Visible to the eye, now in the model: Parameterizing dual porosity water retention functions in structured soils

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1 Introduction

Problem:

- Pore-size distribution in soils is reflected in the water retention curve (WRC) controlling the flux, depth distribution, and availability of soil moisture.
- Accurately characterizing and predicting the WRC is, therefore, important for the parameterization of global and regional hydrologic and climate models.
- Although soil pore-size distributions are often multimodal due to the presence of soil structure and interpedal macropores, current pedotransfer functions (PTFs) assume an unimodal pore-size distribution.

Opportunity:

- Reasons for the use and prediction of unimodal over multimodal PTF models include the difficulty in measuring large pores with typical methods.
- For example, both water retention measurements and CT scanning rely on small sample volumes which restrict the size of pores that can be assessed.
- However, recent application of multistripe laser triangulation (MLT) scanning can characterize structural macropores in both extreme detail and at a representative scale (e.g., a horizon).

Objective:

- Develop and evaluate PTFs that predict (1) the van Genuchten (VG) α and n parameters of the structural macroporous domain, (2) the coefficient, w_p, of a dual porosity model that describes the relative weights of the macropore (p) and matrix (m) domains, and (3) the soil saturated hydraulic conductivity (K_s).

2 Multistripe Laser Triangulation

MLT can be applied to sampled intact soil monoliths after preparing the surface with a freeze and peel method (Fig. 1).

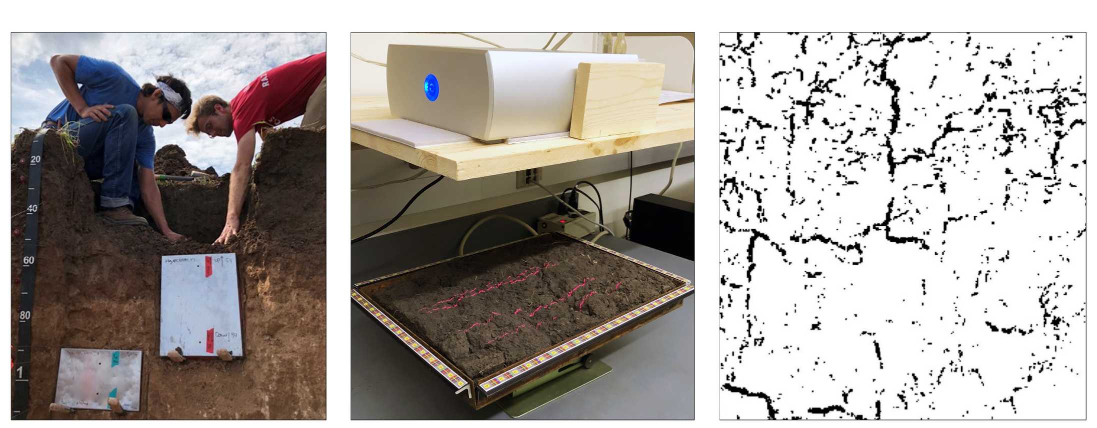


Figure 1: From left to right, field monolith sampling, MLT scanning, and the resulting binarized image (black areas are structural macropores).

MLT images (Fig. 1) are analyzed in ImageJ to measure effective width, fractional area (A), and total perimeter of macropores (P). Because monoliths are air-dried before scanning, macropore metrics reflect their maximum values.

3 Field Site

We sampled across a rainfall and land use gradient in Kansas, USA (Fig. 2).

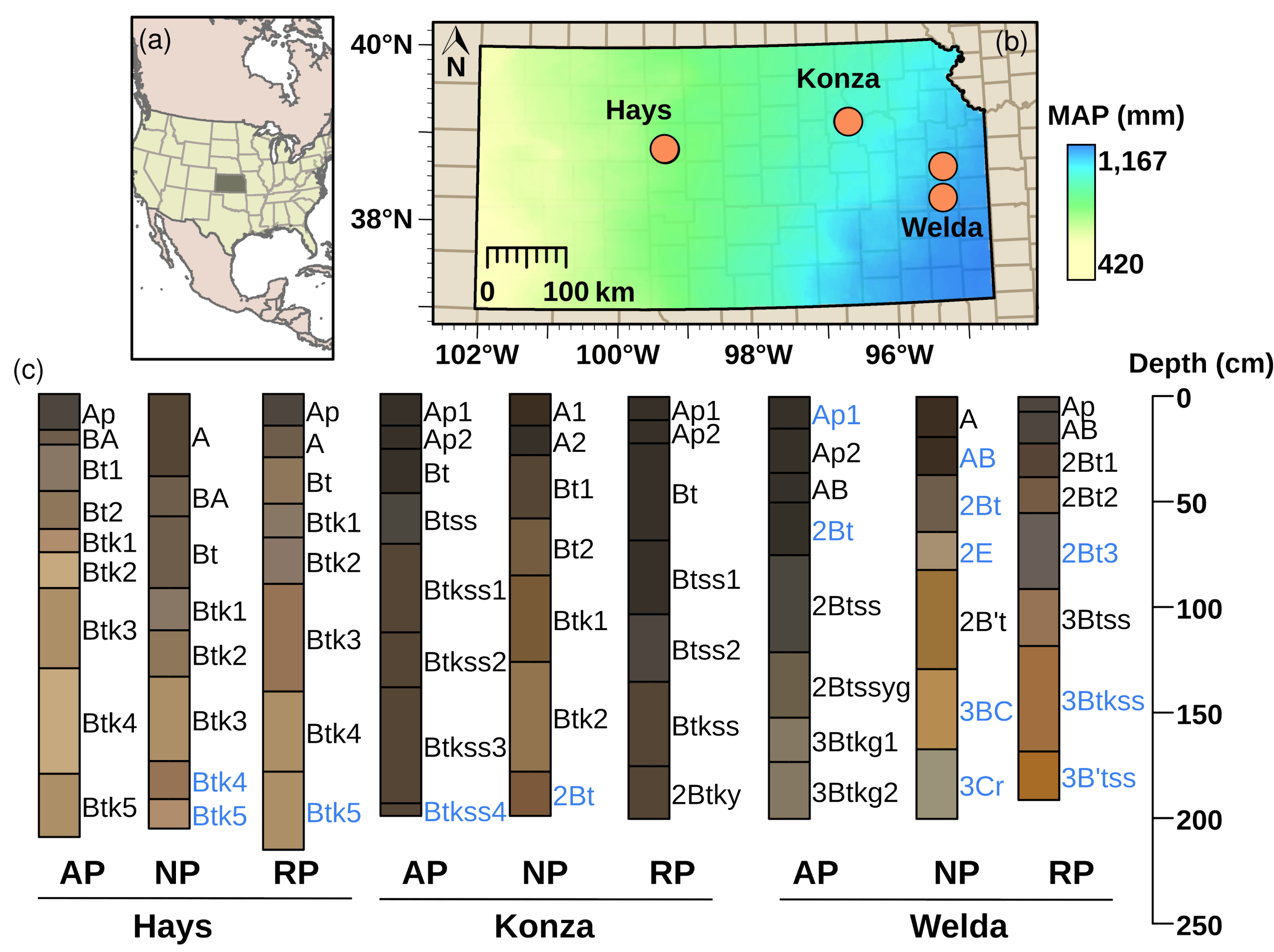


Figure 2: Locations of sampled horizons showing mean annual precipitation (MAP) and diagrams of the agricultural plot (AP), native prairie (NP), and restored prairie (RP) at each site.

4 Pedotransfer Function Development

The overall procedure to develop the PTFs is shown in Fig. 3. Minimum Feret diameter (d) of each macropore was measured in ImageJ and converted to matric potential (h):

$$h = -\frac{\sigma}{\rho_w g d} \quad (1)$$

where ρ_w is water density, g is gravitational acceleration, and σ is surface tension. A VG function of the form:

$$\theta_p = \frac{\phi_p}{\left[1 + (-\alpha_p h)^{n_p}\right]^{1-\frac{1}{n_p}}} \quad (2)$$

was fit to the macropore WRC from the MLT image after converting A values to cumulative volume fractions (θ_p) where ϕ_p is the total macroporosity and α_p and n_p are the VG parameters for the macropore domain. Moisture sensors were used to calculate average soil water content ($\bar{\theta}$) at each of the 3 sensor depths (z) and combined with clay (f_{clay}) to predict $\bar{\theta}$ for each sampling depth:

$$\bar{\theta} = \beta_0 + \beta_1 MAP + \beta_2 z + \beta_3 f_{clay} \quad (3)$$

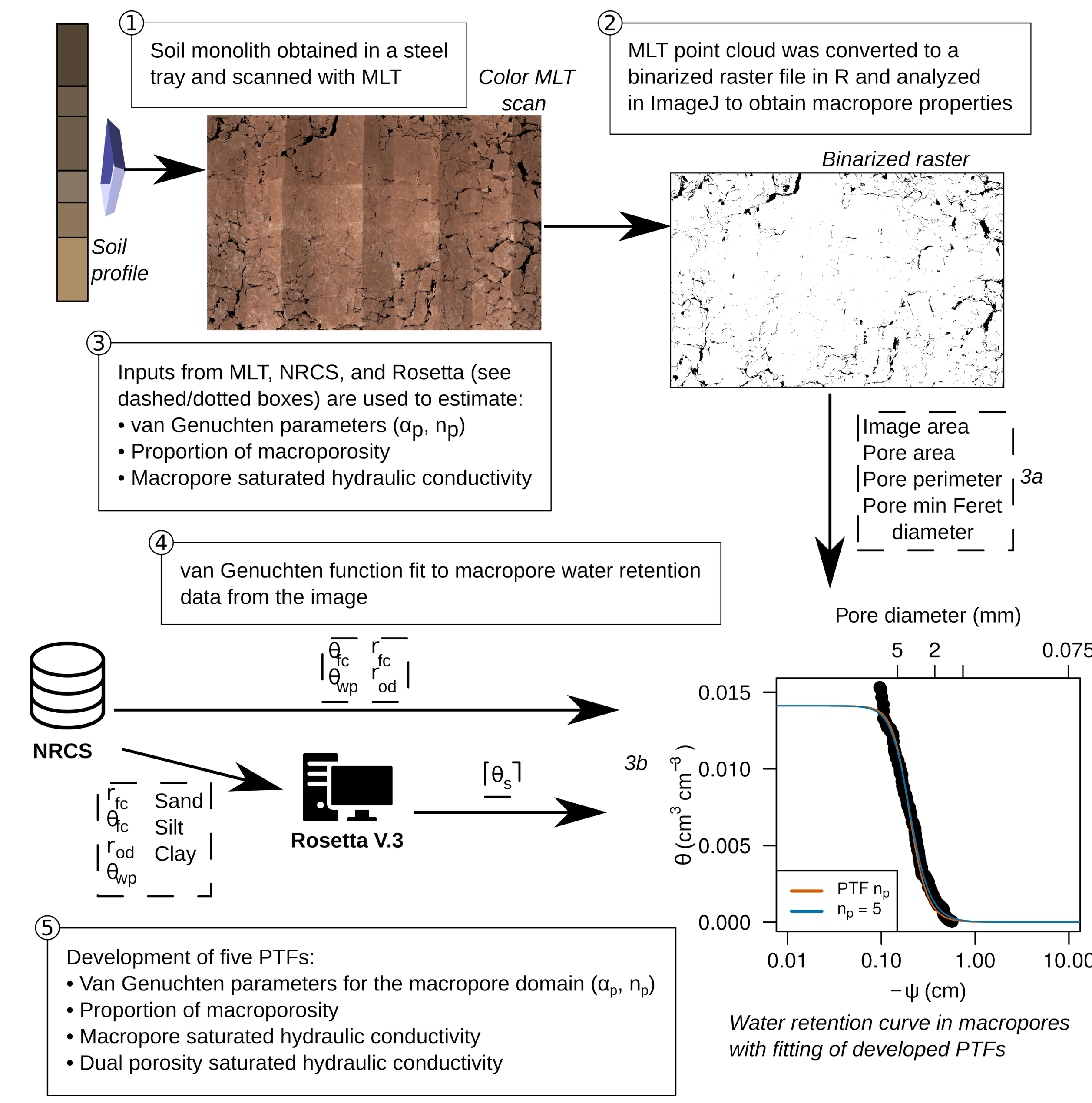


Figure 3: Methods followed to develop the PTFs.

where $\{\beta_0, \beta_1, \cdots\}$ are linear regression coefficients. We used $\bar{\theta}$ to adjust d in Eq. (1) from a dry state to its value at field conditions using the coefficient of linear extensibility. The effective degree of saturation (S_e) was modeled with a dual-porosity model:

$$S_e(h) = (1 - w_p) S_{e_m} + w_p S_{e_p} \quad (4)$$

where the S_e of each domain was modeled with a VG function and w_p was calculated as the ratio of ϕ_p to total porosity. K_s was calculated as:

$$K_s = (1 - \phi_p) K_{sm} + \phi_p K_{sp} \quad (5)$$

and K_{sp} was calculated as:

$$K_{sp} = \frac{d^3 (W - d) \rho_w g}{9 \eta W^2} \quad (6)$$

where $W = \frac{4 \sum A}{P} + d$ is the equivalent length of the representative elementary volume of the structured soil. PTFs were developed through an exhaustive search of multiple linear models that ultimately included MAP, MAT, CEC, depth, and structural roundness and solidity converted from field ped descriptions.

5 Results

Evaluation of PTF models are shown in Fig. 4, implications are shown in Fig. 5, and bias is shown in Fig 6.

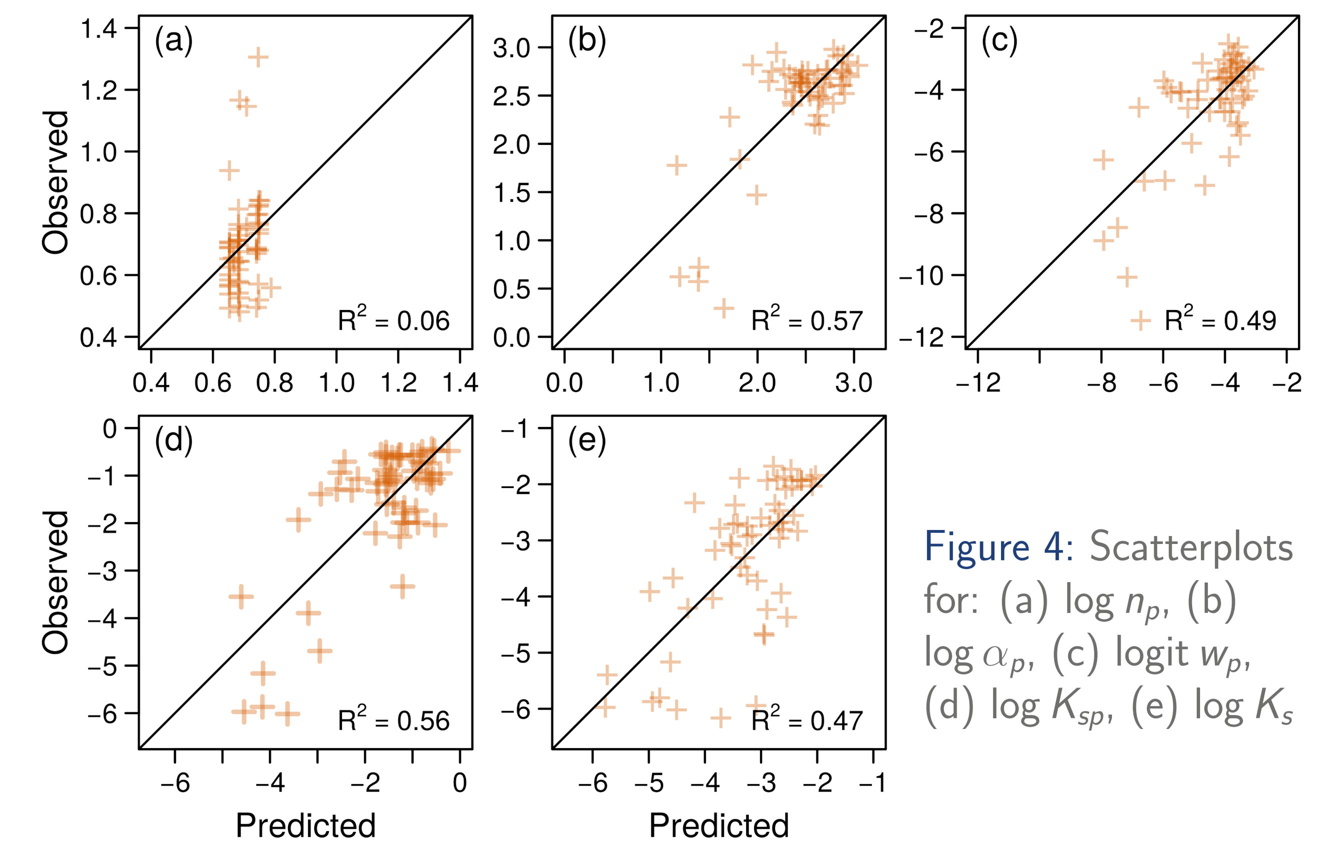


Figure 4: Scatterplots for: (a) log n_p, (b) log α_p, (c) logit w_p, (d) log K_{sp}, (e) log K_s

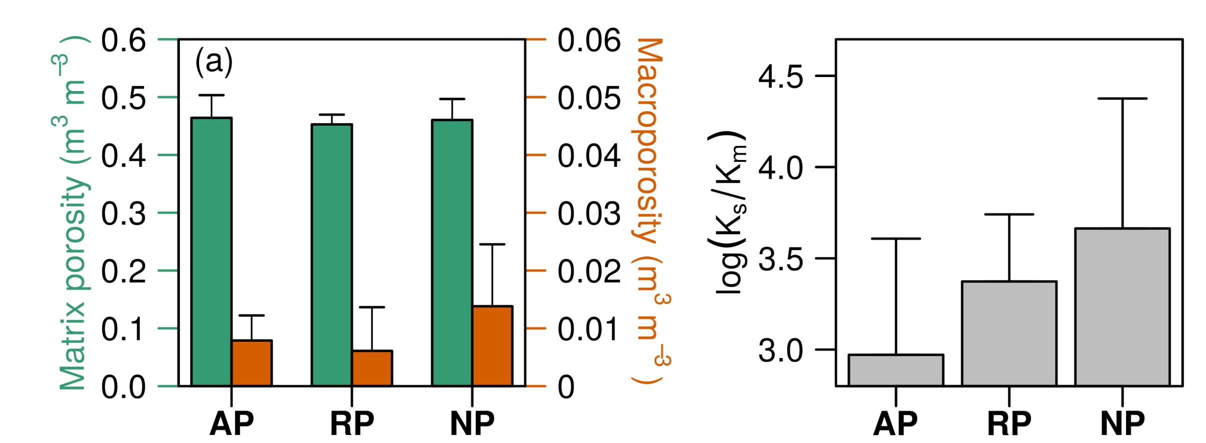
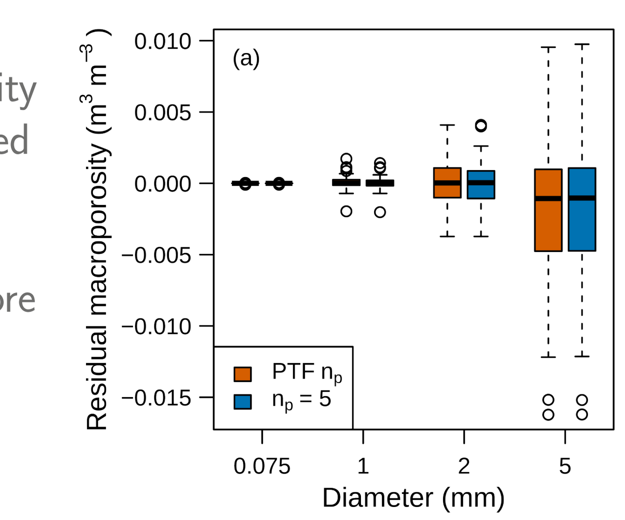


Figure 5: (a) Median matrix porosity and macroporosity and (b) ratio of the PTF-predicted K_s to the K_{sm} predicted from Rosetta.

Figure 6: Error in estimated porosity of the macropore domain calculated as the difference between PTF predicted and MLT image-based porosities at four distinct macropore diameters.



6 Summary

- Coefficients of determination (Fig. 4) showed reasonable agreement between PTF-predicted and imaged-based parameters except for n_p.
- Not accounting for structural macroporosity in PTF parameterizations of hydrologic models can lead to considerable underestimation of K_s (Fig. 5 and 6).

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