SWAP – 50 years

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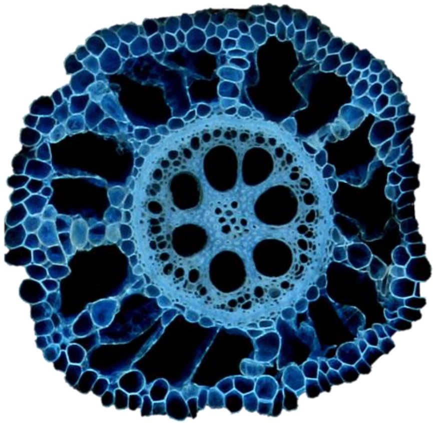

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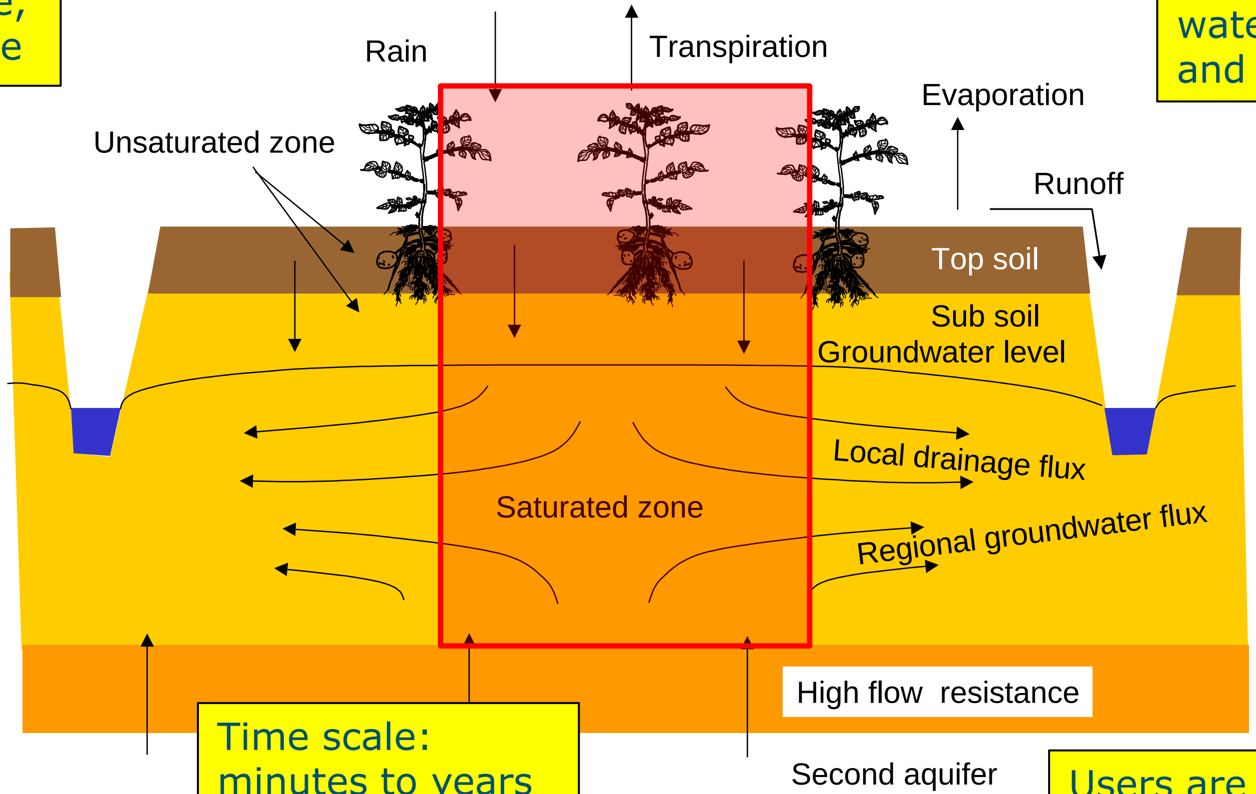
Contents

- Introduction
- Selected developments in past 15 years
    - Crop growth in interaction with soil, climate and water management
    - Root water uptake: drought and oxygen stress
- Examples
- Developments in the future

SWAP model domain

Biosphere,
Field scale

Interaction of soil,
water, solute, heat
and vegetation



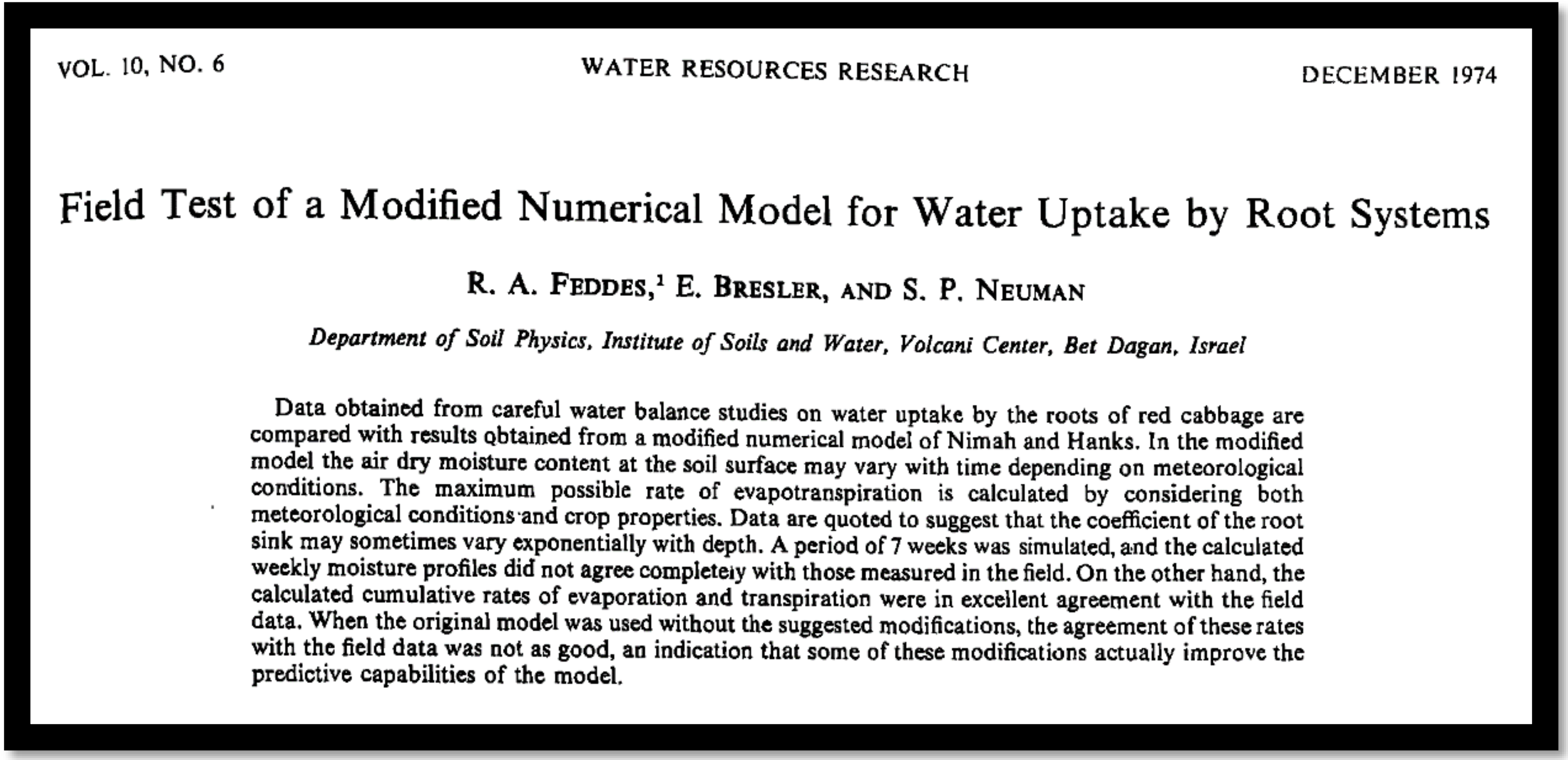
Time scale:
minutes to years

Users are researchers,
students and engineers

https://swap.wur.nl

- SWAP is freely available (open source; GNU GPL license 2.1)
- Manual included
- List references: SWAP studies

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

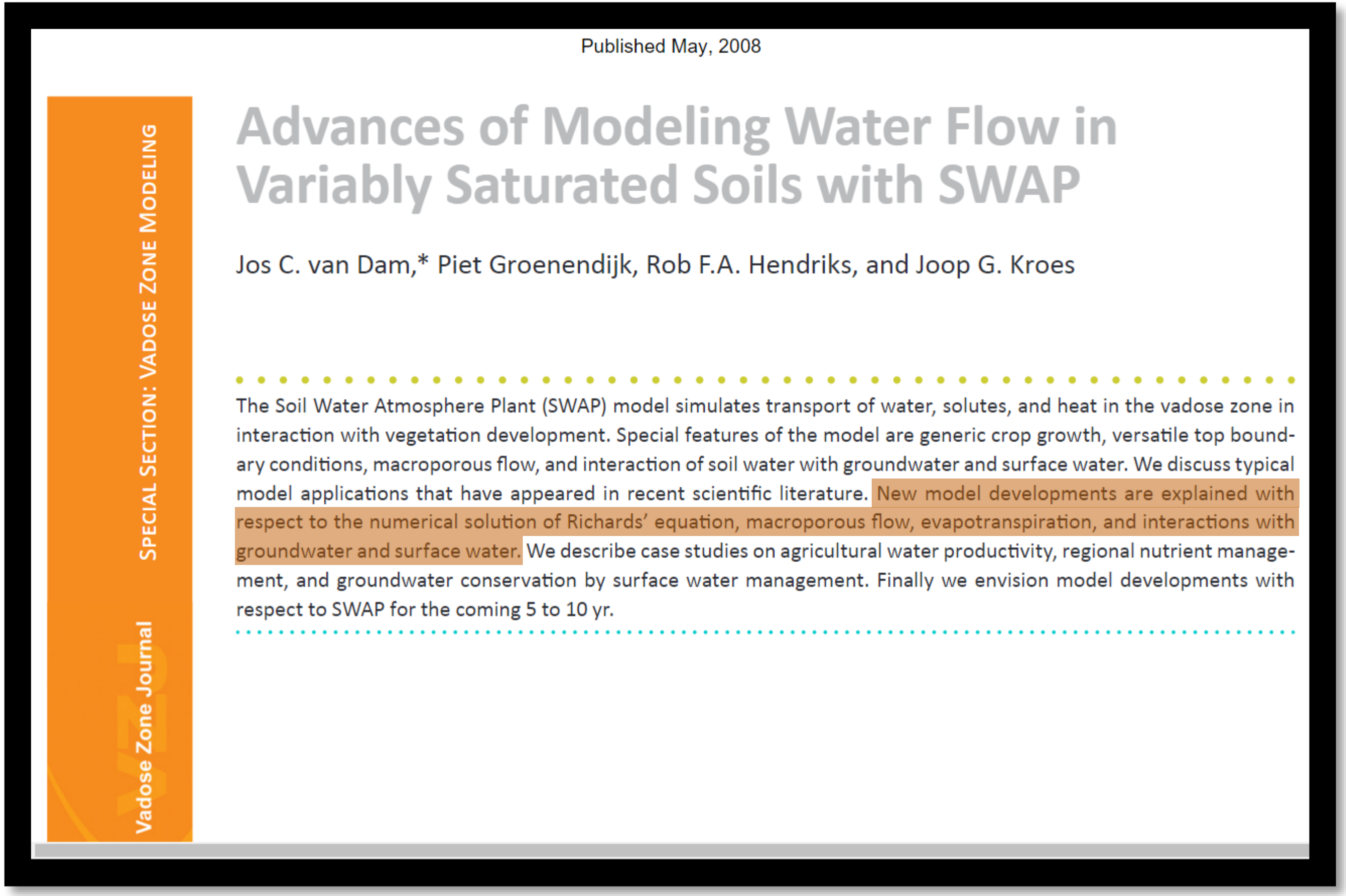
Department of Soil Physics, Institute of Soils and Water, Volcani Center, Bet Dagan, Israel

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.

Key words then and still current

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

Previous overview in 2008



Published May, 2008

SPECIAL SECTION: VADOSE ZONE MODELING

Vadose Zone Journal

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

The Soil Water Atmosphere Plant (SWAP) model simulates transport of water, solutes, and heat in the vadose zone in interaction with vegetation development. Special features of the model are generic crop growth, versatile top boundary conditions, macroporous flow, and interaction of soil water with groundwater and surface water. We discuss typical model applications that have appeared in recent scientific literature. New model developments are explained with respect to the numerical solution of Richards' equation, macroporous flow, evapotranspiration, and interactions with groundwater and surface water. We describe case studies on agricultural water productivity, regional nutrient management, and groundwater conservation by surface water management. Finally we envision model developments with respect to SWAP for the coming 5 to 10 yr.

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Selected developments in past 15 years

- Richards equation: core of the SWAP model

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

- Soil hydraulic properties: $\theta(h)$, $K(h)$ or $K(\theta)$
- Crop growth in interaction with soil, climate and water management
- Root water uptake: drought and oxygen stress: S_r
- Controlled drainage with subirrigation: S_d

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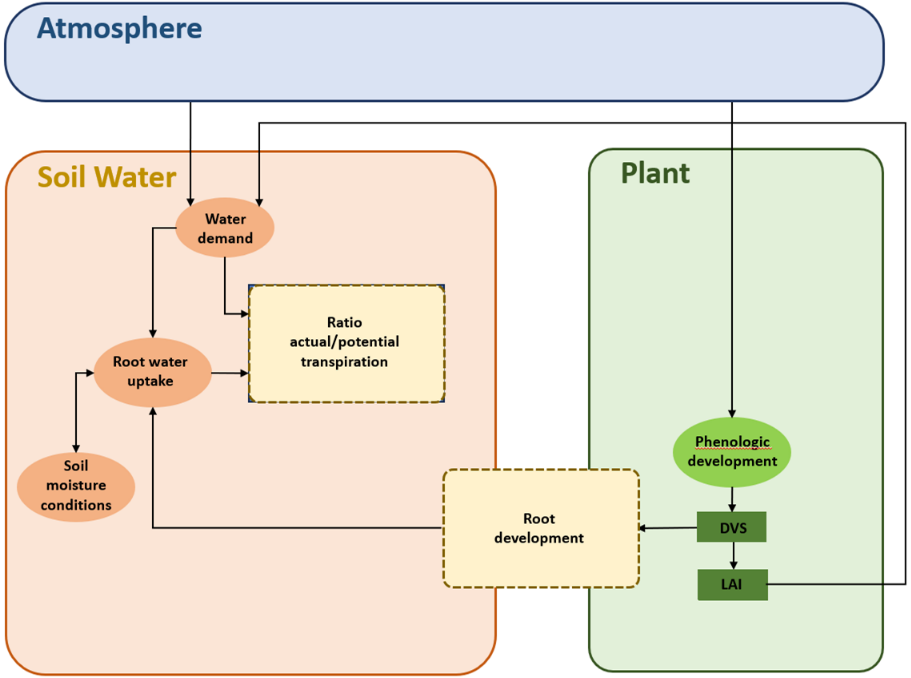
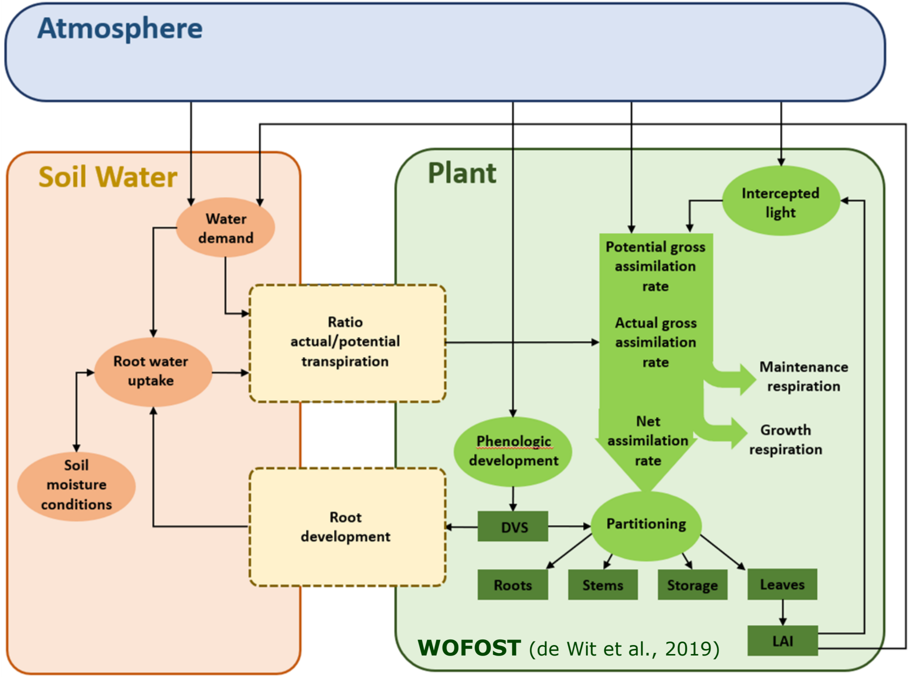
Crop growth

- Crop status determines demand for evapotranspiration
- Soil water status determines actual root water uptake



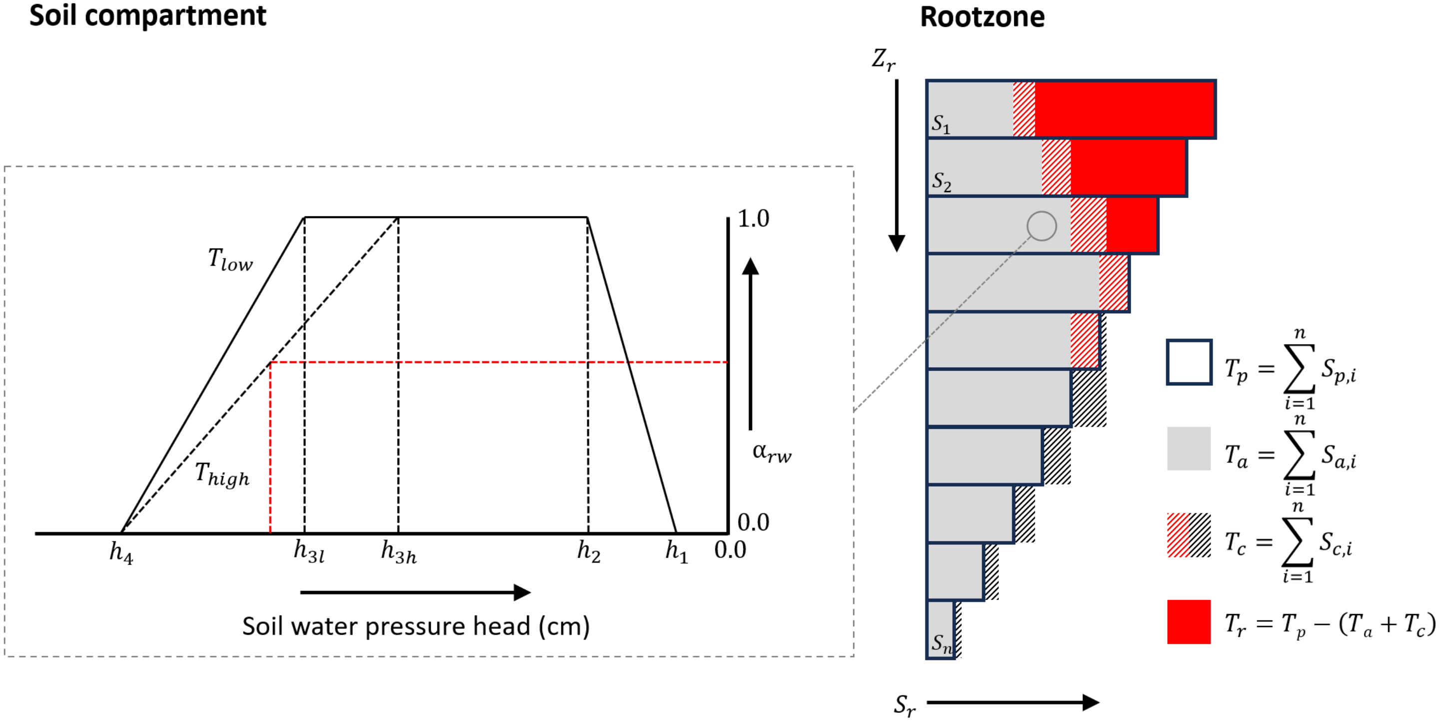
Crop growth

- Crop status determines demand for evapotranspiration
- Soil water status determines actual root water uptake
- Potential and water-limited crop production
- Non optimal root water uptake leads to reduced crop production



WOFOST (de Wit et al., 2019)

RWU modelling: empirical



□ $T_p = \sum_{i=1}^{n} S_{p,i}$

▨ $T_a = \sum_{i=1}^{n} S_{a,i}$

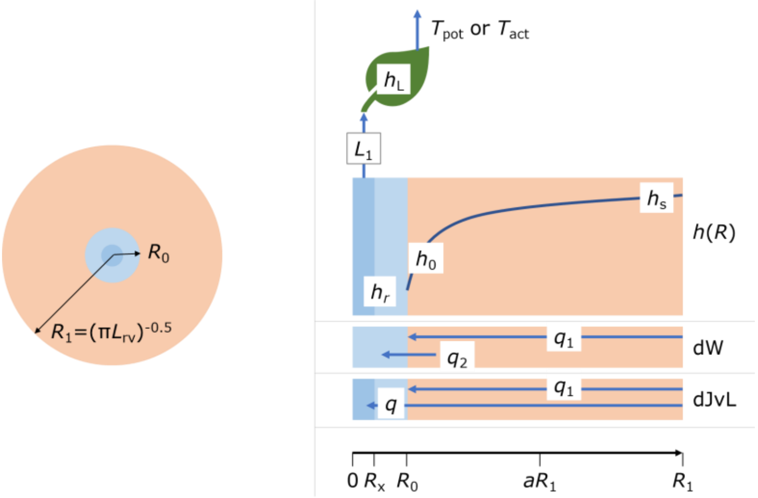
▨ $T_c = \sum_{i=1}^{n} S_{c,i}$

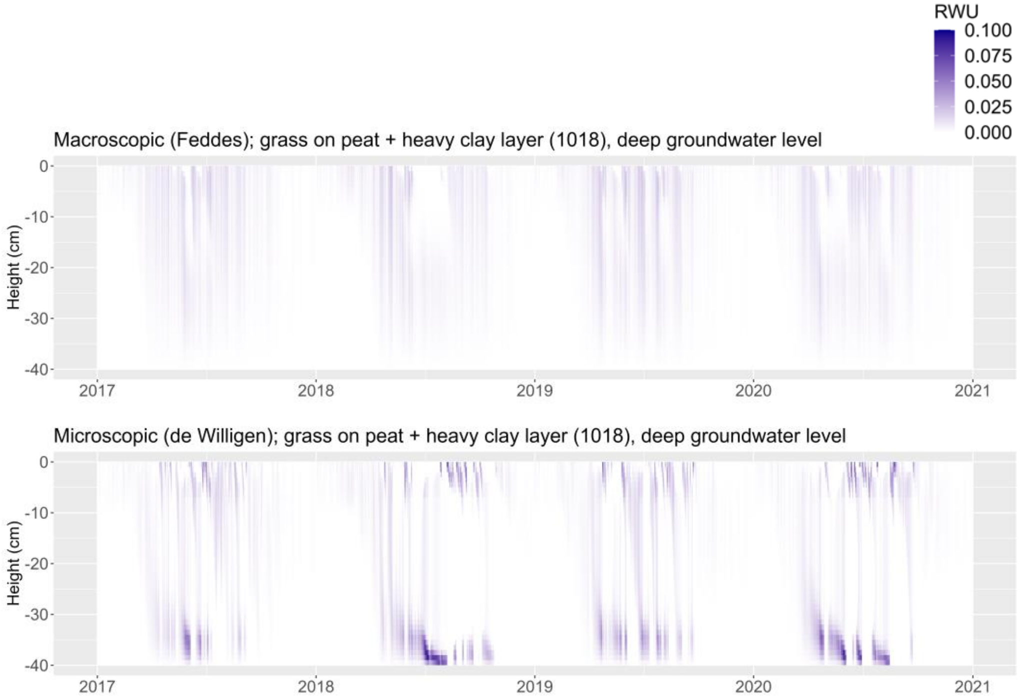
🟥 $T_r = T_p - (T_a + T_c)$

Feddes et al., 1978

Jarvis et al., 2011

RWU modelling: process based



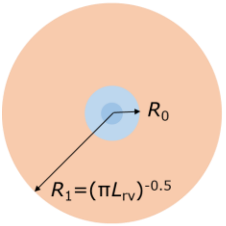

Macroscopic (Feddes); grass on peat + heavy clay layer (1018), deep groundwater level

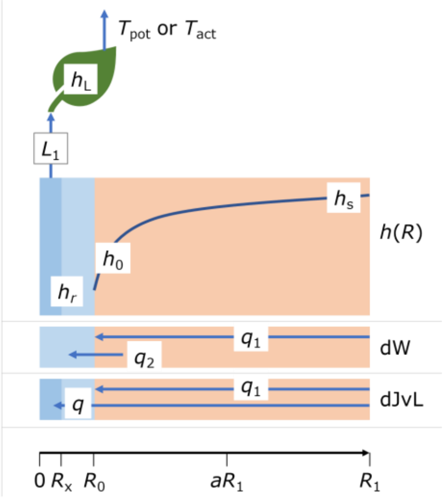
Microscopic (de Willigen); grass on peat + heavy clay layer (1018), deep groundwater level

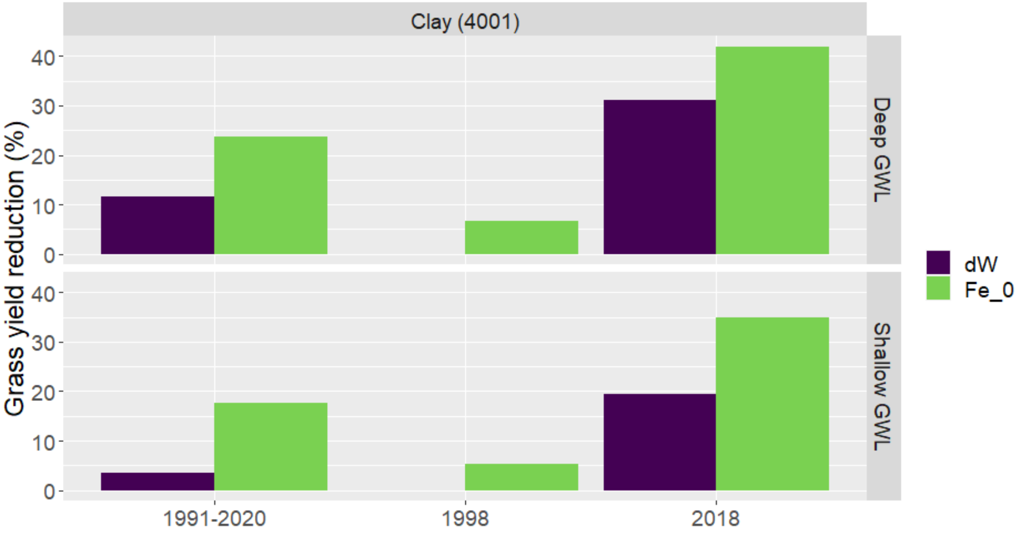
De Jong van Lier et al., 2013

De Willigen et al., 2017

RWU modelling: process based



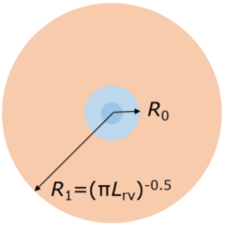


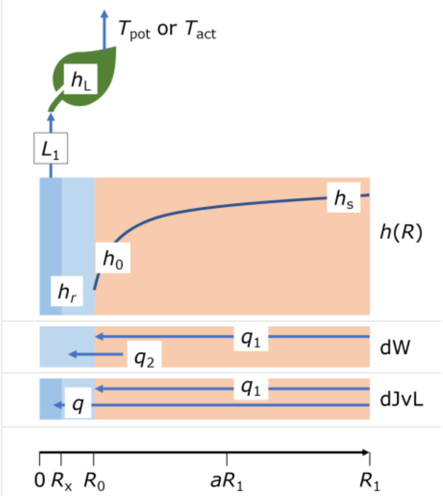


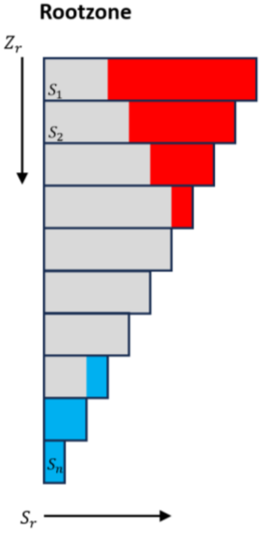
De Jong van Lier et al., 2013

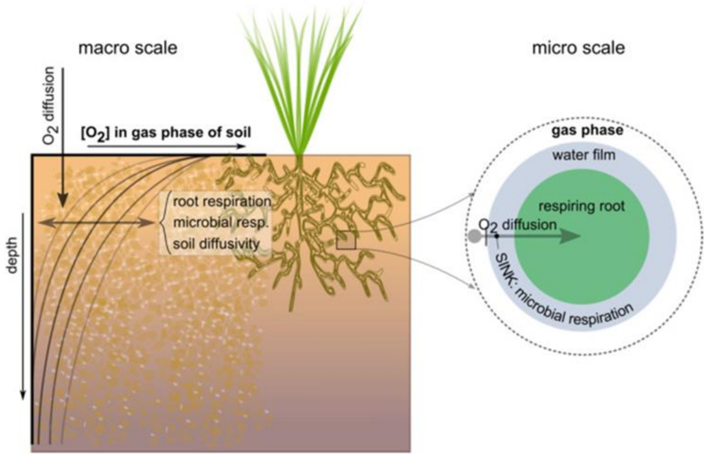
De Willigen et al., 2017

RWU modelling: process based







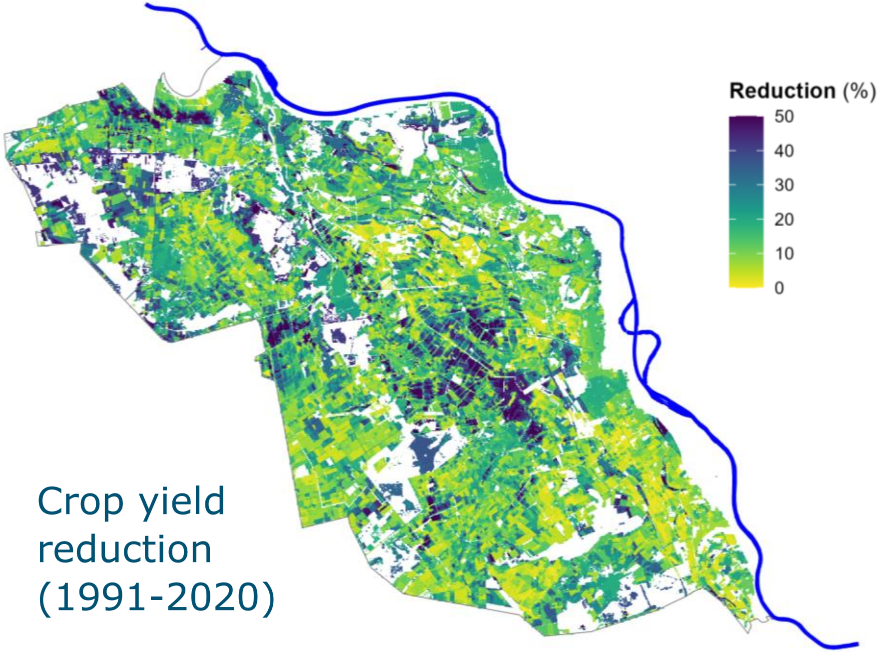


De Jong van Lier et al., 2013

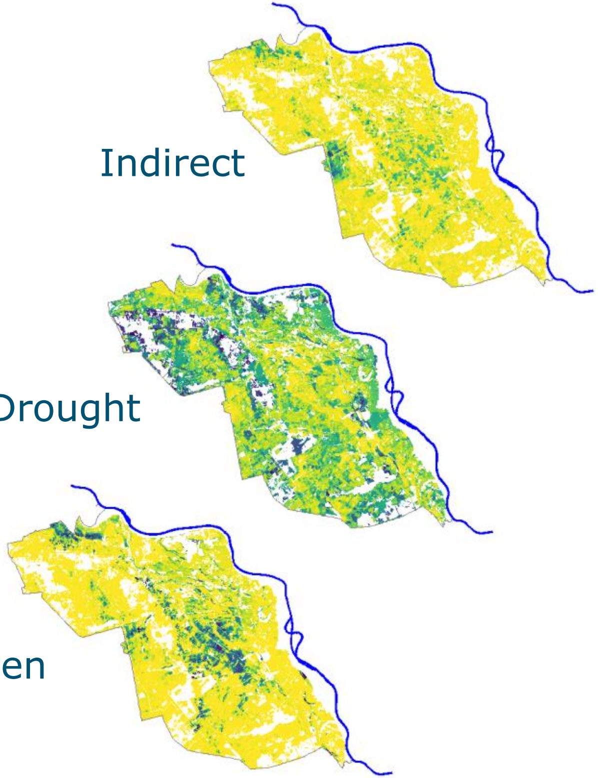
De Willigen et al., 2017

Bartholomeus et al., 2008

Example: SWAP-WOFOST regional



Crop yield reduction (1991-2020)



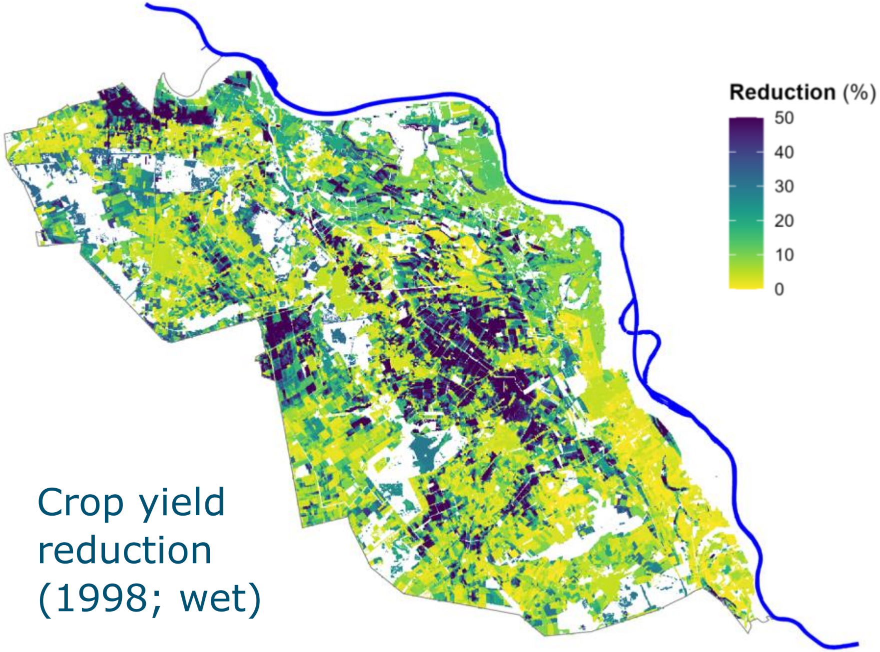
Indirect

Drought

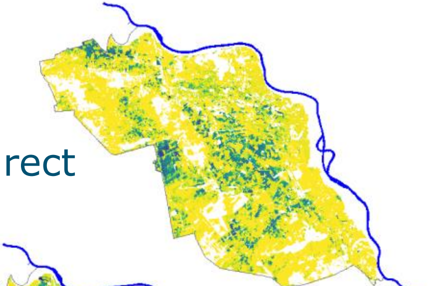
Oxygen

Hack-ten Broeke et al., 2019

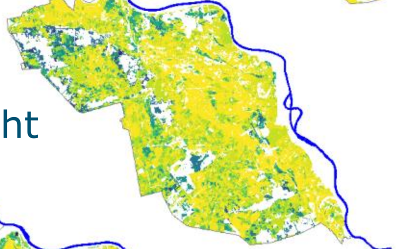
Example: SWAP-WOFOST regional



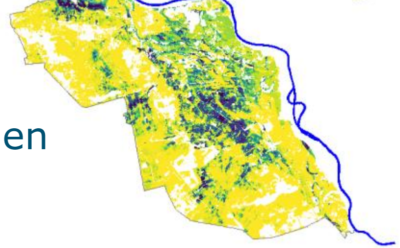
Crop yield reduction (1998; wet)



Indirect



Drought



Oxygen

Hack-ten Broeke et al., 2019

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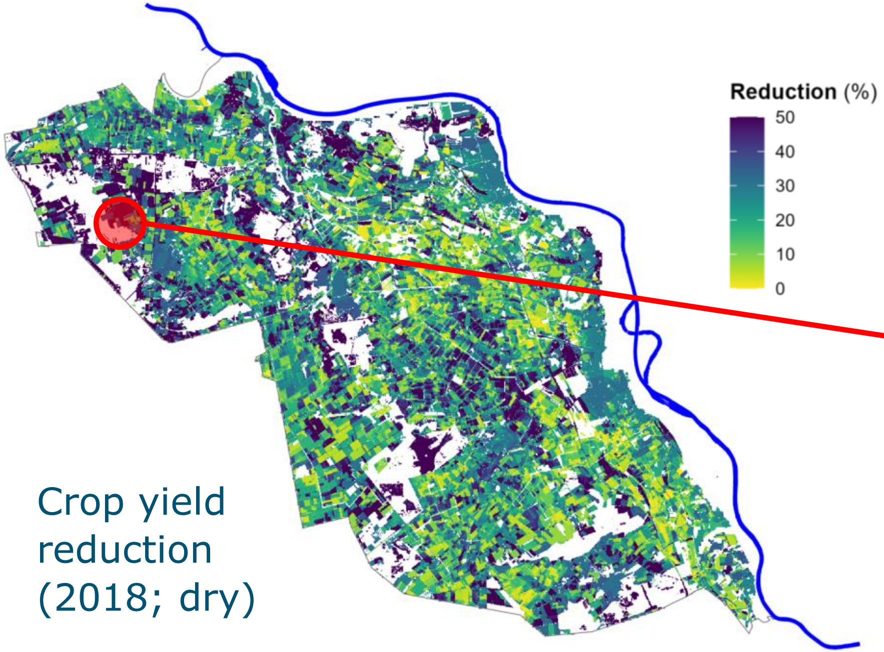
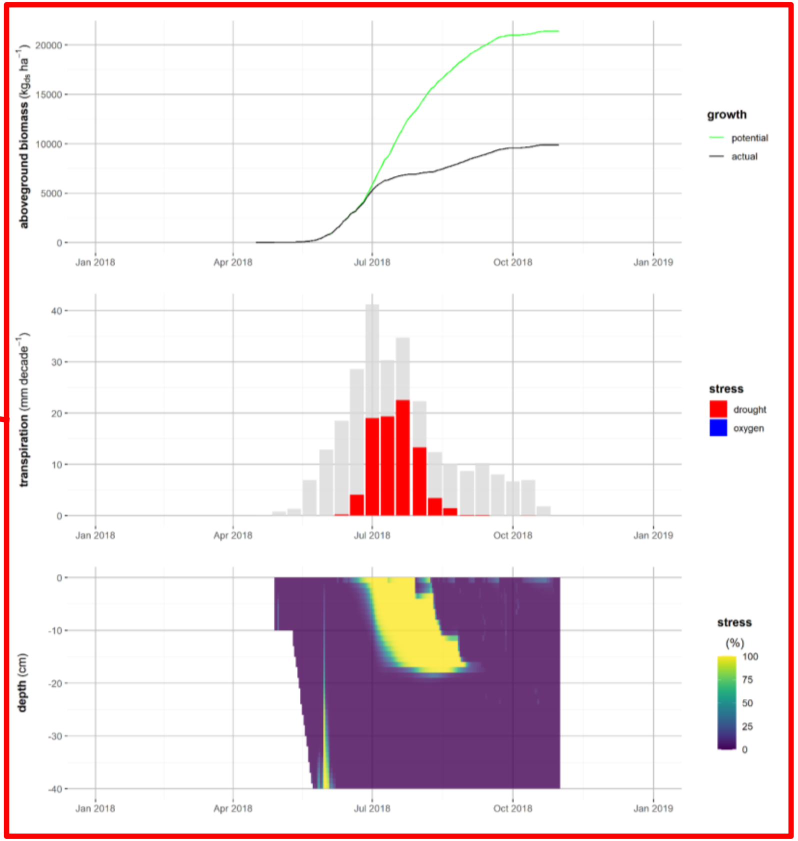
WATERWIJZER Landbouw

Example: SWAP-WOFOST regional



Crop yield reduction (2018; dry)



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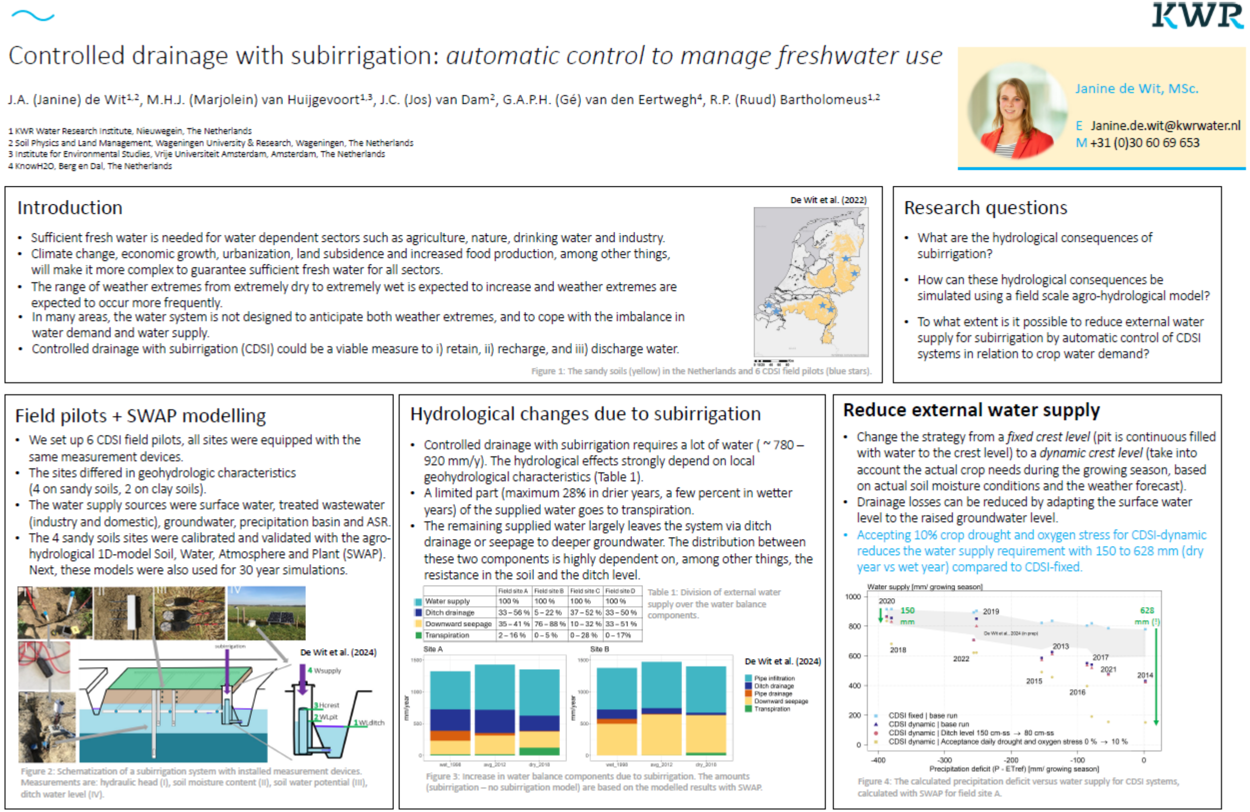
WATERwijzer
Landbouw

Example: Climate adaptive drainage



Controlled drainage with subirrigation: *automatic control to manage freshwater use*

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Introduction

- Sufficient fresh water is needed for water dependent sectors such as agriculture, nature, drinking water and industry.
- Climate change, economic growth, urbanization, land subsidence and increased food production, among other things, will make it more complex to guarantee sufficient fresh water for all sectors.
- The range of weather extremes from extremely dry to extremely wet is expected to increase and weather extremes are expected to occur more frequently.
- In many areas, the water system is not designed to anticipate both weather extremes, and to cope with the imbalance in water demand and water supply.
- Controlled drainage with subirrigation (CDSI) could be a viable measure to i) retain, ii) recharge, and iii) discharge water.

De Wit et al. (2022)

Figure 1: The sandy soils (yellow) in the Netherlands and 6 CDSI field pilots (blue stars).

Research questions

- What are the hydrological consequences of subirrigation?
- How can these hydrological consequences be simulated using a field scale agro-hydrological model?
- To what extent is it possible to reduce external water supply for subirrigation by automatic control of CDSI systems in relation to crop water demand?

Field pilots + SWAP modelling

- We set up 6 CDSI field pilots, all sites were equipped with the same measurement devices.
- The sites differed in geohydrologic characteristics (4 on sandy soils, 2 on clay soils).
- The water supply sources were surface water, treated wastewater (industry and domestic), groundwater, precipitation basin and ASR.
- The 4 sandy soils sites were calibrated and validated with the agro-hydrological 1D-model Soil, Water, Atmosphere and Plant (SWAP). Next, these models were also used for 30 year simulations.

De Wit et al. (2024)

Figure 2: Schematization of a subirrigation system with installed measurement devices. Measurements are: hydraulic head (I), soil moisture content (II), soil water potential (III), ditch water level (IV).

Hydrological changes due to subirrigation

- Controlled drainage with subirrigation requires a lot of water (~ 780 – 920 mm/y). The hydrological effects strongly depend on local geohydrological characteristics (Table 1).
- A limited part (maximum 28% in drier years, a few percent in wetter years) of the supplied water goes to transpiration.
- The remaining supplied water largely leaves the system via ditch drainage or seepage to deeper groundwater. The distribution between these two components is highly dependent on, among other things, the resistance in the soil and the ditch level.

	Field site A	Field site B	Field site C	Field site D
Water supply	100 %	100 %	100 %	100 %
Ditch drainage	33 – 56 %	5 – 22 %	37 – 52 %	33 – 50 %
Downward seepage	35 – 41 %	76 – 88 %	10 – 32 %	33 – 51 %
Transpiration	2 – 16 %	0 – 5 %	0 – 28 %	0 – 17%

Table 1: Division of external water supply over the water balance components.

De Wit et al. (2024)

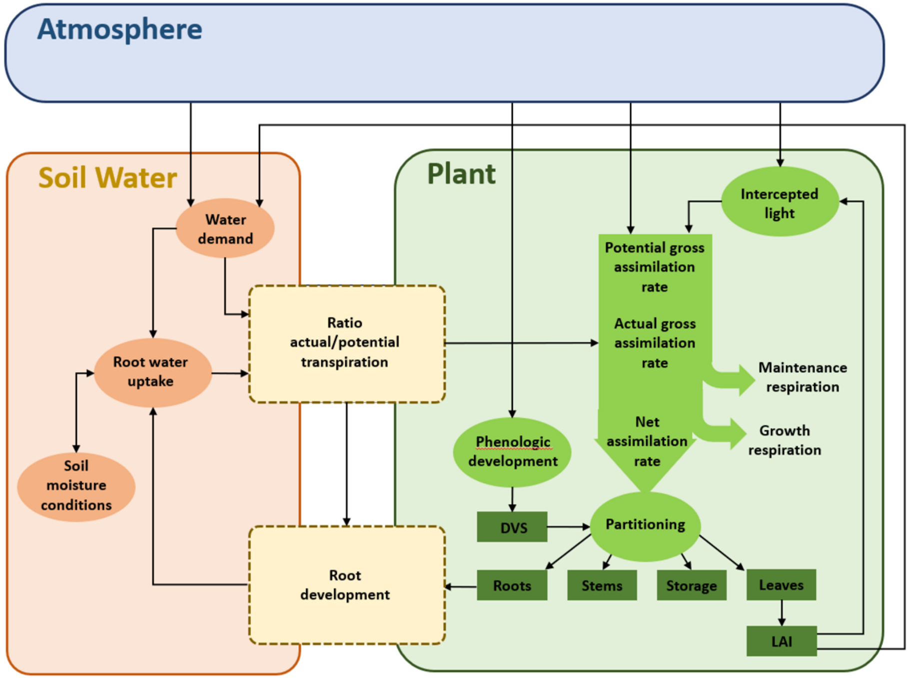
Figure 3: Increase in water balance components due to subirrigation. The amounts (subirrigation – no subirrigation model) are based on the modelled results with SWAP.

Reduce external water supply

- Change the strategy from a *fixed crest level* (pit is continuous filled with water to the crest level) to a *dynamic crest level* (take into account the actual crop needs during the growing season, based on actual soil moisture conditions and the weather forecast).
- Drainage losses can be reduced by adapting the surface water level to the raised groundwater level.
- Accepting 10% crop drought and oxygen stress for CDSI-dynamic reduces the water supply requirement with 150 to 628 mm (dry year vs wet year) compared to CDSI-fixed.

Figure 4: The calculated precipitation deficit versus water supply for CDSI systems, calculated with SWAP for field site A.

SWAP and the future



Atmosphere

Soil Water

Water demand

Root water uptake

Soil moisture conditions

Ratio actual/potential transpiration

Root development

Plant

Intercepted light

Potential gross assimilation rate

Actual gross assimilation rate

Maintenance respiration

Growth respiration

Net assimilation rate

Phenologic development

DVS

Partitioning

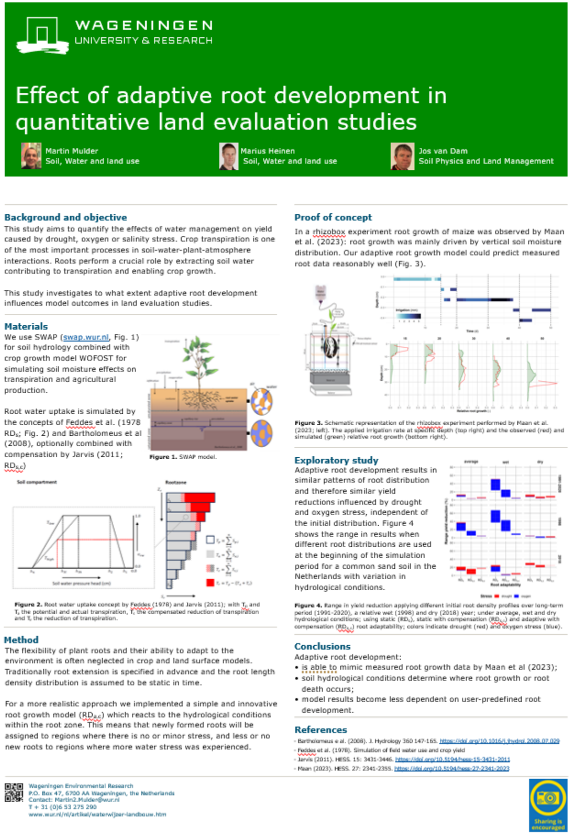
Roots

Stems

Storage

Leaves

LAI



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Effect of adaptive root development in quantitative land evaluation studies

Martin Mulder
Soil, Water and land use

Marius Heinen
Soil, Water and land use

Jos van Dam
Soil Physics and Land Management

Background and objective

This study aims to quantify the effects of water management on yield caused by drought, oxygen or salinity stress. Crop transpiration is one of the most important processes in soil-water-plant-atmosphere interactions. Roots perform a crucial role by extracting soil water contributing to transpiration and enabling crop growth.

This study investigates to what extent adaptive root development influences model outcomes in land evaluation studies.

Materials

We use SWAP (swap.wur.nl, Fig. 1) for soil hydrology combined with crop growth model WOFOST for simulating soil moisture effects on transpiration and agricultural production.

Figure 1. SWAP model.

Root water uptake is simulated by the concepts of Feddes et al. (1978 RD_s; Fig. 2) and Bartholomeus et al (2008), optionally combined with compensation by Jarvis (2011; $RD_{s,c}$)

Figure 2. Root water uptake concept by Feddes (1978) and Jarvis (2011); with T_p and T_a the potential and actual transpiration, T_c the compensated reduction of transpiration and T_r the reduction of transpiration.

Method

The flexibility of plant roots and their ability to adapt to the environment is often neglected in crop and land surface models. Traditionally root extension is specified in advance and the root length density distribution is assumed to be static in time.

For a more realistic approach we implemented a simple and innovative root growth model ($RD_{a,c}$) which reacts to the hydrological conditions within the root zone. This means that newly formed roots will be assigned to regions where there is no or minor stress, and less or no new roots to regions where more water stress was experienced.

Proof of concept

In a rhizobox experiment root growth of maize was observed by Maan et al. (2023): root growth was mainly driven by vertical soil moisture distribution. Our adaptive root growth model could predict measured root data reasonably well (Fig. 3).

Figure 3. Schematic representation of the rhizobox experiment performed by Maan et al. (2023; left). The applied irrigation rate at specific depth (top right) and the observed (red) and simulated (green) relative root growth (bottom right).

Exploratory study

Adaptive root development results in similar patterns of root distribution and therefore similar yield reductions influenced by drought and oxygen stress, independent of the initial distribution. Figure 4 shows the range in results when different root distributions are used at the beginning of the simulation period for a common sand soil in the Netherlands with variation in hydrological conditions.

Figure 4. Range in yield reduction applying different initial root density profiles over long-term period (1991-2020), a relative wet (1998) and dry (2018) year; under average, wet and dry hydrological conditions; using static (RD_s), static with compensation ($RD_{s,c}$) and adaptive with compensation ($RD_{a,c}$) root adaptability; colors indicate drought (red) and oxygen stress (blue).

Conclusions

Adaptive root development:

- is able to mimic measured root growth data by Maan et al (2023);
- soil hydrological conditions determine where root growth or root death occurs;
- model results become less dependent on user-predefined root development.

References

- Bartholomeus e al. (2008). J. Hydrology 360 147-165. https://doi.org/10.1016/j.jhydrol.2008.07.029
- Feddes et al. (1978). Simulation of field water use and crop yield
- Jarvis (2011). HESS. 15: 3431-3446. https://doi.org/10.5194/hess-15-3431-2011
- Maan (2023). HESS. 27: 2341-2355. https://doi.org/10.5194/hess-27-2341-2023

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SWAP and the future

- Extreme weather conditions on crop development
- Salinization
- Interaction with nutrients
- …
- Focus: applicability for
  - Land evaluation studies
  - Studies on climate impact and possible climate adaptation
  - …

Thank you

Acknowledgement

Em. Prof. Reinder A. Feddes

Joop C. Kroes († 2022)

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