ISOTHERMAL AND NONISOTHERMAL EVAPORATION FROM SOIL OF VARYING WATER REPELLENCY

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Introduction

Water repellency has been observed in sand, loam, clay, peat and volcanic ash soils all over the world (Wallis and Horne, 1992; Jaramillo et al., 2000). Soil wettability is known to affect water holding capacity and water flow, but the impact of soil water repellency on evaporation has not been thoroughly investigated. The objectives of this column study were (i) to measure isothermal and nonisothermal moisture flow at the soil surface of four soils having similar particle size distribution but different contact angles, and (ii) to analyze the combined impact of contact angle and temperature on the residual soil water content profiles that arise after the evaporation process in the soil columns, and (iii) to test the ability of a numerical model to describe the observed moisture transport.

Materials and Methods

1. Soils

Four soil materials were used in this study (Table 1). The sampling site for two of the materials was a soil in a former pine plantation, recently since 15 years under agricultural use. The wettability of A horizon at this site varies considerably between slightly water repellent (soil A) and strong natural water repellency (soil A). Soil B was a waterloam sand (subsoil) from a quaternary river deposit with a similar particle size distribution as soils A and A. The fourth material, soil B, was hydrophobized in the laboratory by coating the grain surfaces of soil B with subsamples with 90 ml Dichlorodimethylsilane per kg soil. The degree of repellency of the soils was assessed by a modified sessile drop method (Bachmann et al., 2000).

2. Column setup

For the experiments, 16 closed soil columns (length 700 mm and outside diameter 50 mm) were used (Fig. 1). Soil water content was 0.777 [kg kg⁻¹] for soils A, A, and B and 0.102 [kg kg⁻¹] for B. Eight vertical soil columns (c) of each soil were subjected to isothermal conditions (20 °C), and the other eight columns were buried vertically in a large quartzsand-filled container (base 20 x 40 cm) which was heated at the base. Soil column boundary temperatures were 21 °C (surface) and 55 °C (base). A small cup containing water retention and hydraulic conductivity functions and based further on theoretically calculated

3. Simulation of moisture movement

The nonsteady-state mass balance equation for the water flow may be written as (Nassar and Horton 1997):

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = \nabla \cdot (\mathbf{D} \nabla \psi) - \nabla \cdot \mathbf{q}
\]

Hydraulic properties of all soils were determined independently with separate soil column outflow experiments. The van Genuchten parameters \( \theta_s, \theta_r, \alpha, n, k_s, l \) and \( \theta_r \) were estimated simultaneously for 20°C by using the inverse modeling approach reported by Kool et al. (1988). The vapor flux as calculated with Fick’s law was used as the time-variable boundary condition for moisture flux at the surface of the column. Vapor density, \( \rho_v \) at the soil surface was derived from the soil water potential at this location. The vapor density directly over the saturated salt solution surface was assumed constant throughout the entire experiment. A mean macroscopic path length for the vapor transport was assumed as the mean distance from the soil surface to the liquid surface level of the CaCl₂-solution in the cup (see Fig. 1).

Results and Discussion

1. Evaporation

Evaporation during the initial phase of evaporation (days 1-7) showed little differences for the soils with contact angles smaller than 100°, (3.61 kg m⁻² for soil B, 3.96 kg m⁻² for soil A, and 3.88 kg m⁻² for soil A) but evaporation was lower by about 20 % (3.19 kg m⁻²) for soil B. Total evaporation was considerably greater for nonisothermal conditions compared with isothermal conditions for most soils. However, differences between isothermal and nonisothermal evaporation decreased with increasing repellency. The soil B (contact angle 111°) showed a nonisothermal total evaporation only slightly larger than for isothermal conditions.

2. Moisture transport to the surface

A comparison of the calculated isothermal vapor transport with the observed average moisture flux at the soil surface (days 155-195) led to the conclusion that the water transport in the upper part of the column (0-2 cm) occurred mainly in the liquid phase (Fig. 3). Because of the 5 times larger surface water content of the strongest repellent soil, B, an insufficient moisture flux into the shallow surface zone the column is considered not to be the process that reduced the evaporation rate with increasing contact angle.

3. Predicting evaporation

Modeling the transient evaporation fluxes and the soil column water distributions at the end of the experiment yielded satisfying results for the wettable soil B (Fig. 3). Differences between predicted and measured total evaporation and residual water content became larger with increasing repellency. Variation of the nonisothermal vapor transport coefficient DTV reduced effectively the bias between predicted and observed data of DTV was multiplied by a water content independent factor of 0.35 (Fig. 3). A slightly better approach of the residual water content distribution was obtained for soils A, A, B if the transport coefficient DTV was adjusted by 3.5 * DTV during the entire simulation.

Conclusions

Our experiments showed that under isothermal conditions water repellency decreased the evaporation rate by as much as 25%. The contact angle influenced evaporation rates were different during the entire period of the experiment (195 days), i.e. convergence of the evaporation rates were not observed. Predicted evaporation based on independently measured water retention and hydraulic conductivity functions and based further on theoretically calculated vapor transport coefficients DTV and DTV resulted in an increasing repellency. Constant surface directed thermal gradients enhanced the evaporation rate by a factor of two for the wettable and slightly repellent soil and by a factor of slightly greater than one for the strongly hydrophobic soil. The thermal vapor transport within the soil column became smaller with increasing repellency.

References
