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An assessment of the Beerkan method for determining the hydraulic properties of a sandy loam soil

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ABSTRACT

Establishing the ability of the Beerkan Estimation of Soil Transfer parameters (BEST) procedure to reproduce soil properties is necessary for specific soil types. In this investigation, the BEST predictions for a sandy loam soil were compared with water retention data obtained by a standard laboratory method and with the saturated soil hydraulic conductivity, K_s, obtained by both the Wu et al. (1999) method, applied to the BEST infiltration data, and the Simplified Falling Head (SFH) technique. When the original BEST-slope algorithm with the infiltration constants fixed at $\beta = 1.9$ and $\gamma = 0.79$ was applied, the agreement between the predicted and the measured retention data was satisfactory in terms of similarity of the means and correlation and coincidence between the regression and identity lines. The prediction of K_s at a sampling point differed by not more than a factor of two from the K_s value obtained by the Wu et al. (1999) method. The SFH technique yielded K_s values approximately five times higher than those of BEST, probably because soil disturbance during water application, swelling and air entrapment phenomena had a lower impact on the measured infiltration data with the former technique. In conclusion, BEST is a promising approach for easily characterizing a soil, but its method of application should be adapted to the particular situation under consideration. Additional investigations carried out on different soils would allow development of more general procedures for applying BEST.

1. Introduction

The hydraulic characteristic curves, i.e., the relationships between soil water pressure head, h, volumetric water content, θ, and hydraulic conductivity, K, are generally determined with laboratory and field methods of differing accuracy and experimental effort. The availability of different methods should allow researchers to choose the most appropriate technique for interpreting and simulating a particular hydrological process occurring in a given soil. However, there is also the need to simplify experimental procedures, especially because the economic resources for soil hydraulic characterization are often scarce.

Lassabatère et al. (2006) proposed the Beerkan Estimation of Soil Transfer parameters (BEST) procedure to easily and rapidly estimate the (h) and $K(\theta)$ curves. BEST uses an infiltration experiment in the field with a zero pressure head on a circular soil surface and a few basic soil physical determinations (particle size distribution (PSD), bulk density, and initial and final water content). BEST focuses on the van Genuchten (1980) relationship for the water retention curve with the Burdine (1953) condition and the Brooks and Corey (1964) relationship for hydraulic conductivity. Due to its simplicity and the physical soundness of the employed relationships and procedures, BEST is receiving increased attention from the scientific community. For example, Mubarak et al. (2009a,b) used the method to characterize temporal variability of soil hydraulic properties and to explore the effects of the detected variability on the simulated water transfer processes. Mubarak et al. (2010) reviewed the soil hydraulic properties at a field site after several years of repeated agricultural practices. Lassabatère et al. (2010) established the effect of sediment accumulation on the water infiltration capacity of two urban infiltration basins. Gonzalez-Sosa et al. (2010) determined the spatial variability of the soil hydraulic properties in a small watershed. The unsaturated hydraulic properties of basin oxygen furnace slag were determined by Yilmaz et al. (2010). BEST was the only usable method in areas where more traditional hydraulic characterization methods were technically and economically unaffordable (Bagarello et al., 2011). Investigations specifically focused on BEST procedures were also carried out, including the estimation of the water retention shape parameter (Minasny and McBratney, 2007), the fitting accuracy of the BEST PSD model to the data (Bagarello et al., 2009), the algorithm to analyze the infiltration data (Bagarello et al., 2014c; Yilmaz et al., 2010), the constraint on the duration of the infiltration run (Bagarello et al., 2011), the applicability of the procedure in initially wet soil conditions (Xu et al., 2012), the suitability of the BEST procedures to predict the soil water retention curve (Bagarello and Iovino, 2012), and the role of tortuosity and infiltration constants on the results obtained by the Beerkan method (Nasta et al., 2012).

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However, only a few comparisons of the predicted soil properties with independent measurements, i.e., with soil data collected by other experimental methods, are found in the literature. This gap in the literature is notable, given the importance of establishing whether the simplified method is a practical alternative to more cumbersome and time-consuming methods. For example, field and laboratory measurements of saturated soil hydraulic conductivity, K_s, were generically found to be of the same order of magnitude in the investigation by Yilmaz et al. (2010). In a recent investigation conducted by Bagarello et al. (2014b) at 10 Sicilian sites sampled at the near point scale (i.e., a few square meters at each site), satisfactory predictions of the measured water retention were associated with a particular applicative methodology of the BEST procedure, including a short infiltration run (i.e., pouring for 11 times 800 mL of water on the soil surface confined by a 0.30-m-diameter ring), a shape parameter of the water retention curve estimated on the basis of sand and clay content (Minasny and McBratney, 2007), and a saturated soil water content set at 93% of the estimated porosity. Plausible K_s values were also obtained, but the unsaturated soil hydraulic conductivity was higher than that measured with the tension infiltrometer method. Therefore, the signs of a promising ability of the BEST procedure to yield a reasonably reliable soil hydraulic characterization can be found, but these signs are not enough to arrive at general conclusions. There is still work to do, including more comparisons between predicted and measured soil data for specific soils, considering that i) real soils can differ appreciably from the idealized porous media considered by BEST due to, for example, the presence of macropores in field situations, and ii) Nasta et al. (2012) recently suggested that the proper calibration of the infiltration constants as a function of the soil type should be expected to significantly improve the soil hydraulic parameters estimated by BEST.

The objective of this investigation was to test the applicability of the BEST procedure in a sandy loam soil supporting a young orange orchard in eastern Sicily. To this end, the predicted soil hydraulic parameters were used to establish a comparison with laboratory measured water retention data. A comparison was also carried out in terms of saturated soil hydraulic conductivity obtained with two approaches to analyze the BEST infiltration run and also with the Simplified Falling Head measurement technique by Bagarello et al. (2004).

2. Materials and methods

The study site is located at the experimental farm of the Sicilian Citrus Research Centre (37°20′ N; 14°53′ E) in eastern Sicily, Italy. The climate of the area is semi-arid Mediterranean, with a mean annual air temperature of 17 °C and a rainfall close to 600 mm in 1990–2012. The area, covered by immature orange orchards (6-year-old plants), is rectangular and fairly flat and extends for approximately 0.7 ha (72×98 m^2). It was divided into regular grids, each having a 18×32 m^2 area, where undisturbed soil cores (0.05 m in height and 0.05 m in diameter) were collected at 0–0.05 m and 0.05–0.10 m depths for a total of 32 sampling points and 64 soil samples. The undisturbed soil cores were used to determine the soil bulk density, ρ_b (Mg m^{-3}) and the initial water content, θ_i (m^3 m^{-3}), i.e., the θ value at the time of the field campaign. A total of 32 disturbed soil samples were also collected at 0–0.05 m depth to determine the soil textural characteristics using conventional methods following H_2O_2 pre-treatment to eliminate organic matter and clay deflocculation using sodium metaphosphate and mechanical agitation (Gee and Bauder, 1986). Three textural fractions according to the USDA standards, i.e., clay (0–2 μm), silt (2–50 μm) and sand (50–2000 μm), were used in the study to characterize the soil (Gee and Bauder, 1986) (Table 1). Most soil textures (i.e., 27 out of 32) were sandy loam, and the remaining textures were loamy sand. The organic carbon content, *OC* (%), was determined with the Walkley–Black method (Nelson and Sommers, 1996).

An undisturbed soil sample was collected from the soil surface layer (0–0.05 m depth) at each sampling location (sample size, $N = 32$), using stainless steel cylinders with an inner volume of 10^{-4} m^3 to determine the soil water retention curve. For each sample, the volumetric soil water content at 11 pressure heads, h, was determined by a sandbox ($h = -0.01, -0.025, -0.1, -0.32, -0.63, -1.0$ m) and a pressure plate apparatus ($h = -3, -10, -30, -60, -150$ m). For each sample, the parameters of the van Genuchten (1980, vG) model for the water retention curve with the Burdine (1953) condition were determined by fitting the following relationship to the data:

Table 1
Clay, *cl*, silt, *si* (2–50 μm), and sand, *sa*, percentages, dry soil bulk density, ρ_b, and organic carbon content, *OC*, at the field experimental site (sample size, $N = 32$ for *cl*, *si*, *sa* and *OC*, and $N = 64$ for ρ_b).

Variable	Mean	Coefficient of variation (%)
cl (%)	10.4	7.6
si (%)	19.9	3.8
sa (%)	69.7	5.8
ρ_b (Mg m^{-3})	1.25	6.2
OC (%)	1.25	21.8

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + \left(\frac{h}{h_g}\right)^n\right]^{-m} \tag{1a}$$

$$m = 1 - \frac{2}{n} \tag{1b}$$

where θ (L^3 L^{-3}) is the volumetric soil water content, h (L) is the soil water pressure head, n (>2) and m are shape parameters, and h_g (L), θ_s (L^3 L^{-3}, field saturated soil water content), and θ_r (L^3 L^{-3}, residual soil water content) are scale parameters. The fitting was performed by an iterative nonlinear regression procedure, which finds the values of the optimized parameters by minimizing the sum of the squared residuals between the model and the data. This procedure was applied using the SOLVER routine of Microsoft Excel software (Microsoft Company, Redmond, WA, USA). According to the BEST procedure, θ_r was set equal to zero. To evaluate the fitting performance of the vG model to the measured water retention data, the relative error, *Er* (%), was calculated for each sampling point using the following relationship (Lassabatère et al., 2006):

$$Er = 100 \times \sqrt{\frac{\sum_{i=1}^{q}\left(\theta_{m,i} - \theta_{vG,i}\right)^2}{\sum_{i=1}^{q}\left(\theta_{m,i}\right)^2}} \tag{2}$$

where $\theta_{m,i}$ denotes the experimental data, i.e., the measured soil water content at a given pressure head, $\theta_{vG,i}$ is the corresponding modeled soil water content, and q is the number of the (h, θ) data pairs. According to Bagarello and Iovino (2012), $Er \leq 5\%$ can be assumed to be indicative of a satisfactory fitting ability of the model. The residuals, $\Delta\theta_i$, were also calculated by the following relationship:

$$\Delta\theta_i = \theta_{vG,i} - \theta_{m,i}. \tag{3}$$

For a given pressure head, a good prediction of soil water content would have a mean residual, $Me(\Delta\theta_i)$, close to zero, while positive values indicate overestimation and negative values indicate underestimation. The standard deviation of the residuals, $\sigma(\Delta\theta_i)$, measures the accuracy of prediction, representing the expected magnitude of the error (Minasny and McBratney, 2007). A linear regression analysis of θ_{vG} against θ_m was also carried out. Residual calculation and linear regression analysis were carried out by selecting the six pressure heads