Optimality and Soil Water-Vegetation Dynamics

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Background

- The optimality approach is based on the assumption that vegetation optimises itself to maximise its Net Carbon Profit (the difference between carbon acquired by photosynthesis and carbon spent on maintenance of the organs involved in its uptake).

- Shown to be very useful for predicting above-ground vegetation properties and water use (Schymanski et al. 2007a, b).

Aims

- Test the optimality approach for modelling the below-ground vegetation properties in a tropical savanna (Howard Springs, NT, Australia).

- Formulate a coupled soil moisture and root dynamics model that relates the roots' maintenance costs to their water uptake capacity.

- Compare with the traditional approach using a prescribed fixed root distribution obtained from the literature.

Model Description

- Soil water fluxes modelled using an approximation to Richards' Equation for soil layers of 10 cm thickness.

- Relationship between water uptake capacity and root maintenance costs derived from measurements on citrus roots (Huang & Eissenstat, 2000; Bryla et al., 2001; Eissenstat, 1991).

- Suction force exerted by the roots is a function of the amount of water stored in the plants (Roderick and Canny, 2005).

- Canopy water demand derived from Eddy flux measurements in a tropical savanna (Howard Springs, NT, Australia).

- Stomatal closure occurs if relative plant water store <90%.

- If the water store is drawn down too much, root surface area is increased at the end of the day, otherwise it is decreased.

- In each individual soil layer, changes in root surface area are also dependent on this layer's effectiveness in root water uptake relative to all other soil layers.

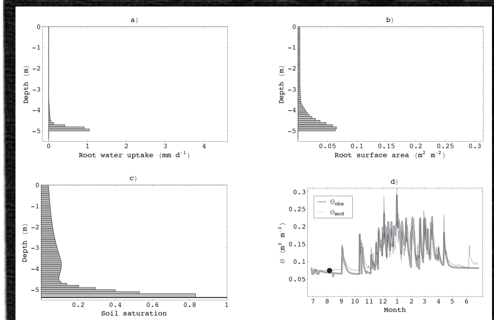

Fig. 1

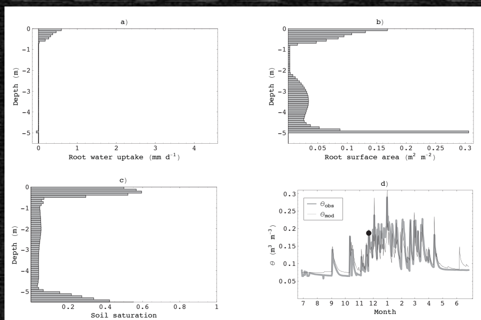

Fig. 2

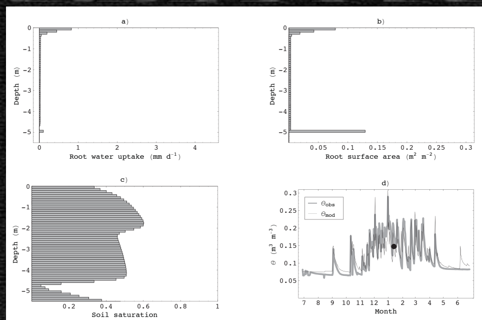

Fig. 3

Figures 1-3: Dynamically optimised root distributions and resulting root water uptake and soil moisture profiles 40, 147 and 200 days after model initialisation. Vertical soil profiles (a-c) show values for each soil layer between the surface and the variable water table. (d) shows midnight snapshots of the observed and modelled soil moisture in the top soil layer for 12 months, with a round dot indicating the position in time of the other three plots. The full animation can be viewed at http://www.bgc-jena.mpg.de/bgc-theory/index. n=Group.Movieoptd.

Results

Optimal Root Dynamics

- Optimised root distribution reflects the direction of water flow (recharge from the bottom during the dry season (Fig. 1) and from the top during the wet season (Figs. 2-3)).

- Simulated annual root water uptake: 1092 mm

- Simulated root respiration rates: 0.1-0.7 μmol CO_2 m^{-2} s

- Daily net water release by roots: <0.06 mm d^{-1} into a single soil layer.

Static Root Distribution

- "Typical" savanna root system: root area index of 43 (Jackson et al., 1997) and exponential decay with depth (Schenk and Jackson, 2002) (Fig. 4b).

- Simulated annual root water uptake: 1055 mm

- Simulated root respiration rate: 10.9 μmol CO_2 m^{-2} s

- Daily net water release by roots: <1.33 mm d^{-1} into a single root layer (Fig. 4).

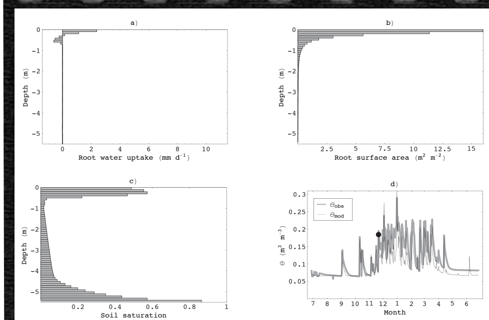

Fig. 4

Figure 4: Fixed root distribution (Panel b) and resulting root water uptake and soil moisture profiles (Panels a and c respecively) 147 days after model initialisation. Negative values in Panel a) denote daily net root water release into a soil layer 10 cm thick.

Conclusions

The optimality-based model...

- came closer to the observed water use of 1118 mm yr^{-1} than the empirical model,

- gave more realistic root respiration rates that never exceeded observed dry season soil respiration rates of 1.5 μmol m^{-2} s^{-1} (Chen et al. 2002),

- allows consideration of below-ground adaptation of vegetation to its environment,

- is independent from prescribed root distributions,

- will be a powerful tool in conjunction with optimality-based above-ground models to simulate the effects of long-term environmental change on vegetation and the water balance.

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