Predicting Soil Hydraulic Properties from Particle Size Distribution and X-Ray Tomography.

Yann Periard (1), Silvio José Gumiere (1), Alain N. Rousseau (2), Dennis W. Hallema (1), and Jean Caron (1)
yann.periard-larrivee.1@ulaval.ca
(1) Université Laval, Faculté des sciences de l’agriculture et de l’alimentation, Département des sols et de génie agroalimentaire, Québec, Canada, (2) Institut national de la recherche scientifique : Centre Eau Terre Environnement (INRS-ETE), Québec, Canada, QC

Session: Revisiting the Most Important Curve in Soil Physics: II
Poster Number 1401

Introduction
- Knowledge about soil hydraulic properties are fundamental
- Characterization of these properties is very time-consuming
- Requires many sample manipulations
- Advances in the field of tomography imagery allow for the characterization of a number of soil hydraulic properties (Wildenschild and Sheppard, 2013)
- The use of the µCT-scan is limited to very small sample (<10 cm³), which is inappropriate to study a representative volume of soil (soil profiles).

Objective
- The main objective of this work is to propose a framework to predict soil hydraulic properties from the combination of particle size distribution with X-ray tomography of a porous media.

Materials & Methods
1. Soils characterization
   - Soil sample contained in a 15-cm long, 5-cm wide cylinder
   - Unconsolidated Ottawa sand
   - Curves of water retention and hydraulic conductivity obtained using the instantaneous profile method
2. Particle distribution
   - Particle size distribution = LA950v2 Laser Particle Size Analyzer (Horiba)
   - nth moment
     \[ m_n = \exp(\mu_n + \frac{\sigma^2}{2}) \]
   - Cumulative mass fraction
     \[ M(R) = \int \left[ \frac{1}{2} \ln(1+\mu_n + \sigma^2) \right] dR \]
   - \( \mu_n \) = mean of ln R
   - \( \sigma_n \) = standard deviation of ln R
   - \( W \) = weighting factor for the nth subdistribution

3. Derivation of soil hydraulic properties
   - Carnahan–Starling approximation of void nearest-surface complementary cumulative density function (Chan and Govindaraju, 2004)
   \[ e_n(\delta) = (1-\eta) \exp\left[-\eta S \left( a_0 \left( \frac{\delta}{m_0} \right)^{a_1 \left( \frac{\delta}{m_0} \right)^2} + a_1 \left( \frac{\delta}{m_0} \right) + a_2 \right) \right] \]
   \[ a_0 = m_1^2 - m_3 \eta (1-\eta) + \frac{4\eta S}{a_2} \frac{m_1^2 - 3m_3\eta}{(1-\eta)} \]
   \[ a_1 = 6 \frac{m_1^2 - m_3 \eta (1-\eta)}{2(1-\eta)} \]
   \[ a_2 = \frac{3}{1-\eta} \]
   - Coefficients \( a_0 \), \( a_1 \), \( a_2 \)
   - \( S \) = surface ratio
   - \( \eta \) = dimensionless reduced density
   - Nearest solid surface
     \[ \delta = a e^b r \]
     \[ r = \frac{2 \sigma \cos \Psi W}{\rho g h} \]
   - Effective saturation
     \[ S_e = W \left( \frac{1-\eta}{\eta} + (1-W) \right) \]
   - Relative hydraulic conductivity (Muallem, 1976)
     \[ K_r = S_e \left( \left[ \int \frac{1}{\psi(S)} dS \right] - (1-W) \left[ \int \frac{1}{\psi(S)} dS \right] \right) \]

4. Tomographic analysis
   - The study was done at Laboratoire Multidisciplinaire de Scanographie du Québec de l’INRS-ETE.
   - Type of Medical CT scan : Somatum Volume Access (Siemens, Oakville, ON, CA).
   - Energy level of 140, 120, 100 and 80 keV
   - Voxel resolution of 0.1x0.1x0.6 mm

Conclusion
- Used and analysis of Medical CT scans clearly show the variability of soil hydraulic properties in the sample.
- The framework provides a good prediction of the mean soil hydraulic properties.
- The framework provides an opportunity to study the variability of soil hydraulic properties over a monolith.

Acknowledgements

References

Figure 1. Cumulative mass fraction of particle sizes (R)
Figure 2. Polydisperse impenetrable hard spheres systems in 2D
Figure 3. Dual model of effective saturation
Figure 4. Medical CT scan
Figure 5. Vertical and horizontal slices
Figure 6. Soil water retention curves
Figure 7. Soil hydraulic conductivity curves
Figure 8. Radial plane of soil water content (A) and relative hydraulic conductivity (B) as a function of soil matric potential (h).

> Good performance of the models to predict soil hydraulic properties (Figures 6 & 7)
> High variability of soil hydraulic properties (Figure 8)
> Specifically in position of the curve with high variation of water content and relative hydraulic conductivity according to the matric potential (h).