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An optimality-based model of the coupled soil moisture and root dynamics

S. J. Schymanski[1,*], M. Sivapalan[2,**], M. L. Roderick[3], J. Beringer[4], and L. B. Hutley[5]

[1]School of Environmental Systems Engineering, The University of Western Australia, Australia
[2]Centre for Water Research, The University of Western Australia, Australia
[3]Environmental Biology Group, Research School of Biological Sciences and Research School of Earth Sciences, The Australian National University, Canberra, Australia
[4]School of Geography and Environmental Science, Monash University, Australia
[5]School of Science & Primary Industries, Charles Darwin University, Australia
[*]now at: Max Planck Institute for Biogeochemistry, Postfach 10 01 64, 07701 Jena, Germany
[**]now at: Dept. of Geography and Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, USA

Abstract. The main processes determining soil moisture dynamics are infiltration, percolation, evaporation and root water uptake. Modelling soil moisture dynamics therefore requires an interdisciplinary approach that links hydrological, atmospheric and biological processes. Previous approaches treat either root water uptake rates or root distributions and transpiration rates as given, and calculate the soil moisture dynamics based on the theory of flow in unsaturated media. The present study introduces a different approach to linking soil water and vegetation dynamics, based on vegetation optimality. Assuming that plants have evolved mechanisms that minimise costs related to the maintenance of the root system while meeting their demand for water, we develop a model that dynamically adjusts the vertical root distribution in the soil profile to meet this objective. The model was used to compute the soil moisture dynamics, root water uptake and fine root respiration in a tropical savanna over 12 months, and the results were compared with observations at the site and with a model based on a fixed root distribution. The optimality-based model reproduced the main features of the observations such as a shift of roots from the shallow soil in the wet season to the deeper soil in the dry season and substantial root water uptake during the dry season. At the same time, simulated fine root respiration rates never exceeded the upper envelope determined by the observed soil respiration. The model based on a fixed root distribution, in contrast, failed to explain the magnitude of water use during parts of the dry season and largely over-estimated root respiration rates. The observed surface soil moisture dynamics were also better reproduced by the optimality-based model than the model based on a prescribed root distribution. The optimality-based approach has the potential to reduce the number of unknowns in a model (e.g. the vertical root distribution), which makes it a valuable alternative to more empirically-based approaches, especially for simulating possible responses to environmental change.

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