Analysis and Optimization of the Simplified Evaporation Method for Determining Soil Hydraulic Properties

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Introduction

The evaporation method, as originally proposed by Wind (1968) is a robust experimental methodology to obtain hydraulic properties of soils. In the simplified method by Schindler (1980), the temporal changes of the weight of a soil sample and of the pressure heads in two depths are recorded during the evaporation of water from a soil sample. Contrary to parameter estimation by inverse modeling of the Richards equation, the water flux densities and the temporal and spatial distributions of pressure head and water content are linearized. This results in a simple and stable data evaluation routine, and gives a series of points of the soil moisture characteristic and the hydraulic conductivity function. Parametric functions can be fitted to these data points in order to obtain closed-form functions of the soil hydraulic properties. Here, we analyze the errors of the method, and to optimize it with respect to minimize the errors. Furthermore, we quantify the errors and uncertainties of the results in their dependence on the measurement resolution, both with respect to measurement precision and temporal resolution.

Theory and Method

Basic Equations:

\[ \frac{\theta(h)}{\Delta h} = \frac{q}{\Delta h / \Delta z + 1} \]

\[ K(h) = \frac{1}{\Delta h - \theta(h)} \int \theta(h) \, dh \]  

(Fig. 1: Temporal development of pressure head and column weight. The interpolated data are used in the subsequent numerical data analysis)

\[ \Delta \theta = \int \theta(h) \, dh \]  

Linearization error by large \( \Delta z \):

\[ \sigma_\theta (\Delta h) = \sqrt{\sigma_\theta / \Delta z} \]

Solution: reject all \( K(h) \) data for \( \Delta h < 4 \sigma_\theta (\Delta h) \) (Fig. 2)

\[ h = \frac{\theta(h)}{\Delta h} - \frac{\theta(h)}{\Delta h} \]  

(Fig. 3: True \( K(h) \) function (red) and data points from a Monte Carlo simulation of the evaporation experiment with loam. Black: accepted data; gray: rejected data.)

\[ \sigma_\theta = \frac{\theta(h)}{\Delta h} \]

Solution: Interpolate with Hermitian Splines (Fig. 1)

Test result: Interpolate with Hermitian Splines (Fig. 1)

Line of best fit: Interpolate with Hermitian Splines (Fig. 1)

Results

Fig. 5: Pressure head and water content distribution in a sand column a different stages of the evaporation process.

- In the first phase of the experiment, the pressure head distribution is quasi linear (Fig. 5). This means that the integral fit of the retention function (Peters and Durner, 2006) leads to an unbiased determination. In the second phase of the experiment the pressure head becomes non-linear, but surprisingly this does not cause a significant error in the calculated retention and conductivity data.

- If Hermitian splines are used to interpolate the measured data, a temporal resolution of one measurement per day is sufficient for sandy and loamy soils. For clay soils and for structured soils, measurements in higher temporal resolution are required.

- Offset errors in the tensiometer calibration that lead to an overestimation of the hydraulic gradient (Offset = -1 cm) cause significant underestimation of \( K(h) \) (Fig. 6) in the moist range. An underestimation of \( \gamma_{\text{radil}} \), on the other hand, just narrows the moisture range where valid \( K(h) \) data are obtained, but bias in the data is negligible (Fig. 3). Errors in tensiometer positioning have moderate effects on the estimation of the function in the dry range (see Peters and Durner, 2008, for details).

- The evaporation method gives no information about the \( K(h) \) function near saturation (Fig. 3 and 6).

Conclusion

The simplified evaporation method as designed by Schindler (1980) in combination with the advanced evaluation by Peters and Durner (2008) (temporal interpolation of the measured data by Hermitian splines; consideration of the mean water content as the integral of local water content distribution; intelligent filtering of the calculated \( K(h) \) data near saturation) is a robust and accurate method to obtain hydraulic properties of soils, despite the underlying linearization assumptions. Retention and conductivity data are identified with very small errors.

Using the software package HYDRUS-1D, we simulated numerically evaporation experiments for a variety of soil hydraulic properties. Furthermore, we investigated the influence of errors in positioning the tensiometers and errors in the calibration of the tensiometers, as they occur in practice (Fig. 4). From the simulations results, ‘measured’ data were extracted with different temporal resolutions. The data were interpolated as shown in Fig. 1, and evaluated. Finally, we fitted hydraulic functions to the resulting data points \( \theta(h) \) and \( K(h) \) and compared those to the true functions.

If coupled with a robust fitting procedure for the hydraulic functions, the evaporation method is a procedure that is suitable for everyday analyses of soil hydraulic properties of soil samples in laboratories. At low operation expense, it yields precisely determined hydraulic functions. Further details, which go beyond the scope of this leaflet are found in Peters and Durner (2008).

The experimental setup (hardware) and the evaluation software are commercially available under the product name HYPROP by UMS Munich.

Literature


