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A Software to Calculate Soil Hydraulic Conductivity from Internal Drainage Experiments

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NOTE

A SOFTWARE TO CALCULATE SOIL HYDRAULIC CONDUCTIVITY FROM INTERNAL DRAINAGE EXPERIMENTS (SHC, VERSION 2.00)[1]

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ABSTRACT

A software for the calculation of unsaturated soil hydraulic conductivity $K(\theta)$ is presented for commonly used methods found in the literature, based on field experiments in which a soil profile is submitted to water infiltration followed by internal drainage.

Index terms: soil hydraulic conductivity, internal drainage, soil water content, water infiltration.

RESUMO: PROGRAMA PARA O CÁLCULO DA CONDUTIVIDADE HIDRÁULICA DO SOLO ATRAVÉS DE EXPERIMENTOS DE DRENAGEM INTERNA

É apresentado um programa para o cálculo da condutividade hidráulica do solo não saturado $K(\theta)$ para métodos da literatura mais utilizados, baseados em experimentos de campo nos quais o perfil de solo é submetido à infiltração de água, seguida da drenagem interna.

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(1) missing title or information related to software

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Termos de indexação: condutividade hidráulica do solo, drenagem interna, umidade do solo, infiltração de água.

INTRODUCTION

The history of soil internal drainage description started with Richards, who first studied the physical processes determining water loss from field soils by drainage (Richards et al, 1956). After this, we had the pioneer contributions of Nielsen et al (1964), Rose et al (1965) and Watson (1966). This latter named the procedure for calculating hydraulic conductivity as “the instantaneous profile method”. After that decade when several contributions were made from field measurements (e.g., van Bavel et al, 1968; La Rue et al, 1968; Davidson et al, 1969), Hillel et al (1972) published a procedure to calculate soil hydraulic conductivity *in situ*.

Somewhat later, several simple methods were published (Chong et al, 1981; Libardi et al, 1980; Sisson et al, 1980). Most of them were based on the assumption that a unit soil hydraulic gradient existed during the drainage process (Reichardt, 1993). Several others also made contributions – Jones and Wagenet (1984) compared different methods; Bacchi (1988) improved Hillel’s method with improved calculations of the derivatives; Reichardt et al (2004) made equation (1) easier to evaluate by introducing regression parameters to obtain $K(\theta)$; and Hurtado et al (2005) gave more attention to $K(\theta)$ when the soil had drained to drier conditions.

In order to facilitate the establishment of $K(\theta)$ relations by the instantaneous profile method, we present a software to perform the calculations, based on field data collected during internal drainage experiments, using the methods of Hillel et al (1972), Libardi et al (1980), Bacchi (1988), and Reichardt et al (2004).

MATERIAL AND METHODS

Input data for the software consist of matric soil water potential (*h*, cm of water) and soil water content (θ, cm^3.cm^{-3}) data collected during soil internal drainage. To obtain these data, a soil profile is initially submitted to infiltration. After a steady-state water flux density at the soil surface is achieved, the internal drainage process starts at a time (t = 0) when the supply of water is interrupted and the soil surface is covered with a plastic sheet to avoid evaporation. For several days and perhaps weeks, if necessary, measurements of $h(z, t)$ and $\theta\,(z, t)$ where z (cm) is the depth below soil surface and t (day) the drainage time. For these experimental conditions, the integration of Richards' equation leads to the expression used for the determination of the soil hydraulic conductivity $K(\theta)$ relation at any chosen depth $z = L$

$$K(\theta)_L = \frac{-\int_0^L \left[\frac{\partial\theta(z,t)}{\partial t}\right] dz}{\left[\frac{\partial H(z,t)}{\partial z}\right]_L} \tag{1}$$

where H =($h + z$) is the total hydraulic head (cm of water).

<u>Hillel et al (1972) Method</u>: These authors used equation (1) making calculations by finite differences. At that time, because computation tools were not as developed as they are today, they estimated $\partial\theta / \partial t$ graphically, point by point, from graphs of $\theta(z,t)$. Thereafter, they calculated $(\partial\theta / \partial t)\Delta z$ for each depth increment. They evaluated the numerator of equation (1) by summing these values $\Sigma(\partial\theta/\partial t)\Delta z$ to depth L. The gradients in the denominator of equation (1) were also calculated graphically, point by point, from graphs of $H(z, t)$. The parameters of the $K(\theta)$ relation were obtained from a semi-log plot of K for each depth L versus θ. They suggested the relation

$$K(\theta) = \alpha \exp(\beta\,\theta) \tag{2}$$

<u>Libardi et al (1980) Method</u>: These authors used equation (1) assuming that i) $K(\theta)$ is of the form:

$$K(\theta) = K_0 \exp[\beta(\theta - \theta_0)] \tag{3}$$

where K_0 and θ_0 are the values of K and θ at t = 0, respectively; ii) that the total hydraulic gradient $\partial H / \partial z$ is unity for all times; and iii) that the average θ^* in the profile ($0 \le z \le L$) is linearly related to the value of θ at depth L:

$$\theta^* = a\theta + b \tag{4}$$

Using the last assumption,

$$\int_0^z \left(\frac{\partial \theta}{\partial t}\right) dz = z\left(\frac{\partial \theta^*}{\partial t}\right) \approx az\frac{\partial \theta}{\partial t} \tag{5}$$

equation (1) is approximated by

$$-az\frac{\partial \theta}{\partial t} = K_0 \exp[\beta(\theta - \theta_0)]\,. \tag{6}$$

Integrating equation (6) from ($t = 0$, $\theta = \theta_0$) to ($t = t$, $\theta = \theta$) yields:

$$(\theta_0 - \theta) = \frac{1}{\beta}\ln t + \frac{1}{\beta}\ln\left(\frac{\beta K_0}{a z}\right) \tag{7}$$

The constant a is obtained from a regression of measured values of θ^* versus measured values of θ. With θ_0 being measured directly in the field, the parameters K_0 and β are obtained from a regression of $(\theta_0 - \theta)$ versus ln t.

Bacchi (1988) Method: This author improved the calculation of the derivatives proposed by Hillel et al. (1972). For $\partial\theta / \partial t$ he simply took the derivative of the regression equation of θ versus ln t. And because H is generally linearly related to z, he obtained $\partial H / \partial z$ from the derivative of the linear regression equation between H and z. He was aware that $\partial H / \partial z$ had the same value for all depths and varied only in time. He suggested $K(\theta)$ relations described by equations (2) and (3).

Reichardt et al (2004) Method: These authors parameterized Equation (1) by fitting measured values of $\theta(z,t)$ and $h(z, t)$ data for each chosen depth $z = L$ to the following logarithmic models:

$$\theta_L(t) = a + b\ln t \tag{8}$$

$$S_L(t) = c + d\ln t \tag{9}$$

$$H_L(t) = e + f\ln t \tag{10}$$

where S_L (cm) is the soil water storage for the layer $0 \le z \le L$. When the fitting of the experimental data to equations (8), (9) and (10) was significant, equation (1) was parameterized as follows:

$$K(\theta)_L = \left\{ \frac{-d\exp\frac{1}{b}(a-\theta_0)\cdot\exp\left[-\frac{1}{b}(\theta-\theta_0)\right]}{e' + \frac{f'}{b}(\theta - a)} \right\} \qquad (11)$$

where $e' = (e_1 - e_2)/2\Delta z$, $f' = (f_1 - f_2)/2\Delta z$ and e_1, e_2, f_1 and f_2 are the coefficients of equation (10) for the regressions of $H(t)$ at depths $(L + \Delta z)$ and $(L - \Delta z)$. Equation (11) is of the form of equation (3) with K_0 being a function of θ. Equations (3) and (11) are identical only when $e' = 1$, $f' = 0$ and the hydraulic gradient is unity.

RESULT

The output of the software are the parameters of equations (2) and (3): α, β, K_0 and θ_0 for the methods of Hillel et al. (1972), Libardi et al. (1980) and Bacchi (1998). For the method of Reichardt et al. (2004), the output are the parameters of equation (11): *a*, *b*, *d*, *e'*, *f'* and θ_0.

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