

**Abstract**

In the past few decades, many researchers have studied evaporation from soil columns in the presence of a water table. Several water retention functions have been developed to describe the water flow behavior in the field environment. While most studies involving these functions focus on analysis of water flow and solute transport in variably saturated porous media, there is a limited amount of research to estimate the evaporation rate at bare ground surface for an arbitrary matric potential head. In previous studies, Jury and Horton proposed a method of calculating the evaporation rate above a water table on the basis of the Haverkamp unsaturated and saturated hydraulic conductivity equations and an assumption that the potential evaporation rate is much less than the saturated hydraulic conductivity of the soil. In this study, we developed a new method to estimate the evaporation rate for an arbitrary matric potential head at bare soil surface. We also presented two programs to calculate evaporation rates for a wide range of depths and the fitting parameters of the Haverkamp equation. The results show that the evaporation rates calculated by these solutions fit well with the experimental data and can reproduce the result of potential evaporation rate calculated from previous equations under the special condition of an infinite matric potential head at bare soil surface.

**Equations involved with models**

Haverkamp retention equation (1977)

\[ E_p = \frac{-a \pi h^2}{N \sin(\pi/N)} \]

Jury and Horton (2004) assumed that the relative evaporation rate \( E_p \) is much less than 1, the potential evaporation rate can be calculated as:

\[ E_p = K \]

\[ \frac{E_p}{K} = \left( \frac{1}{N} \right) \sin(\pi/N) \]

Jury and Horton (2004) presented a one-dimensional model to describe water flow from a shallow water table upward to an evaporation surface. The potential evaporation rate can be calculated by Haverkamp retention equation (1977) and Buckingham-Darcy law to vertical flow as:

\[ \frac{E_p}{K} = \left( \frac{1}{N} \right) \sin(\pi/N) \]

\[ E_p = K \]

\[ \frac{E_p}{K} = \left( \frac{1}{N} \right) \sin(\pi/N) \]

**Results for \( E_p \) calculation**

The general evaporation rate can be calculated by Haverkamp retention equation as below:

\[ \sum_{i=1}^{n} \frac{E_p}{K} \left( \frac{1}{N} \right) \sin(\pi/N) = \frac{1}{2} \left( 1 - \frac{1}{2} \right) \]

\[ E_p = \left( \frac{1}{N} \right) \sin(\pi/N) \]

The general evaporation rate can be calculated by Brooks-Corey retention equation as below:

\[ \sum_{i=1}^{n} \frac{E_p}{K} \left( \frac{1}{N} \right) \sin(\pi/N) = \frac{1}{2} \left( 1 - \frac{1}{2} \right) \]

\[ E_p = \left( \frac{1}{N} \right) \sin(\pi/N) \]

**Results (Haverkamp model)**

**Results (Brooks-Corey model)**

**Methods**

We developed several numerical root-searching programs to calculate the equations which transformed by Haverkamp retention equation, Brooks-Corey retention equation and Buckingham-Darcy law function.

**Comparison with HYDRUS-1D**

**Conclusions**

The Haverkamp model, the Brooks-Corey model and HYDRUS-1D have been used to analytically and semi-analytically estimate the steady-state evaporation rate for an arbitrary matric potential head at ground surface within the presence of a water table, as the Haverkamp model and Brooks-Corey model are widely used in analytical study of unsaturated zone. This is different from most previous analytical and semi-analytical studies which usually focused on estimating the potential evaporation rate at ground surface (with infinitely large matric suction at ground surface). In actual field conditions, the surface suction may be affected by the humus climate, in calculating the infinity matric suction assumption, or the actual evaporation rate is much less than the potential evaporation rate.

**References**

