Determining hydraulic properties of a loam soil by alternative infiltrometer techniques

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INTRODUCTION

Field infiltrometer techniques are becoming very popular for soil hydraulic characterization because the experiments are relatively easy, rapid and inexpensive. Loam soils generally exhibit a good balance between large and small pores, thus movement and retention of water is almost optimal. Hydraulic characterization of loam soils is important since they have high economic interest.

OBJECTIVES

1) Validation of the soil hydraulic properties obtained by the Beerkan Estimation of Soil Transfer parameters (BEST) procedure

The BEST procedure is receiving increasing attention by the scientific community due to its simplicity and the physical soundness of the employed relationships and techniques. However, only a few comparisons of the predicted soil properties with data collected by other experimental methods can be found in the literature (Yilmaz et al., 2010; Aiello et al., 2014; Bagarello et al., 2014).

The water retention and hydraulic conductivity predicted by the BEST procedure were compared with water retention data collected by standard laboratory techniques and saturated and unsaturated hydraulic conductivity estimated by independent infiltration experiments.

2) Comparison of six infiltrometer techniques to determine the saturated soil hydraulic conductivity K_s

Among the soil hydraulic properties, K_s is particularly important since it controls many soil hydrological processes such as water infiltration. Comparing methodologically similar techniques allows to better establish what kind of information is contained in a measurement of K_s carried out with a particular method. Many infiltrometer methods have been developed over time for measurement of K_s and much is known about these methods. However, there are still poorly understood issues like, for example, the usability of the Tension Infiltrometer (TI) for K_s determination, or the relative performance of the Mini-Disk Infiltrometer (MDI), that is a particular type of TI. The performances of BEST in comparison with other infiltrometer methods to determine K_s are also largely unknown.

FIELD SITE

Field experiments were carried out in a loam soil (*cl* = 24.9%, *si* = 37.4%, *sa* = 37.7%) at randomly selected sites within a nearly flat 150 m^2 area, with a spontaneous herbaceous vegetation. Gravimetric soil water content, *w*, and dry soil bulk density, ρ_b, were periodically checked during the period from May to October 2013 in order to perform infiltration tests under similar initial soil water content and bulk density conditions.

INFILTROMETER TECHNIQUES

<u>*Beerkan Estimation of Soil Transfer parameters (BEST)*</u>

BEST was developed to estimate the whole set of parameters for water retention and hydraulic conductivity curves in the form of van Genuchten-Mualem model with the Burdine condition and $\theta_r = 0$. Shape parameters (*n*, *m* and η) are deduced from particle size distribution using specific pedotransfer functions; K_s and scale parameter h_g are derived from the analysis of a Beerkan infiltration.

Three algorithms BEST-slope (BSL), BEST-intercept (BIN) and BEST-steady (BST) were used to analyze the Beerkan experiment.

<u>*Pressure infiltrometer (PI)*</u>

Two-Ponding-Depth (TPD) approach (Reynolds and Elrick, 1990) to estimate of both K_s and the so-called α^* parameter.

<u>*Tension infiltrometer (TI1)*</u>

Multi-potential TI runs to estimate the soil hydraulic conductivity at pressure heads of -10 (K_{10}), -30 (K_{30}), -60 (K_{60}) and -120 mm (K_{120}).

<u>*Tension infiltrometer (TI2)*</u>

One-potential (h_0 = 0) experiments analyzed by the BEST-steady algorithm to estimate K_s.

<u>*Minidisk infiltrometer (MDI)*</u>

Estimation of K_s by one-potential experiment (h_0 = 0) and BEST-steady algorithm.

<u>*Simplified falling head (SFH)*</u>

Infiltration time of a single volume of water equal to the porosity of the soil confined by the ring (diameter *D* = 0.15 m, depth of insertion *L* = 0.12 m).

<u>*Bottomless bucket (BB)*</u>

Time required for the water level, inside a ring (*D* = 0.15 m, *L* = 0,02 m) to move from 0.1 m to 0.02 m until the rate of decline of the falling head was nearly constant.

METHODS

1) Testing BEST against independent soil data

Independent measurements of water retention were obtained by the hanging water column apparatus at high pressure heads ($h \geq$ -1.5 m) and the pressure plate apparatus at low potential ($h \leq$ -3 m) (Dane and Hopmans, 2002). The vG model was fitted to the mean (θ, *h*) data pairs with both θ_s equal to porosity (ϕ) and fitted to measured values (fit).

The K_s and *K* data predicted by BEST were compared with independent data collected in the field by the PI and the multi-potential TI experiments.

2) Comparing methods to determine K_s

The BEST-ϕ algorithm was considered for the aim of comparison among independent K_s data obtained with different techniques and procedures. The Tukey Honestly Significant Difference test was applied to compare the six datasets of K_s values obtained by the selected techniques.

RESULTS AND CONCLUSION

1) Testing BEST against independent soil data

The vG model fitted well to the laboratory data (coefficient of determination, R^2 = 0.973; relative error, E_r = 4.2%) (Figure 1). The fitted saturated soil water content (θ = 0.3996 m^{3}m^{-3}) was only 76% of the calculated porosity (ϕ = 0.5280 m^{3}m^{-3}) but this result was considered plausible according to the literature.

The three algorithms (BSL, BIN and BST) applied with the same θ_s value (ϕ or fitted value) showed similar performances in predicting the water retention values (Table 1). When θ_s was set at the fitted value, the linear regression line between predicted and experimental θ values did not differ from the identity line. Therefore, the choice of θ_s was more important than the applied algorithm to reproduce the laboratory measured θ values.

Table 1

Predictive approach	Regression coefficients			95% confidence intervals		Relative error (%)
	Intercept	Slope	R^2	Intercept	Slope	
BSL-ϕ	0.0029	1.2619	0.9752	-0.05 – 0.05	1.10 – 1.43	27.6
BIN-ϕ and BST-ϕ	-0.0276	1.2522	0.9588	-0.09 – 0.04	1.04 – 1.46	18.2
BSL-fit	0.0278	0.9325	0.9791	-0.01 – 0.06	0.82 – 1.04	4.5
BIN-fit and BST-fit	-0.0127	0.9701	0.9660	-0.06 – 0.03	0.82 – 1.12	8.4

The K_s values obtained with BEST and the PI were similar regardless of the applied algorithm (Table 2). The highest similarity between the PI and BEST estimates of K_s was detected with the BIN-fit algorithm but the BST-ϕ algorithm yielded practically equivalent results.

With the exception of the BSL-fit algorithm, the BEST procedures yielded plausible K_s values, i.e., greater than K_{10} (Figure 2).

The *K* values were always higher with BEST than the TI1 (Figure 3) and the differences ranged up to a factor of 35 for $h \leq$ -30 mm but were considerably smaller (i.e., by a factor of 1.2-3.0), for the highest pressure head (*h* = -10 mm).

Table 2

Method	PI	BSL-ϕ	BIN-ϕ	BST-ϕ	BSL-fit	BIN-fit	BST-fit
Sample size	10	9	10	10	7	10	10
Mean	97.6a,b,c,d,e,f	56.2a	133.8b	111.5c	35.1d	99.5e	82.5f
CV (%)	113.4	185.9	113.0	114.3	235.5	111.8	113.9

Conclusion 1

The BIN-fit and the BST-ϕ algorithms performed best among the tested ones for the following reasons: i) relatively good prediction of laboratory measured water retention values; ii) almost perfect correspondence with K_s measured with the PI; iii) plausible K_s values; and iv) ability to reproduce the TI-measured unsaturated soil hydraulic conductivity, but only close to saturation. The BSL-fit algorithm allowed to improve water retention prediction but it was not a good choice for soil hydraulic conductivity prediction.

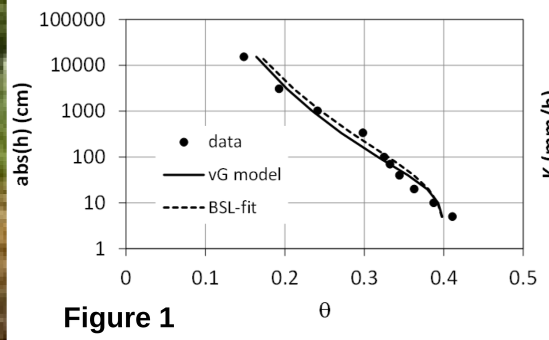

Figure 1

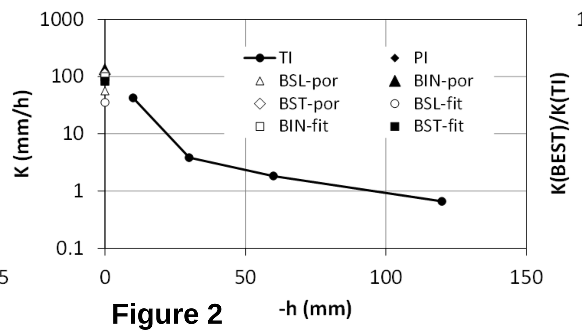

Figure 2

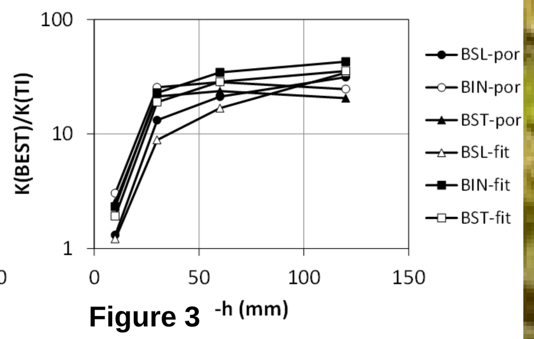

Figure 3

2) Comparing methods to determine K_s

The means of K_s varied within a relatively narrow range (i.e., by a factor of not more than 2.9) and were not statistically significant (Table 3). However, measured K_s was highest for the TI2 and the MDI methods, intermediate for the SFH technique and lowest for the BB, BEST and PI methods thus detecting a different probability of the selected methods to alter the infiltration surface during the run.

Table 3

Method	TI2	MDI	SFH	BB	BEST	PI
Sample size	7	20	10	10	10	10
Mean K_s (mm h^{-1})	284.3	236.9	170.9	131.6	111.5	97.6
CV (%)	95.3	36.1	122.1	98.7	114.3	113.4

The MDI showed an appreciably lower variability of the K_s data as compared with the other methods. A smaller soil volume was found to be more homogeneous than a larger volume and, as a practical implication, a larger ring or disc was more appropriate to represent field soil heterogeneity. Moreover, a source having a diameter of 0.15-0.24 m was enough to give a representation of soil variability because experiments with sources of this size yielded similar *CV* values.

Conclusions 2

The six considered infiltrometer methods yielded statistically similar estimates of K_s for the sampled area thus indicating that the applied measurement technique had a reduced impact on K_s determination.

However, the methods were not perfectly equivalent probably of the different levels of soil disturbance at the infiltration surface during the run. The TI, MDI and SFH data should be considered more appropriate to characterize the soil before wetting by a rainfall event. The BEST, BB and PI data seem more appropriate to characterize a soil at some later stage during a rainfall event.

OPERATIONAL REMARKS

Sampling the soil at the end of the Beerkan run to obtain an experimental value of θ_s may yield a more reliable estimation of soil hydraulic properties by the BEST procedure.

This investigation suggested that soil stability upon wetting influences the relative performances of the considered infiltrometer methods to determine K_s. This suggestion could be further tested by replicating the experiment in a more stable (or unstable) soil than the loam soil of this investigation.

Another point deserving consideration is an improved representation of the unsaturated soil hydraulic conductivity function in the BEST procedure.

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