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Comparison of root water uptake modules using either the surface energy balance or potential transpiration

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Abstract

Numerical models simulating changes in soil water content with time rely on accurate estimation of root water uptake. This paper considers two root water uptake modules that have a compensation mechanism allowing for increased root uptake under conditions of water stress. These modules, proposed by Lai and Katul and Li et al. [Adv. Water Resour. 23 (2000) 427 and J. Hydrol. 252 (2001) 189] use potential transpiration weighted, for each soil layer, by a water stress and a compensation function in order to estimate actual transpiration. The first objective of the paper was to assess the accuracy of the proposed root extraction modules against two existing data sets, acquired under dry conditions for a winter wheat and a soybean crop. In order to perform a fair comparison, both modules were included as possible root water extraction modules within the Simple Soil Plant Atmosphere Transfer (SiSPAT) model. In this first set of simulations, actual transpiration was calculated using the solution of the surface energy budget as implemented in the SiSPAT model. Under such conditions, both root extraction modules were able to reproduce accurately the time evolution of soil moisture at various depths, soil water storage and daily evaporation. Results were generally improved when we activated the compensation mechanisms. However, we showed that Lai and Katul [Adv. Water Resour. 23 (2000) 427] module was sensitive to soil hydraulic properties through its water stress function, whereas the Li et al. [J. Hydrol. 252 (2001) 189] module was not very sensitive to the specification of its parameter. The latter module is therefore recommended for inclusion into a larger scale hydrological model, due to its robustness.

When water balance models are run at larger scales or on areas with scarce data, actual transpiration is often calculated using models based on potential transpiration without solving the surface energy balance. The second objective of the paper was to assess the loss of accuracy in such conditions for the Lai and Katul and Li et al. [Adv. Water Resour. 23 (2000) 427 and J. Hydrol. 252 (2001) 189] modules. For this purpose we compared results from the SiSPAT model solving the surface energy balance with those of a degraded version where only potential evapotranspiration was imposed as input data. We found that actual transpiration and evapotranspiration were in general underestimated, especially for the Lai and Katul [Adv. Water Resour. 23 (2000) 427] module, when we used the potential evapotranspiration as calculated from FAO standards. The use of crop coefficients improved the simulation although standard values proposed by the FAO were too small. The definition of

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the potential evapotranspiration was the major source of error in simulating soil moisture and daily evaporation rather than the choice of the root extraction modules or the inclusion of a compensation mechanism. When used for water management studies, a sensitivity to the definition of potential evapotranspiration used to run the models is therefore advisable.

Keywords: Compensation; Root extraction; Water stress; SVAT; Potential evapotranspiration; Energy balance

1. Introduction

In the context of sustainable agriculture and environmental management, there is a need for modelling tools able to assess the influence of management practices, changes in land use and climate on crop yield and/or water resources. In order to be applied over large areas and long temporal sequences, these models need to be simple enough to remain computationally tractable, although keeping enough realism to represent the main physical processes. One of these processes is transpiration by plants, as reviewed by Molz (1981). In the so-called Soil Vegetation Atmosphere Transfer (SVAT) models, transpiration, assumed to be equal to root water uptake, is modelled based on the water—and energy balance approach. In an analogy with Ohm's law, the driving force for water uptake is the water potential gradient between the soil and the leaves, with resistances along the flow path, including a soil resistance, a soil-root resistance, and resistances within the plant. This approach is used, among others by Lynn and Carlson (1990), Daamen and Simmonds (1994), Braud et al. (1995) and De Ridder and Schayes (1997). These models are often used when diurnal information on surface fluxes is required or in the context of remote sensing data assimilation.

A simpler group of SVAT models deals only with the water balance and ignores the vegetation energy balance equation. In the latter models, root water extraction is incorporated as a sink term in the mass conservation equation. Generally, root water uptake from each soil layer is modelled as a function of potential transpiration, vertical root distribution and soil water availability, with or without a water stress function accounting for increased water uptake from deeper, more moist soil layers. The water balance models are easier to use and require less information on root geometry, soil characteristics and weather conditions than the fully comprehensive SVAT models. Their use is consequently favoured in hydrological and management-oriented water simulation models. However, there is a need to assess which type of root extraction module is better suited for inclusion into such less comprehensive models and to quantify the errors associated with their simplifications.

The study focuses on models where root water uptake is represented as a sink term within the soil water transfer equation (for instance Richards (1931) equation), assumed to be proportional to a 'potential' transpiration rate and an effective root distribution function. This approach, pioneered by Feddes et al. (1978) for water balance studies was used in recent studies of crop modelling (e.g. Green and Clothier, 1999; Wu et al., 1999) and chemicals transport (e.g. Vogeler et al., 2001). Limited root water uptake due to soil dryness can be accounted for by a weighting function. Feddes et al. (1978) proposed a module related to soil water potential, accounting for a reduction of transpiration for very wet soil and for drying soils, down to the wilting point. Homaee et al. (2002) recently compared alternative formulations for this reduction function. The root distribution function was originally uniform with depth. Various authors proposed improvements based on linear and non-linear functions, generally decreasing with depth (e.g. Hoogland et al., 1981; Prasad, 1988; Li et al., 1999). In most models, with the exception of the SOIL model (Jansson, 1998), water stress occurring in one layer cannot be compensated through increasing the water uptake from other layers. In recent papers by Lai and Katul (2000) and Li et al. (2001) root uptake modules accounting for compensation between dry and wet layers were proposed. In each of these papers, compensation improved the simulation of soil moisture.

The first objective of this paper was the evaluation of these two modules against measured data sets. We selected two data sets, covering a full growing cycle of a winter wheat crop and a soybean crop, respectively. Both data sets were collected under dry