Determining soil hydraulic properties using γ- ray attenuation in an evaporation experiment

Quirijn de Jong van Lier [qdjvlier@usp.br]
Everton Alves Rodrigues Pinheiro

Soil Physics Lab, Center for Nuclear Energy in Agriculture - CENA/University of São Paulo, Brazil

Introduction and Objective

The ability of a soil to provide transpirable water to plants under dry conditions is crucial in the establishment and maintenance of rainfed crops. Hydraulic properties determine this ability. A popular laboratory method for determining retention and conductivity properties of soil samples is the evaporation method as proposed by Wind (1968), Schindler (1980) and Wendroth et al. (1993), among others. The method is interesting given its relative simplicity and small data demand and is normally performed with tensiometers as measuring devices. Common tensiometers measure within a pressure head range between 0 and -9 m, imposing limitations on the applicability of the method for root water uptake models dealing with drier conditions. We aimed to measure soil hydraulic properties by inverse modeling of evaporating samples monitored using a γ-ray beam and detector.

Materials and Methods

Soil samples

Undisturbed soil samples were taken at three locations near the city of Piracicaba, São Paulo State, Brazil (approximate coordinates 22 °S and 48 °W) in metal rings 7 cm high and 7.4 cm diameter. Two depths were sampled, 0-15 cm and 30-45 cm. Soils varied in texture from Sandy Loam (>80% sand) to Clay (>60% clay). More detailed texture data are in ***Table 1***.

Soil ID	depth (cm)	Sand%	Silt%	Clay%	Texture class
A	0-15	84	3	14	Sandy Loam
	30-45	84	1	15	
B	0-15	20	17	63	Clay
	30-45	22	12	65	
C	0-15	18	13	69	Clay
	30-45	14	11	75	

***Table 1** – Soil texture data for the three sampled soils*

Evaporation monitoring

Samples were slowly saturated from bottom to top and subsequently the excess water was allowed to drain for one or two hours. After that, the bottom was sealed with a plastic cap whereas water was allowed to evaporate freely from the upper surface. Readings were performed for about two weeks, one reading per day at the beginning and one reading per two days near the end, until samples reached a very low water content. Each reading consisted of weighing to determine the average evaporation rate over the previous period, immediately followed by the measurement of attenuation of a collimated γ-ray, produced by a ^{137}Cs source (***Figure 1***) at five depths below the sample surface: 1, 1.5, 2, 3.5 and 5 cm. Samples were finally oven dried and one last reading was performed to determine the attenuated reading of the dry sample. Water contents corresponding to attenuated readings were calculated using Beer´s law. Five samples were analyzed per soil layer.

***Figure 1** – Experimental setup showing a soil sample and γ-ray collimator*

Data processing – Inverse modeling

Observations from the evaporation experiments (water contents per depth and over time) were used as objective function to determine Van Genuchten-Mualem parameters for water retention and conductivity using the inverse modeling option available in the Hydrus-1D software, using no internal weighting, measured evaporation rates as time-variable upper-boundary and a constant zero-flux at the lower boundary.

Results and Discussion

Observed evaporation rates were homogeneous among the five replicas of each soil layer. Average values are shown in ***Figure 2***, starting at 2-4 mm d^{-1} with the expected decrease over time, reaching very low values (< 0.5 mm d^{-1}) after 10 to 15 days.

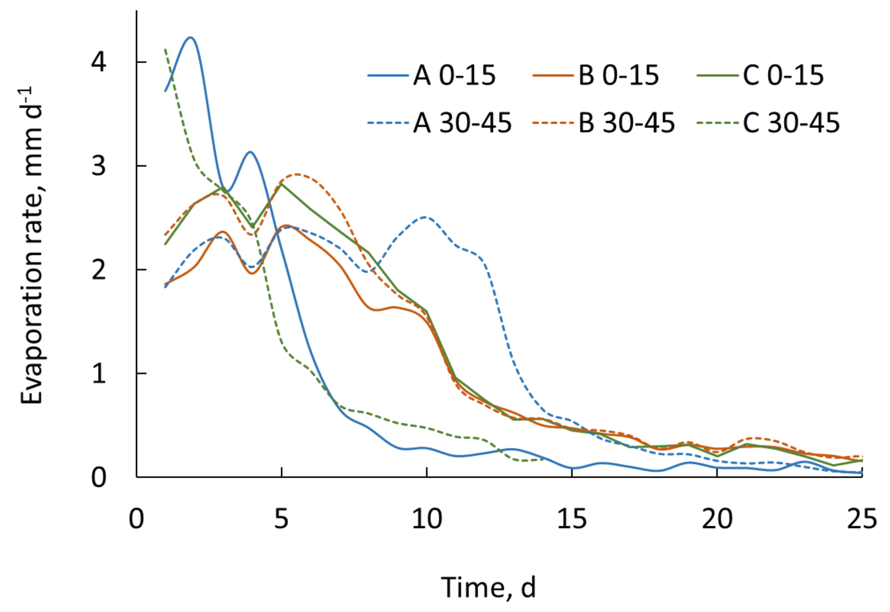

***Figure 2** – Observed evaporation rates for the six evaluated soil layers, average values of five replicas*

The inverse modeling optimization of hydraulic parameters (results in ***Table 2***) yielded good fits of model predictions to the observed water contents at the five depths below the sample surface over the entire time range (an example in ***Figure 3***). This indicates that results may be considered reliable over the evaluated water content range, from nearly saturated to very dry conditions.

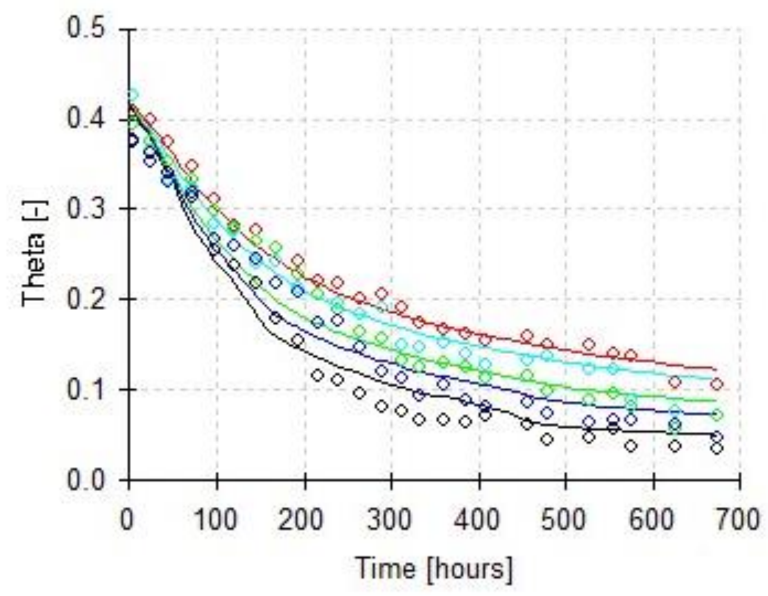

***Figure 3** – Example of observed water contents at the 5 monitored depths (1, 1.5, 2, 3.5 and 5 cm) over time and inverse modeling fitted lines for one of the samples from soil B, 0-15 cm.*

Soil ID	depth (cm)	α (m^{-1})	n	θ_r	θ_s	K_s (m d^{-1})	l
A	0-15	0.639	1.598	0.012	0.332	0.142	0.216
	30-45	15.399	1.732	0.011	0.365	1.665	0.000
B	0-15	4.513	1.569	0.000	0.398	0.018	0.175
	30-45	3.256	1.488	0.005	0.416	0.034	0.115
C	0-15	1.898	1.400	0.000	0.385	0.040	0.085
	30-45	6.726	1.460	0.000	0.397	0.068	0.288

***Table 2** – Van Genuchten – Mualem parameters for both layers of the three sampled soils*

When analyzing individual samples, results appeared to be reasonably similar among replicates. Examples of retention and conductivity functions determined for each sample versus the average are shown in ***Figure 4***.

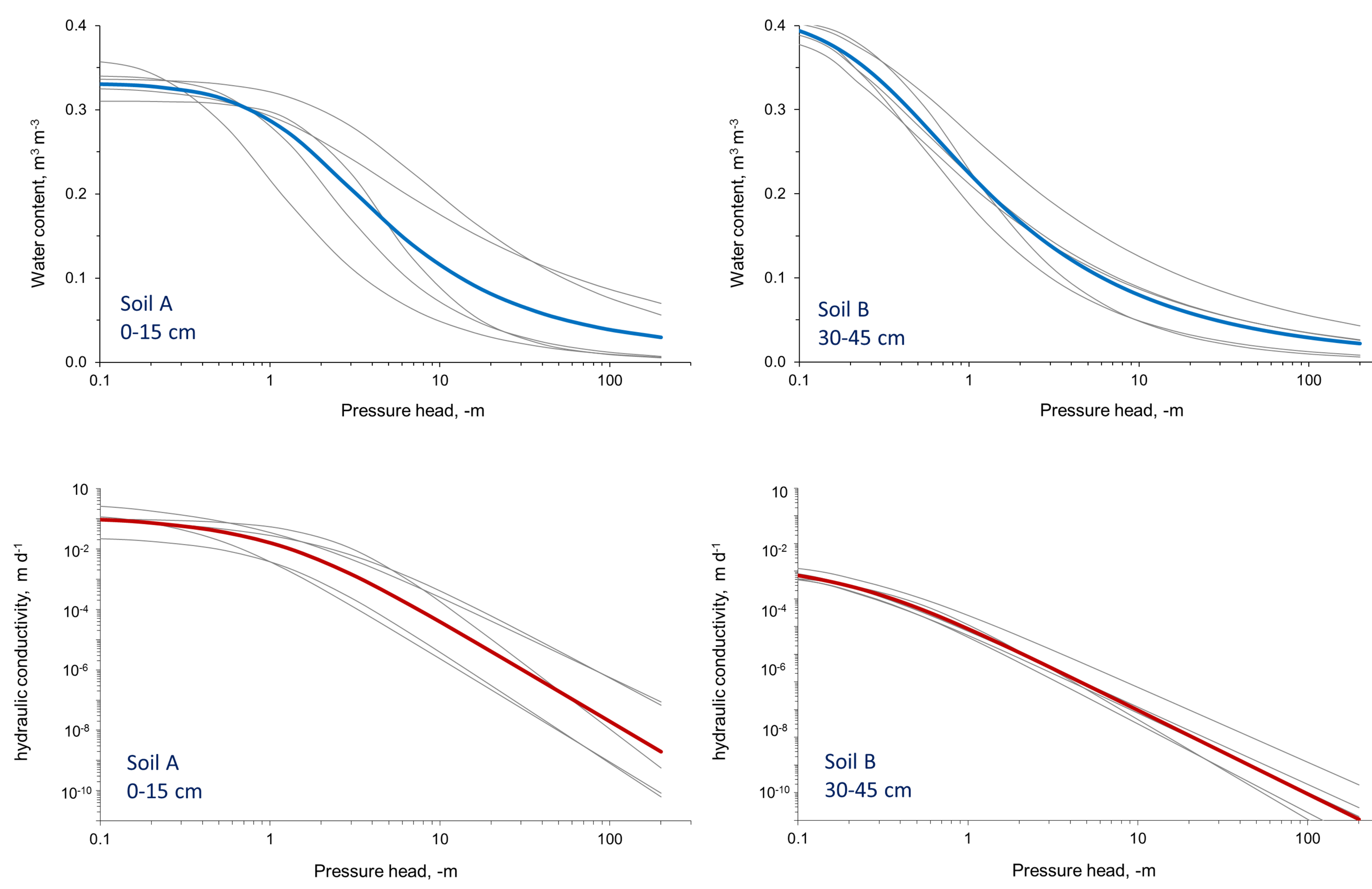

***Figure 4** – Retention and conductivity functions for two of the analyzed soil layers; thick colored line is the average curve for all samples, thin grey lines represent the curves obtained for each of the five individual samples.*

Conclusions

1. The proposed methodology using inverse modeling of evaporation experiments monitored by γ–ray attenuation measurements allowed determining soil hydraulic properties (retention and conductivity) over the entire range of water contents with a good reproducibility;
2. The method is especially interesting for the assessment of dry-soil hydraulic conductivity, important to quantify and model crop water availability.

Cited literature

Schindler, U. 1980. Ein Schnellverfahren zur Messung der Wasserleitfähigkeit im teilgesättigten Boden an Stechzylinderproben. Arch. Acker-u. Pflanzenbau u. Bodenkd. Berlin 24:1–7.

Wendroth, O., W. Ehlers, J.W. Hopmans, H. Klage, J. Halbertsma, and J.H.M. Wösten. 1993. Reevaluation of the evaporation method for determining hydraulic functions in unsaturated soils. Soil Sci. Soc. Am. J. 57:1436–1443.

Wind, G.P. 1968. Capillary conductivity data estimated by a simple method. In: Rijtema, P.E., Wassink, H. (Eds.), Water in the Unsaturated Zone, vol. 1. Proceedings of the Wageningen Symposium, 19–23 June 1968. Int. Assoc. Sci. Hydrol. Publ. (IASH), Gentbrugge, The Netherlands and UNESCO, Paris.

cena 1966 2016 50 anos
USP Universidade de São Paulo
FAPESP SÃO PAULO RESEARCH FOUNDATION