as well as modifications near saturation and addressing hysteresis. An important sink term in the Richards equation is root water uptake. Crop development plays an important role in a robust simulation of root water uptake. That is why a link has been made with the dynamic crop growth model WOFOST. Instead of using a prescribed crop development, a distinction between potential and actual crop development is calculated by reducing the potential photosynthesis as a result of water or oxygen stress. Since the early days of SWAP, empirical and macroscopic concepts have been used to simulate root water uptake. Recently two process-based concepts of root water uptake and oxygen stress have also been implemented. Another important sink-source term in the Richards equation is the interaction with artificial drains. In SWAP, drainage can be simulated by either using prescribed or simulated drain heads and simulation of controlled drainage with subirrigation is possible. Finally, we briefly elaborate on three studies using SWAP: water stresses in agriculture in the Netherlands, regional water productivity in China, and controlled drainage with subirrigation. We finish discussing promising developments for the near future.

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Selected developments in past 15 years

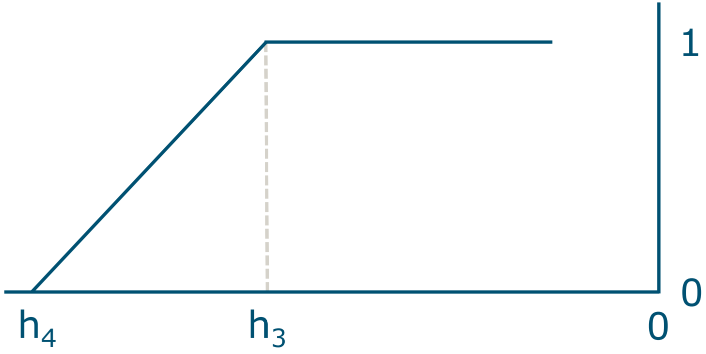
- Crop growth i.r.t. soil, climate and water management
  - including root development (Martin Mulder)
- Soil hydraulic properties
- Drought stress: empirical and process-based concepts
- Oxygen stress
- Case studies (Janine de Wit)
- Promising developments in the near future

RWU modelling

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{h(\theta)}{\partial z}\right) - \frac{\partial K(\theta)}{\partial z} - S_r \pm S_d$$

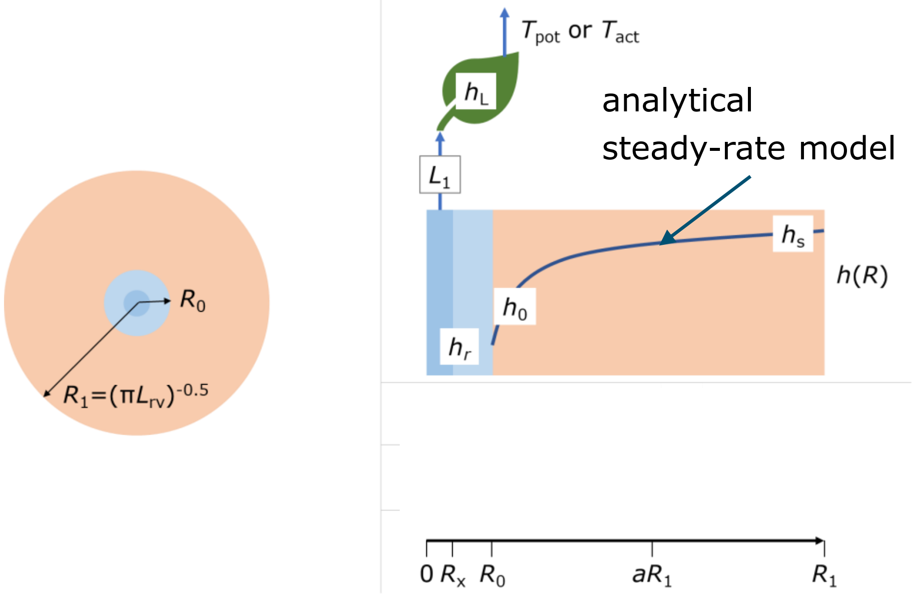
Root water uptake is a key process in the global water cycle (Jasechko et al., 2013; Rothfuss and Javaux, 2016).

- Empirical: Feddes-concept

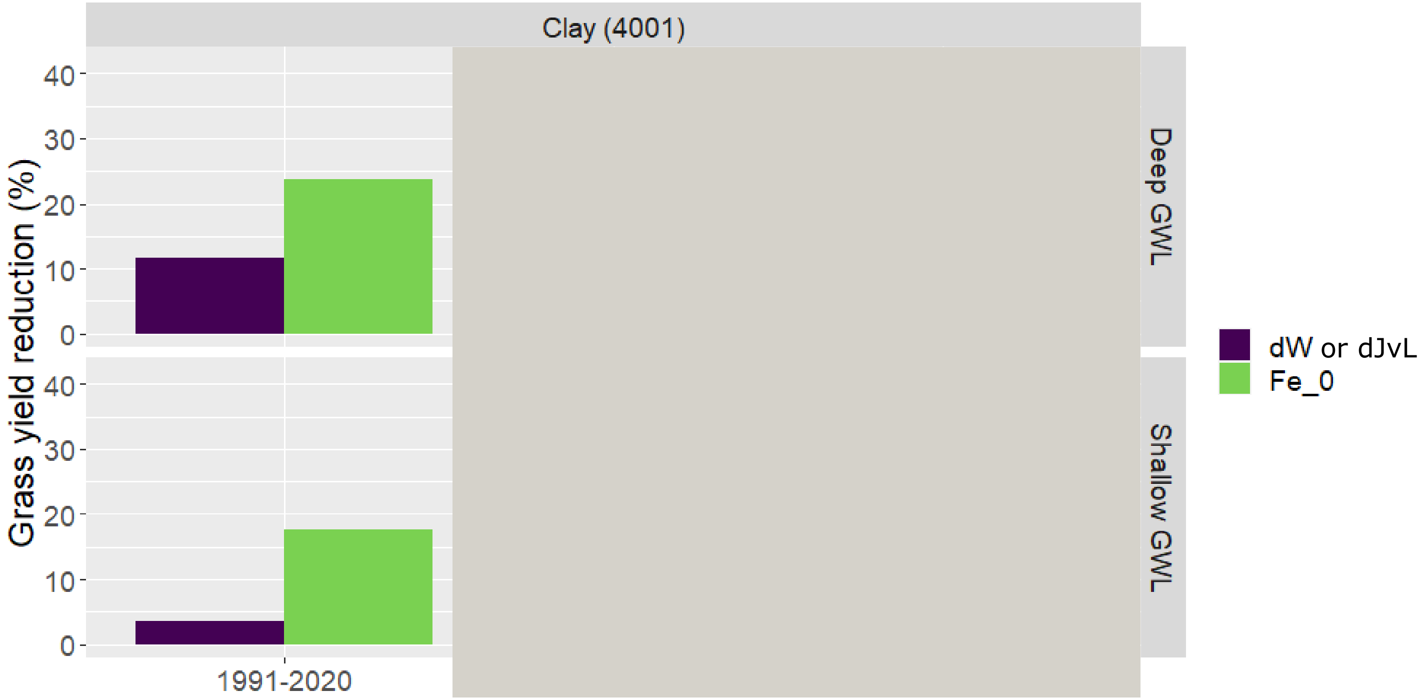


- Crop dependent: h_3, h_4
- Not directly soil dependent

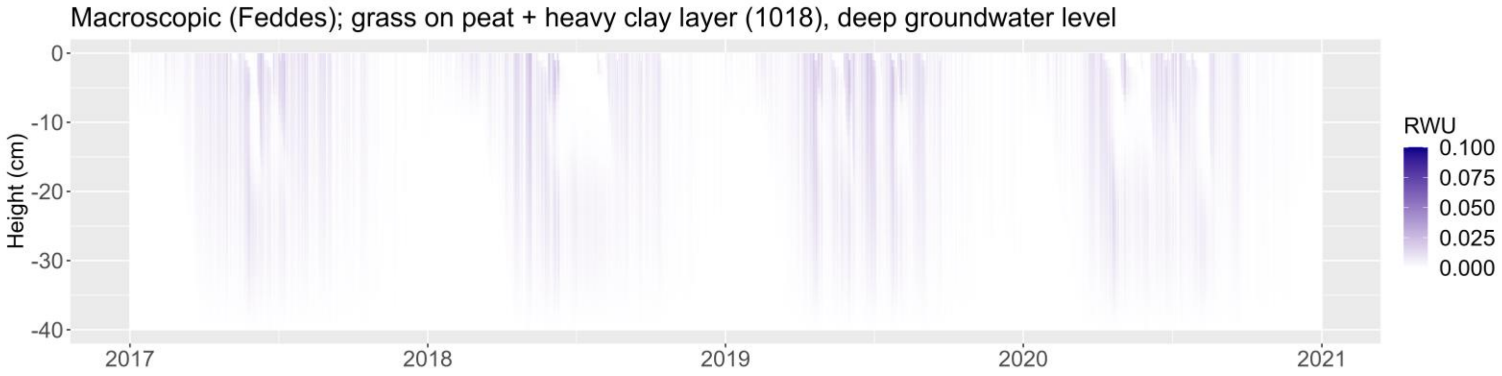
- Process-based

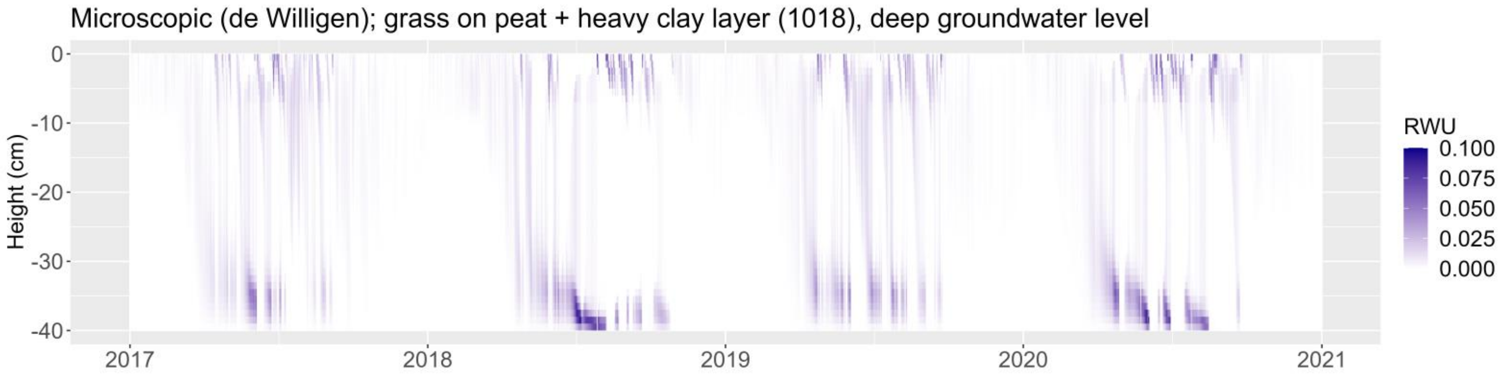


Example: differences root water uptake models



Example: differences root water uptake models





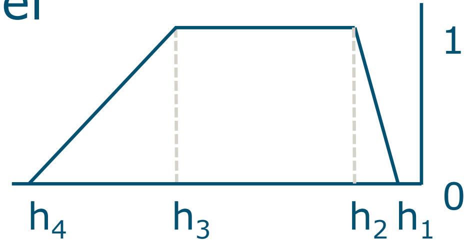
Process-based models require L_{rv}

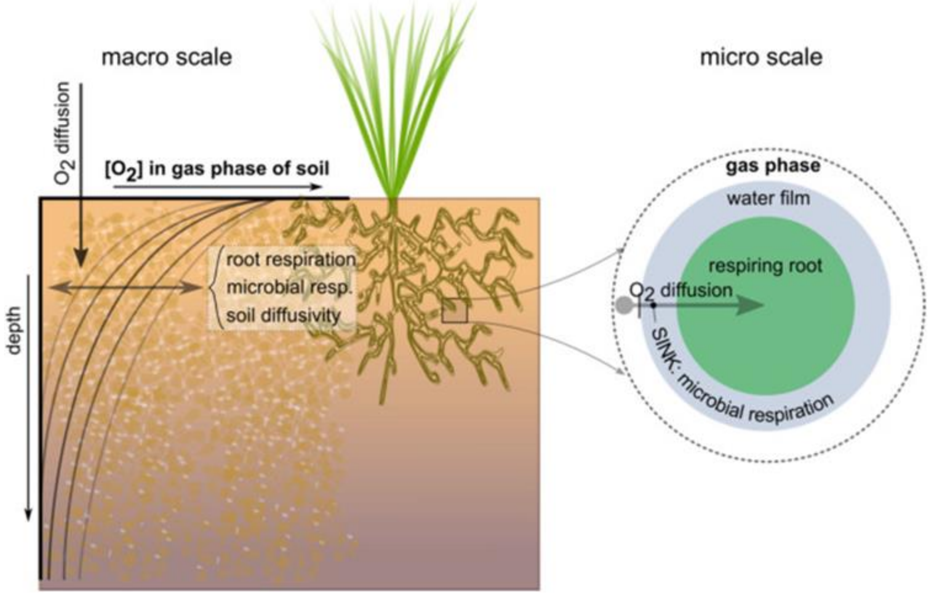
- L_{rv}: root length density: length per unit volume of soil (cm cm^{-3})
- Empirical model: relative $L_{rv}(z,t)$
- Process-based model: absolute $L_{rv}(z,t)$

- Root length density distribution as a function of time and depth
  - Martin Mulder: Dynamic crop growth and root development

Process-based oxygen uptake

- Bartholomeus et al. (2008)
- Analogy with process-based RWU
- Oxygen stress reduces potential assimilation rate similar as drought stress
- Replaces wet-end of empirical Feddes-model



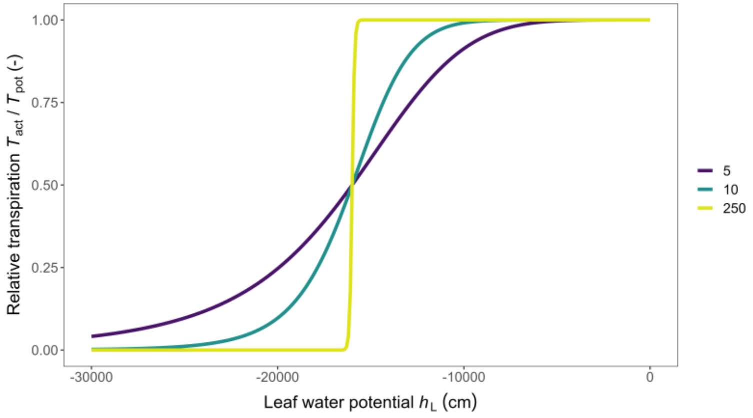


SWAP and the future

- Continue proper description of severe drought, oxygen and prolonged heat waves (climate change) on crop development
- Salinization: salinity stress
- Interaction with nutrients, pesticides
    - Afternoon: Piet Groenendijk (ANIMO), Aaldrik Tiktak (PEARL)
- Many more …
- Focus: applicability for
    - land evaluation studies
    - impact of hydrological management options
    - studies on climate impact and possible climate adaptation

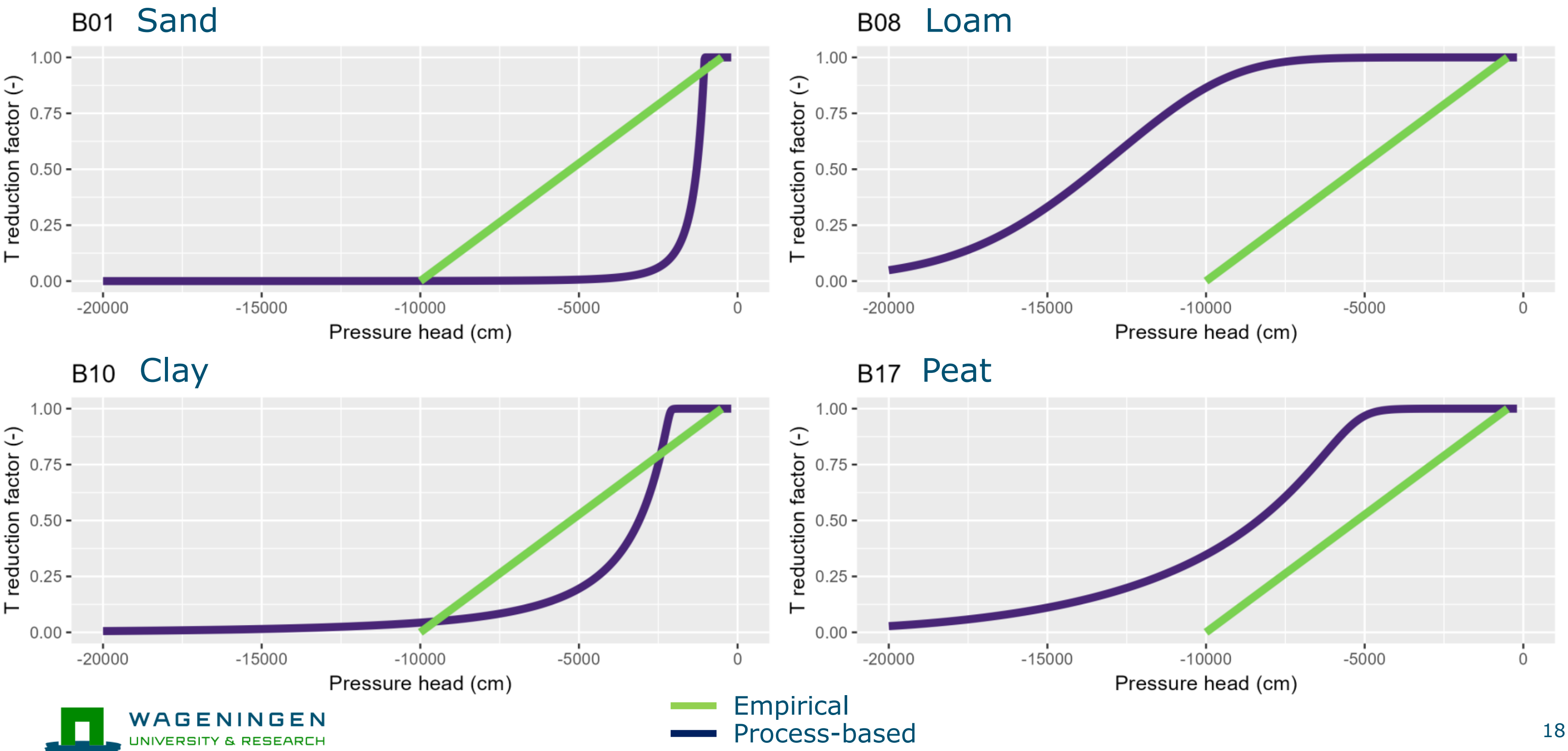
Thank you

Process-based models require other input



- Root length density
- Root radius and root xylem radius
- Root hydraulic conductivity
- Root-stem-leaf conductance
- Leaf water potential where 50% transpiration reduction + shape parameter

Single layer: comparison



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Compensation

- Empirical
  - reduction per soil compartment
  - post-processing Jarvis compensation (linear)
- Process-based
  - implicitly included in solution procedure
  - solve for all n soil layers + reduction function
    - n+1 equations with n+1 unknowns