



An assessment of the BEST procedure to estimate the soil water retention curve: A comparison with the evaporation method

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ABSTRACT

The Beerkan Estimation of Soil Transfer parameters (BEST) procedure is an attractive, easy, robust, and inexpensive way for a complete soil hydraulic characterization but testing the ability of this procedure to estimate the water retention curve is necessary as relatively little information is available in the literature. In this investigation the soil water retention curve was predicted for four differently textured soils by applying three existing BEST algorithms (i.e., slope, intercept and steady) and the results compared with those measured by the standard Wind evaporation method. A sensitivity analysis of the infiltration constants, β and γ , was also carried out and their impact on the estimated retention curve scale parameter, h_g , was evaluated. BEST-slope underestimated the soil water retention for three of the four soils under consideration, providing relatively low root mean squared differences between estimated and measured data ($0.0261 \text{ cm}^3\text{cm}^{-3} \leq \text{RMSD} \leq 0.0483 \text{ cm}^3\text{cm}^{-3}$). For one site (PAL, sandy-loam soil), BEST-steady provided the lowest RMSD value ($0.0893 \text{ cm}^3\text{cm}^{-3}$) among the considered algorithms, but the water retention was systematically overestimated as a consequence of a relatively higher difference between field and lab saturated soil water contents. A specific calibration performed for β and γ highlighted that: i) the water retention estimations by BEST-slope were more sensitive to β than those obtained by BEST-intercept and BEST-steady; ii) with the exception of PAL soil, the lowest RMSD values were obtained with BEST-slope. Estimation of the soil water retention curve was not significantly worse when reference values of infiltration constants ($\beta = 0.6$ and $\gamma = 0.75$) were used as detected by negligible differences in RMSDs as compared to calibrated β and γ . Therefore, it was concluded that the BEST-slope algorithm yielded predictions of water retention closer to the laboratory estimated ones than the alternative BEST algorithms (i.e. BEST-intercept and -steady). For these algorithms, the less accurate estimates of the water retention data were attributed to h_g overestimations due to the independence of the retention curve scale parameter from γ .

1. Introduction

The water retention curve describes the soil's ability to store or release water and its determination is important in many fields, such as the agro-environmental modeling (Ventrella et al., 2012; Pirastru et al., 2017), soil physical quality assessment (Castellini et al., 2013, 2014; Iovino et al., 2016) and soil use impact evaluation on the physical and hydraulic properties (Pirastru et al., 2014; Francaviglia et al., 2015; Castellini et al., 2015, 2016; Ferrara et al., 2017).

The Beerkan Estimation of Soil Transfer (BEST) parameters procedure developed by Lassabatère et al. (2006) allows for the simultaneous determination of both the water retention curve, i.e. the relationship between volumetric water content, θ , and pressure head, h , and the

hydraulic conductivity function, i.e. the relationship between the soil hydraulic conductivity, K , and θ (or h). In particular, BEST is based on the analytical infiltration model proposed by Haverkamp et al. (1994) and, provided that $\theta(h)$ and $K(\theta)$ are expressed by given empirical relationships, it estimates the unknown parameters from a pedotransfer function and a simple field infiltration test conducted under ponded conditions. The van Genuchten (1980) relationship with the condition of Burdine (1953) is used for the water retention curve and the Brooks and Corey (1964) relationship for hydraulic conductivity function. Alternative algorithms were developed to analyze field infiltration data, i.e., BEST-slope (Lassabatère et al., 2006), BEST-intercept (Yilmaz et al., 2010) and BEST-steady (Bagarello et al., 2014c). Moreover, BEST was tested in different soils and compared with several alternative field and

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laboratory methodologies highlighting the pros and cons of the method. Many authors pointed out that BEST is a promising, easy, robust, and inexpensive way of characterizing soil hydraulic behavior (Alagna et al., 2016a; Bagarello et al., 2014a; Bagarello et al., 2014b; Castellini et al., 2016; Di Prima, 2015; Di Prima et al., 2016; Gonzalez-Sosa et al., 2010; Mubarak et al., 2010). For instance, Gonzalez-Sosa et al. (2010) used the BEST method to study the spatial variability of soil hydraulic properties (including retention curve) linked to pedology and land use within a 7 km² catchment. These authors showed the importance of an accurate determination of saturated water content to get reliable description of soil hydraulic properties over the whole range of water content suggesting that soil texture alone might not be sufficient to properly map the variability of soil hydraulic properties. Bagarello and Iovino (2012) specifically focused on the reliability of the BEST procedure to estimate the water retention shape index (Haverkamp et al., 2005). Considering a large dataset of Sicilian soils, the laboratory determined water retention shape index did not coincide with the estimated one according to BEST, particularly in soils with a clay content lower than 10%. However, estimation of water retention shape index depends only on the soil particle size distribution, whereas the influence of soil structure on water retention curve is accounted for by the saturated volumetric soil water content (θ_s) and the scale parameter (h_g). With BEST, these soil properties are estimated from, respectively, soil bulk density and saturated hydraulic conductivity and sorptivity. As a consequence, a thorough assessment of the water retention estimations obtained by BEST needs comparison with independently collected $\theta(h)$ data. In the few investigations specifically conducted at this aim, direct measurements of the soil water retention curve were obtained by the evaporation method (Siltecho et al., 2015) or by a combination of the sand-box or the hanging water column apparatus and the pressure plate apparatus (Aiello et al., 2014; Bagarello et al., 2014b; Alagna et al., 2016b). Evaporation method (Wind, 1968) is a widespread laboratory technique for measuring the soil hydraulic properties (Bruckler et al., 2002; Schindler et al., 2010; Pirastru et al., 2014). Volumetric soil water content and tensions measured at multiple depths during an evaporation process allow simultaneous computation of $\theta(h)$ and $K(\theta)$ (Halbertsma, 1996). Evaporation method has been subject to several experimental validations (Simunek et al., 1998; Romano and Santini, 1999) and improvements (Wendroth et al., 1993; Schelle et al., 2011) and it is considered a reference method for evaluating alternative soil water retention estimation techniques (Siltecho et al., 2015).

Another aspect deserving further investigations is the role of the infiltration constants, β and γ , on the soil water retention estimates conducted by BEST. In particular, for the specific case of a sandy loam soil, Aiello et al. (2014) reported a good correspondence with the experimental water retention data only when the original BEST-slope algorithm was applied with specifically calibrated infiltration constants, β and γ . The constant β is defined as an “integral” shape parameter (Haverkamp et al., 1994) and is expected to increase for finer soils (Lassabatère et al., 2009). The constant γ accounts for geometrical correction of the infiltration front shape, i.e. a scaling factor between 3-D and 1-D cumulative infiltrations (Lassabatère et al., 2009), which depends on the geometry of the infiltration source (Warrick et al., 2007; Warrick and Lazarovitch, 2007). Haverkamp et al. (1994) initially proposed an averaged value of 0.75 for γ and 0.6 for β . Later, Haverkamp et al. (1999, 2005) considered these constants as dependent on the soil type (Lassabatère et al., 2009). Lower values of γ parameter are expected for medium textured soils (loam, silty-loam) and larger values for coarser soils (sand) and finer soils (clay) (Warrick and Lazarovitch, 2007). Lassabatère et al. (2009) proposed optimized values of the β and γ as a function of the soil type (see Lassabatère et al., 2009; Table 4). Nasta et al. (2012) first investigated the role of the infiltration constants in their feasible range for real experimental data (a loamy and two sandy soils), concluding that a proper calibration of these two constants, as a function of the soil type, could significantly improve the soil hydraulic parameters estimated by BEST. Aiello et al.

(2014) suggested that water retention data estimated with BEST-slope were more sensitive to β than to γ , thus concluding that calibration is particularly important for β . However, to our knowledge, a sensitivity analysis based on an adequate number of experimental tests conducted on different soils with the aim to detect the variability of the scale parameter, h_g , as a function of β and γ was not yet conducted.

Therefore, further investigations are needed considering that: i) few comparisons of BEST with standard methods are available in literature; ii) the infiltration constants are not known a priori (Nasta et al., 2012) and correct values of β and γ need to be implemented into the BEST algorithm to avoid erroneous estimations of soil hydraulic characteristics (Lassabatère et al., 2009); iii) there is not in the scientific literature any exhaustive testing of the relative performances of the three existing BEST algorithms with regards to the estimation of the water retention curve.

The objectives of this investigation were to test the applicability of the BEST procedure to estimate the water retention curve in four contrasting real soils and to analyze the impact of β and γ on the estimates of h_g conducted by the three existing BEST algorithms. To this end, a sensitivity analysis of the infiltration constants was carried out. The predicted water retention curves were compared with laboratory measured water retention data obtained by the evaporation method.

2. Theory

The BEST method was applied to calculate the soil hydraulic parameters of the van Genuchten (1980) water retention curve with the Burdine (1953) condition:

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

$$m = 1 - \frac{2}{n} \quad (1b)$$

where h (L), is the water pressure head, h_g (L) is the van Genuchten scale parameter, θ_r (L³L⁻³) is the residual soil water content (θ_r is assumed to be zero in BEST), and m and n are water retention shape parameters. In BEST, n and m are estimated from the analysis of the particle size distribution (PSD) with the pedotransfer function included in the procedure. Structure dependent scale parameters are estimated by a three-dimensional (3D) field infiltration experiment at zero pressure head, using the two-term transient infiltration equation by Haverkamp et al. (1994). Specifically, the 3D cumulative infiltration, I (L), and the infiltration rate, i (L T⁻¹), can be approached by the following explicit transient [Eqs.(2a) and (2b)] and steady-state [Eqs.(2c) and (2d)] expansions (Haverkamp et al., 1994; Lassabatère et al., 2006):

$$I(t) = S\sqrt{t} + (AS^2 + BK_s)t \quad (2a)$$

$$i(t) = \frac{S}{2\sqrt{t}} + (AS^2 + BK_s) \quad (2b)$$

$$I_{+\infty}(t) = (AS^2 + K_s)t + C\frac{S^2}{K_s} \quad (2c)$$

$$i_s = AS^2 + K_s \quad (2d)$$

where i_s (L T⁻¹) is the steady-state infiltration rate, A (L⁻¹), B and C are constants defined taking into account initial conditions as (Haverkamp et al., 1994):

$$A = \frac{\gamma}{r(\theta_s - \theta_0)} \quad (3a)$$

$$B = \frac{2 - \beta}{3} \left[1 - \left(\frac{\theta_0}{\theta_s} \right)^\gamma \right] + \left(\frac{\theta_0}{\theta_s} \right)^\gamma \quad (3b)$$

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