Measurement of dry-end soil water diffusivity on intact soil cores

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Abstract

For analysis of plant water uptake, particularly in dry environments, knowledge of the soil water diffusivity function, (D(θ)), at low water content is needed. There is limited data on D(θ) from undisturbed soil at low water content. We measured the evaporation from undisturbed soil collected from south eastern Australia, and then modelled the evaporation. The D(θ) used in the model was adjusted until the modelled evaporation matched the experiment. The D(θ) was almost constant, ranging between 7.3x10^{-9} and 7.9x10^{-9}?[m^2/s]. This is roughly 7 to 8 times greater than other minimum values published in the literature for re-packed material. The high value of D(θ) implies that water flow from soil to the root surface is unlikely to limit the extraction of water by plants from the soil.

Key Words

soil-water diffusivity, evaporation,

Introduction

The soil water diffusivity function, (D(θ)), is the product of the hydraulic conductivity, *K*, and the slope of the soil water retention curve at the particular water content, θ, ie $D(\theta) = K(\theta) \times d\psi/d\theta$, where ψ is the soil water potential. For modelling plant water uptake from the soil, D(θ) at low water content must be known. There is limited published data on D(θ) from undisturbed field soil at medium to low soil water contents. The measurement of D(θ) on re-packed soil is more common. The method of Rose (1968) uses evaporation under a turbulent condition, and sections the core before the water content at the non-evaporating end changes, to determine the water content profile. On intact soil, this technique is experimentally difficult as the soil becomes very hard when air dry and difficult to section. Also, the effects of heterogeneity on water holding capacity, even at small scales, limit the reliability of the analysis. The analysis of Passioura (1976) uses outflow data obtained by subjecting the soil sample to a single pneumatic pressure step. Pneumatic pressure is applied to one end of the soil sample, with a uniform initial water content. The outflow is measured at the other end, where it is assumed that the water content is reduced to the final water content at the onset of outflow. This paper describes a simple method to estimate D(θ) on intact material using evaporation. The evaporation is modelled and D(θ) adjusted until the model agrees with the experiment.

Methods

Experimental

Undisturbed soil samples, contained in 3?cm length by 3?cm diameter cylinders, collected from the field (30?cm depth) were allowed to saturate from the base up. The samples were then drained to a matric potential of –1?m, giving the initial water content, θ_i. The base of the core, *x?=?L*, (where *x* is distance and *L* is the length of the core) was then sealed and the top, *x?=?0*, subjected to a controlled, continuous flow of air (nominally 60?L/min, 30-40% relative humidity). Evaporation is measured from the top end, *x?=?0*, where it is assumed that θ, is reduced to the final water content, θ_f, at the onset of evaporation. The experiment continued until the evaporation rate from the core became zero. Neglecting gravity, the diffusion equation for one-dimensional flow of water in a stable soil is equation (1), subject to the conditions in (2), where *D* is diffusivity and *t* is time.

$$\frac{\partial \theta}{\partial t} = \frac{\theta}{\partial x}\left(D(\theta)\frac{\partial \theta}{\partial x} \right) \quad (1)$$

$$\begin{aligned} &\theta = \theta_i, && 0 \le x \le L, && t = 0 \\ &\theta = \theta_f, && x = 0, && t > 0 \\ &\frac{\partial \theta}{\partial x} = 0, && x = L, && t > 0 \end{aligned} \quad (2)$$

In practice, θ_f is not obtained immediately at *x?=?0*, instead the condition is met in the first 7 to 10?min. This is checked by observing, in the early stage of evaporation (<10?min), (1) the steep slope of evaporation with $t^{1/2}$ and (2) the local cooling at *x?=?0*. We found that except for the early stage of evaporation, where the evaporation rate is driven by the evaporative demand, the process is isothermal. This was checked by positioning thermocouples at the evaporating surface and at the base of the core.

Model

A program was written in Qbasic, modified from Campbell (1985), that simulates the evaporation from a one dimensional soil profile. Equation (1) is solved subject to (2) by replacing the spatial and time derivatives by suitable approximations (x_i?=?*iδx*, t_j?=?*jδt*), and numerically solving the resulting difference equations.

$$\frac{\theta_{i,j} - \theta_{i,j+1}}{\partial t} = D_i\left(\frac{\theta_{i+1,j} - 2\theta_{i,j} + \theta_{i-1,j}}{(\partial x)^2} \right) + \left(\frac{D_{i+1,j} - D_{i-1,j}}{2\delta x} \right)\left(\frac{\theta_{i+1,j} - \theta_{i-1,j}}{2\delta x} \right) \quad (3)$$

A constant concentration boundary condition was set at *x?=?0* by fixing *θ?=?*θ_f. A zero flux boundary condition was set at *x?=?L*. The experiment was repeatedly simulated, using the experimental values of θ_i and θ_f, until by modifying D(*θ*) empirically at the completion of a simulation, a suitable agreement between the model and experiment was reached.

Results

The evaporation experiments were described using a D(*θ*) of the form D(*θ*)?=?y?+?a?*?θ (Figure?1). Implying that the D(*θ*) is almost constant over most of the dry end. Figure?1 shows close agreement between evaporation data obtained from a typical experiment and the model. The D(*θ*) range of 7.3×10^{-9} and 7.9×10^{-9}?[m^2/s] is nearly an order of magnitude greater than minimum values of D(*θ*) found in the literature.

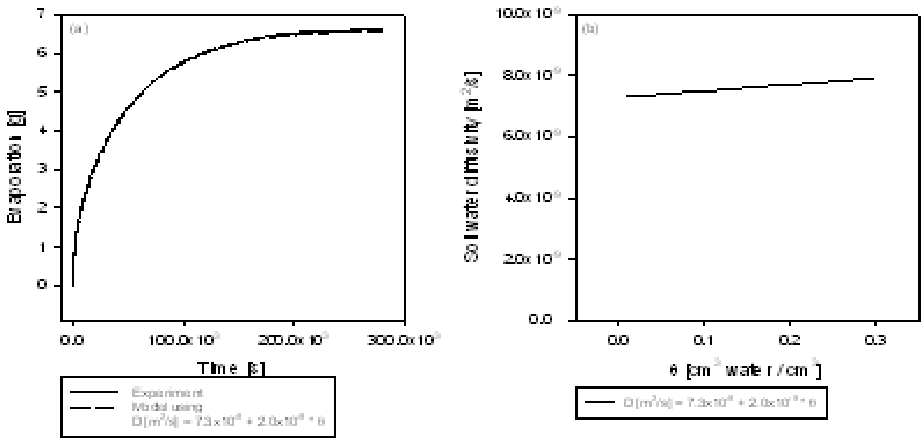

Figure 1. (a) Evaporation with time from an experiment and model. (b) Soil water diffusivity function used to model (a).

Conclusion

The evaporation from intact soil cores was well described when modelled using a D(*θ*) of the form D(*θ*)?=?y?+?a?*?θ. The D(*θ*) ranged between $7.3x10^{-9}$ and $7.9x10^{-9}$?[m^2/s]. This is 7 to 8 times greater than the minimum values of D(*θ*) reported by Rose (1968). The high value of D(*θ*) implies that water flow from the soil to the root surface is unlikely to limit the extraction of water by plants from the soil.

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