

available at [www.sciencedirect.com](http://www.sciencedirect.com)journal homepage: [www.elsevier.com/locate/ecolmodel](http://www.elsevier.com/locate/ecolmodel)

# Modeling compensated root water and nutrient uptake

Jiří Šimůnek<sup>a,\*</sup>, Jan W. Hopmans<sup>b</sup>

<sup>a</sup> Department of Environmental Sciences, University of California Riverside, Riverside, CA 92521, USA

<sup>b</sup> Department of Land, Air and Water Resources, 123 Veihmeyer Hall, University of California, Davis, CA 95616, USA

## ARTICLE INFO

### Article history:

Received 30 October 2007

Received in revised form

27 October 2008

Accepted 13 November 2008

Published on line 26 December 2008

### Keywords:

Root water uptake

Nutrient uptake

Compensated uptake

Unsaturated water flow

Numerical model

HYDRUS

## ABSTRACT

Plant root water and nutrient uptake is one of the most important processes in subsurface unsaturated flow and transport modeling, as root uptake controls actual plant evapotranspiration, water recharge and nutrient leaching to the groundwater, and exerts a major influence on predictions of global climate models. In general, unsaturated models describe root uptake relatively simple. For example, root water uptake is mostly uncompensated and nutrient uptake is simulated assuming that all uptake is passive, through the water uptake pathway only. We present a new compensated root water and nutrient uptake model, implemented in HYDRUS. The so-called root adaptability factor represents a threshold value above which reduced root water or nutrient uptake in water- or nutrient-stressed parts of the root zone is fully compensated for by increased uptake in other soil regions that are less stressed. Using a critical value of the water stress index, water uptake compensation is proportional to the water stress response function. Total root nutrient uptake is determined from the total of active and passive nutrient uptake. The partitioning between passive and active uptake is controlled by the a priori defined concentration value  $c_{\max}$ . Passive nutrient uptake is simulated by multiplying root water uptake with the dissolved nutrient concentration, for soil solution concentration values below  $c_{\max}$ . Passive nutrient uptake is thus zero when  $c_{\max}$  is equal to zero. As the active nutrient uptake is obtained from the difference between plant nutrient demand and passive nutrient uptake (using Michaelis–Menten kinetics), the presented model thus implies that reduced passive nutrient uptake is compensated for by active nutrient uptake. In addition, the proposed root uptake model includes compensation for active nutrient uptake, in a similar way as used for root water uptake. The proposed root water and nutrient uptake model is demonstrated by several hypothetical examples, for plants supplied by water due to capillary rise from groundwater and surface drip irrigation.

© 2008 Elsevier B.V. All rights reserved.

## 1. Introduction

Root surfaces represent one of the most important phase boundaries in nature since most mineral nutrients essential for life enter the biosphere and the food chains of the animal world through the roots of higher plants (Nissen,

1991). Similarly, root water and nutrient uptake is one of the most important processes considered in numerical models simulating water content and fluxes in the subsurface, thus controlling water flow (recharge) and nutrient transport (leaching) to the groundwater, and exerting a major influence on predictions of climate change impacts (Feddes and

\* Corresponding author. Tel.: +1 951 827 7854; fax: +1 951 827 7854.

E-mail addresses: [Jiri.Simunek@ucr.edu](mailto:Jiri.Simunek@ucr.edu) (J. Šimůnek), [jwhopmans@ucdavis.edu](mailto:jwhopmans@ucdavis.edu) (J.W. Hopmans).  
0304-3800/\$ – see front matter © 2008 Elsevier B.V. All rights reserved.  
doi:10.1016/j.ecolmodel.2008.11.004

Raats, 2004) on terrestrial ecological systems, driving new research at understanding roots and their functioning (Skaggs and Shouse, 2008).

There are two major approaches generally used for the simulation of root water uptake in vadose zone hydrological models, to be applied at the plot or field scale (Hopmans and Bristow, 2002). Early detailed quantitative studies of water extraction by plant roots were based on a *microscopic* or *mesoscopic* (Feddes and Raats, 2004) approach that considered a single root to be an infinitely long cylinder of uniform radius and water-absorbing properties (Gardner, 1960). Water flow to a root was described using the Richards equation formulated in radial coordinates, with flow into the root driven by water potential gradients between the root and surrounding soil and proportional to the hydraulic conductivity of the soil surrounding the root (Mmolawa and Or, 2000) or the root radial water conductivity parameter (Roose and Fowler, 2004). Recent numerical modeling studies are increasingly applying the integrated plant root–soil domain approach, whereby total plant transpiration is computed from solution of water potential in the combined soil and root domain, solving for both root and soil water potential (e.g., Doussan et al., 2006; Javaux et al., 2008). Several models have been suggested that simulate individual roots and overall plant root architecture (e.g., Clausnitzer and Hopmans, 1994; Kastner-Maresch and Mooney, 1994; Brown et al., 1997; Grant, 1998; Somma et al., 1998; Biondini, 2001). These models often consider specific processes such as biomass allocation to individual roots (e.g., Kastner-Maresch and Mooney, 1994; Grant, 1998; Somma et al., 1998; Biondini, 2001), root growth redirection to areas with high soil nutrient concentrations (e.g., Somma et al., 1998; Biondini, 2001), linking of functioning of microbial ecosystems (Brown et al., 1997) and mycorrhizal growth (Grant, 1998) to spatial structure of roots, or competition of different plant species for nutrients (e.g., Biondini, 2001; Raynaud and Leadley, 2005). In addition to being more realistic in simulating soil–root interactions at the individual rootlet scale, the main advantage of this approach is that it automatically allows for compensation of soil water stress, as root water uptake is controlled by computed local water potential gradients and root conductivity for the whole root system. However, because of the lack of relevant soil and root data and the huge computational requirements for simulation purposes at this microscopic scale, soil water flow models that consider flow to each individual rootlet or plant root architecture have been limited to applications at a relatively small scale of a single plant.

Most vadose zone models that are used at the plot or field scale (e.g., Jarvis, 1994; Flerchinger et al., 1996; van Dam et al., 1997; Fayer, 2000; van den Berg et al., 2002; Šimůnek et al., 2008) utilize the *macroscopic* approach, whereby the potential transpiration is distributed over the root zone proportionally to root density, and is locally reduced depending on soil saturation and salinity status (Molz, 1981). This much more widely used approach (e.g., Feddes et al., 1974; Bouten, 1995) neglects effects of the root geometry and flow pathways around roots, and formulates root water uptake using a *macroscopic* sink term that lumps root water uptake processes into a single term of the governing mass balance equation. A wide variety of root water uptake reduction functions have been suggested, ranging from a simple two-parameter threshold and slope function

(Maas, 1990) or an S-shaped function (van Genuchten, 1987), to more complex functions that can include up to 5 fitting parameters such as suggested by Feddes et al. (1978). We refer readers to the review paper by Feddes and Raats (2004) for more details.

Usually, a *compensation* mechanism to balance reduced water uptake from one part of the rhizosphere by increased uptake in another less-stressed region of the rooting zone, while simulated in microscopic models, is neglected in vadose zone models. There is, however, growing experimental evidence that plants, especially non-cultural plants, can compensate for water stress in one part of the root zone by taking up water from parts of the root zone where water is available (e.g., Taylor and Klepper, 1978; Hasegawa and Yoshida, 1982; English and Raja, 1996; Stikic et al., 2003; Leib et al., 2006). The MACRO model (Jarvis, 1994) is an exception among the more widely used models as it uses a critical value of the water stress index, or root adaptability factor, to allow for compensated root water uptake. This factor represents a threshold value above which root water uptake that is reduced in stressed parts of the root zone is fully compensated for by increased uptake from other parts. Among the research models, in their ENVIRO-GRO model, Pang and Letey (1998) used a similar threshold value to compute partial root water uptake compensation. Similarly, Li et al. (2001) and Bouten (1995) distributed the potential transpiration across the root zone according to a weighted stress index, which was a function of both root distribution and soil water availability or water saturation fraction, respectively. A different approach was used by Adiku et al. (2000), who assumed that plants seek to minimize the total rate of energy expenditure during root water uptake. They formulated the root water uptake problem as a minimization problem and solved it using a dynamic program framework. Their optimized model simulated patterns of water extraction from uniformly wet soil profiles, with highest water extraction rates in the section where the root length density was also highest. For conditions with a dry soil surface, a reduction of root water uptake from the drier near soil surface zone was compensated for by an increased root activity at greater soil depths, irrespective of root distribution. A review of compensatory modeling approaches was recently presented by Skaggs et al. (2006).

Plant nutrient availability and uptake is controlled by both soil transport and plant uptake mechanisms. A detailed description of nutrient uptake is often included in agronomic models that simulate differentiation of plant nutrient demand during various physiological growth stages (e.g., Parton et al., 1987; Jones and Ritchie, 1990). These models, however, typically greatly simplify soil water flow and nutrient transport towards the root–soil interface. In contrast, vadose zone models greatly simplify root nutrient uptake, often considering only its passive component and neglecting plant growth dynamics (e.g., Jarvis, 1994; Flerchinger et al., 1996; van Dam et al., 1997; Fayer, 2000; van den Berg et al., 2002; Šimůnek et al., 2008).

Solute transport in soils occurs by both mass flow and molecular diffusion. In the case of non-adsorbing nutrients, nutrient uptake is controlled mainly by mass flow, as is the case of nitrate-N (e.g., Barber, 1995). In some cases, mass flow of specific nutrients (e.g.,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) may exceed the plant

Download English Version:

<https://daneshyari.com/en/article/4377701>

Download Persian Version:

<https://daneshyari.com/article/4377701>

[Daneshyari.com](https://daneshyari.com)