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Estimating the macroscopic capillary length using steady state infiltration

Simone Di Prima[1,2], Ryan D. Stewart[3], Mirko Castellini[4], Vincenzo Bagarello[5], Majdi R. Abou Najm[6], Mario Pirastru[1], Filippo Giadrossich[1], Massimo Iovino[5], Rafael Angulo-Jaramillo[2], and Laurent Lassabatere[2]

[1]Department of Agricultural Sciences, University of Sassari, Viale Italia, 39, 07100 Sassari, Italy
[2]Univ. Lyon, Univ. Claude Bernard Lyon 1, CNRS, ENTPE, UMR5023 LEHNA, F-69518, Vaulx-en-Velin, France
[3]School of Plant and Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, United State
[4]Council for Agricultural Research and Economics-Agriculture and Environment Research Center (CREA-AA), Via Celso Ulpiani 5, 70125 Bari, Italy
[5]Department of Agricultural, Food and Forest Sciences, University of Palermo, Palermo, Italy
[6]Department of Land, Air and Water Resources, University of California, Davis, CA 95616, United States

Abstract: The macroscopic capillary length is a critical parameter for the modeling of infiltration in single-ring experiments. Current methods to quantify this parameter either require multiple infiltration experiments, thus increasing effort and potential for error, or laboratory characterization that does not reflect field condition. We propose a simple field method for the estimation of the macroscopic capillary length, λ_c, from Beerkan runs (single-ring infiltration experiment with measurements of initial and saturated soil water contents). In the proposed method, we use the final portion of the cumulative infiltration, corresponding to the steady state of the water infiltration, to develop a reliable predictor of λ_c. The proposed model was validated using analytically generated data from a wide range of conditions and types of soils. The analytical validation demonstrated the reliability of the proposed λ_c estimates for different soil textures and initial soil water contents. Altogether, the proposed method constitutes a simple solution for estimating λ_c, and it can improve our ability to estimate K_s in the field.

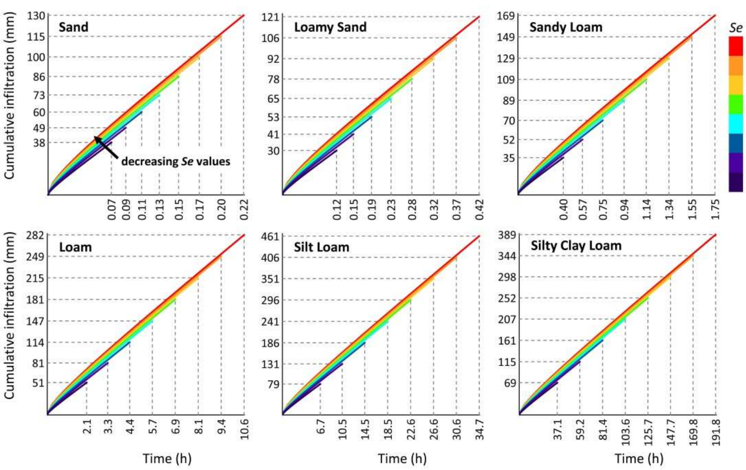

Figure 1. Cumulative infiltration curves for different soils and initial effective saturation degrees, *Se*. The labels in ordinate and abscissa report respectively the total infiltrated water and the duration of the infiltration process. Note that the duration was fixed at three times the maximum time (t_{max}) for which the explicit transient infiltration model proposed by Haverkamp et al. (19994) is valid.

Material and methods

Analytically generated data: We assessed the accuracy of the proposed calculation approach for λ_c and K_s by using six soils: sand, loamy sand, sandy loam, loam, silt loam, silty clay loam. We modelled the infiltration experiments for these synthetic soils using the infiltration model proposed by Smettem et al. (1994) and Haverkamp et al. (1990) (**Figure 1**). We estimated the reference macroscopic capillary length, λ_c, for each combination of soil type and value of the initial effective saturation degrees, *Se*. Relative error, *Er*, was then calculated for each estimated value for $\hat{\lambda}_c$ and $\hat{K}_s$ compared to the corresponding reference value (i.e., λ_c and K_s). The estimates were deemed accurate for $Er \leq 25\%$.

Estimating K_s: K_s values were estimated by four λ_c-dependent methods:

- the One-Ponding Depth (**OPD**) method by Reynolds and Elrick (1990)
- Method 2 by Wu et al. (1999) (**WU2**)
- the Steady version of the Simplified method based on a Beerkan Infiltration run (**SSBI**) by Bagarello et al. (2017)
- Approach 4 (**A4**) by Stewart and Abou Najm (2018).

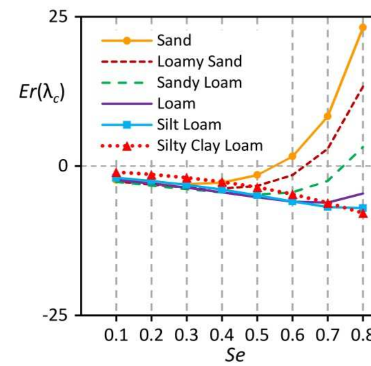

Figure 2. Relative error, $Er(\lambda_c)$, of the estimated macroscopic capillary length compared to reference values for six synthetic soils.

Results

Analytical validation: Relative error, $Er(\lambda_c)$, between estimated $\hat{\lambda}_c$ and reference λ_c values ranged from -7.9 to 23.3%, indicating that all λ_c values were accurate based on our stated criterion (**Figure 2**). $Er(K_s)$ ranged from -9.5 to 3.1% for OPD, from -5.4 to 7.4% for WU2, from 2.2 to 24.7% for SSBI, and from -14 to -2.4 % for A4 (**Figure 3**). The four methods always yielded accurate estimates, since $|Er(K_s)|$ values were always < 25%. Mean $|Er(K_s)|$ values were ordered as OPD < A4 < WU2 < SSBI, showing that the OPD method yielded the lower $|Er(K_s)|$ values.

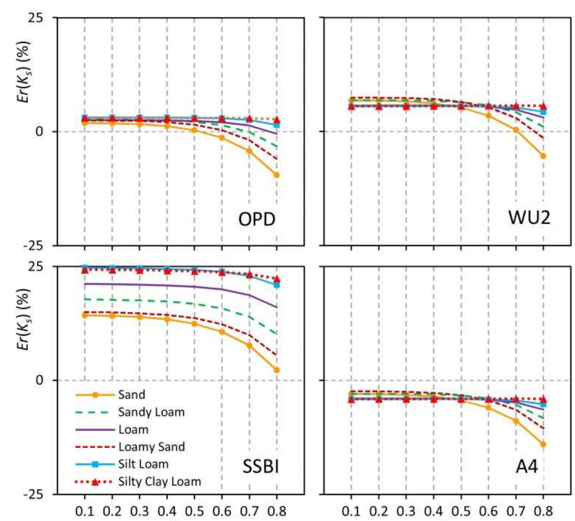

Figure 3. Relative error of the estimated values for saturated soil hydraulic conductivity, Er(Ks), for six synthetic soils that were analyzed using four different methods. OPD = one-ponding depth; WU2 = Method 2; SSBI = Steady version of the Simplified method based on a Beerkan Infiltration run; A4 = Approach 4.

Conclusions

In this investigation, we assessed a simple field method for estimating the macroscopic capillary length, λc, by only using a single-ring infiltration experiment of the Beerkan type and a measurement of the initial and saturated soil water contents. This method constitutes an easy solution to estimate λ_c, and it can allow the user to generate better K_s estimates based on field measurements. The proposed method may also avoid uncertainty due to an imprecise description of the transient state of infiltration, and any subjectivity caused by the selection of a representative λ_c value on the sole basis of textural and structural characteristics.

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