Evaluation of Models Describing Soil Water Retention Curves from Saturation to Oven Dryness

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Problem and Objectives

- Soil water retention curve (SWRC) measurements commonly restricts the matric suction (*h*) below 1500 kPa. Above the this point, fine texture soils still hold substantial water (Ross et al., 1991). It is significant to develop models that can describe the entire SWRC from saturation to oven dryness, due to lack matric suctions data greater than 1500 kPa.
- Most of the entire SWRC models were established from measurements on six soils by Campbell and Shiozawa (1992), and have not been validated with independent data sets.
- Study objectives: 1) to compare three models that characterize the entire SWRC from data in 0-1500 kPa, using independent data from saturation to oven dryness; 2) to test the validity of the Khlosi et al. (2006) model for entire SWRC using reduced data sets.

Soil Water Retention Curve Models

- **Fayer and Simmons (1995) model (FS model)**

The FS function is:

$$\theta = \chi\theta_a + (\theta_s - \chi\theta_a)\left[1+(\alpha h)^{n'}\right]^{-m'} \quad h > h_c$$
$$\theta = \theta_s \quad h \le h_c \qquad [1]$$

where θ_s is saturated water content, h is matric suction (cm), θ_a, n', and m' ($m' = 1\text{-}1/n'$) are FS model parameters, h_c is the lower limit of matric suction (typically 10^{-7} to 10^{-20} cm), α is the van Genuchten (VG) parameter.

The parameter χ is defined as

$$\chi = 1 - \frac{\ln(h)}{\ln(h_o)} \qquad [2]$$

where h_o is the matric suction at oven dryness, taken as 10^7 cm (Ross et al., 1991).

The parameter n' is calculated from n (VG parameter) using the following relationship:

$$n' = 1.23n - 0.16 \qquad [3]$$

Finally the only unknown parameter θ_a in Eq. [1] is estimated using the measured data point near the matric suction of 1500 kPa (Fayer and Simmons, 1995).

- **Webb (2000) model (W model)**

The W model divides the SWRC from saturation to oven-dryness into two regions: a higher water content region described by the VG model and a lower water content region by a semi-log function. The intersection of the two regions, the "matching point", is obtained by solving the following equation,

$$\log_{10}(10^7) = \log_{10}\left\{\frac{1}{\alpha}\left[\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{\frac{-1}{m}}-1\right]^{\frac{1}{n}}\right\} + (\log_{10} e)\frac{1}{mn}\frac{\theta}{\theta-\theta_r}\frac{1}{1-\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{\frac{1}{m}}} \qquad [4]$$

where θ_r, θ_s, α, and n are the VG fitting parameters, $m = 1\text{-}1/n$, 10^7(cm) indicates the matric suction at oven dryness.

- **Khlosi et al. (2006) model (KCGS model)**

Khlosi et al. (2006) combined the Kosugi (1999) model and the semi-log function of Campbell and Shiozawa (1992) to express the SWRC. The proposed function is:

$$\theta = \theta_b\left[1-\frac{\ln(h)}{\ln(h_o)}\right] + \left\{\theta_s - \theta_b\left[1-\frac{\ln(h)}{\ln(h_o)}\right]\right\}\frac{1}{2}erfc\left[\frac{\ln(h/h_m)}{\sqrt{2}\sigma}\right] \qquad [5]$$

where θ_b, θ_s, h_m, and σ are curve fitting parameters, "erfc" is the complementary error function, and h_o is the matric suction at oven dryness (10^7 cm). Khlosi et al. (2006) fitted the KCGS model (Eq. [5]) to two reduced data sets ($\le$100 kPa and $\le$ 1500 kPa, designated as KCGS-1 model and KCGS-15 model, respectively) of the measurements respectively, then applied the functions to obtain SWRC from oven dryness to saturation.

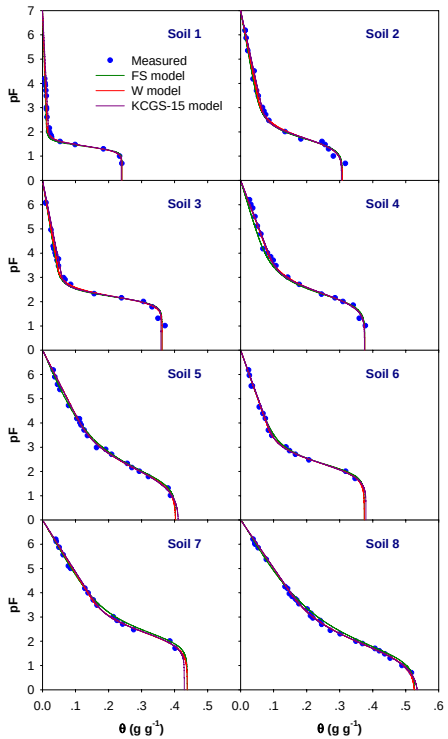

Fig. 1 Comparison of the measured soil water retention curves versus the estimations from the FS model, W model and KCGS-15 model. The KCGS-15 model are established from water retention data of 0-1500 kPa.

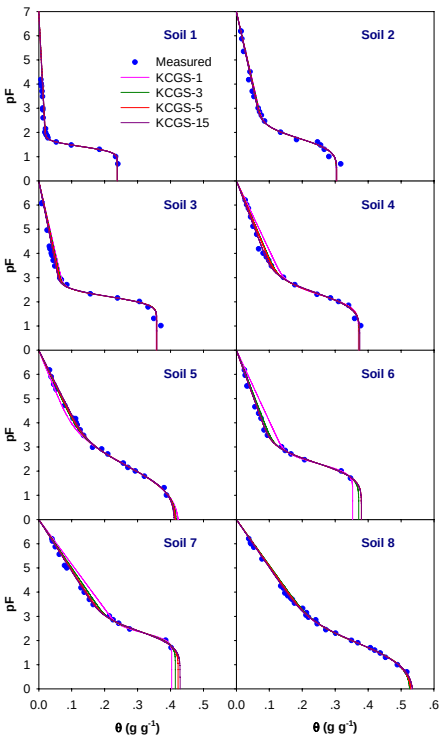

Fig. 2 Comparison of the measured SWRCs versus the estimations from the KCGS model developed on the basis of different water retention range. KCGS-1, KCGS-3, KCGS-5, and KCGS-15 indicate the model is established from water retention data of 0-100 kPa, 0-300 kPa, 0-500 kPa, and 0-1500 kPa, respectively.

Conclusions

- Predictions from the W model and the KCGS-15 model agreed well with measured data from saturation to oven dryness.
- The FS model provided satisfactory fits over the entire range of soil water content, but relatively large errors were observed in comparison with the other models. This model was sensitive to the data point near matric suction of 1500 kPa.
- When measured data in the 0-100 kPa suction range were used for calculating model parameters, the KCGS model (KCGS-1) produced mixed results: worked well on some soils but provided poor extrapolation on others. Soil water retention measurements up to suction of 300 kPa were required for the KCGS model to extrapolate to an acceptable SWRC for the complete water content range.

References

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Table 1. Texture, particle-size distribution, and organic matter (OM) content of the soils.

Soil ID	Texture	Particle size distribution			OM
		Sand	Silt	Clay	(%)
1	Sand	0.93	0.01	0.06	0.07
2	Sandy loam	0.67	0.21	0.12	0.86
3	Loam	0.40	0.49	0.11	0.49
4	Silt loam	0.27	0.51	0.22	1.19
5	Silty clay loam	0.19	0.54	0.27	0.39
6	Silt loam	0.11	0.70	0.19	0.84
7	Silty clay loam	0.08	0.60	0.32	3.02
8	Silt loam	0.02	0.73	0.25	4.40

Procedures

SWRC measurement

- *h* < 1500 kPa: the pressure plate device.
- *h* > 1500 kPa: the WP4-T Dewpoint PotentiaMeter (Decagon Devices Inc).

Model Evaluation

- The RETC code was employed to fit the measured data below 1500 kPa, and VG fitting parameters θ_r, θ_s, α, and n ($m = 1\text{-}1/n$) were obtained.
- Four data sets were used to establish the KCGS model: h < 100 kPa (KCGS-1), h < 300 kPa (KCGS-3), h < 500 kPa (KCGS-5), and h < 1500 kPa (KCGS-15).
- The KCGS model parameters were calculated by using the Mathcad software, where the quasi-Newton algorithm was used for least-squares analysis.

Results and Discussion

- On all the eight soils, the ME and RMSE of the W model and the KCGS-15 model are less than 0.01, indicating that these two models are capable of giving accurate information of SWRC in the entire soil water content range (**Fig. 1**). Although the FS model showed slightly higher ME and RMSE values than the W model and KCGS-15 model, the calculated results were acceptable because the numbers were mostly within 0.01.
- On soil 4, calculated results from the FS model showed relative larger deviations from the observed data **(Fig. 1)**. This was explained by the fact that the data point near the matric suction of 1500 kPa from pressure plate measurement was applied for the FS model establishment. Measurement error in this datum would be transferred to the parameter of θ_a, which had directly influence on the FS model performance.
- The KCGS-1 model was compatible with the KCGS-15 model on three soils (soils 1, 2, and 8), but produced relative larger errors on the other five soils (soils 3, 4, 5, 6, and 7), especially in the dry regions **(Fig. 2)**. For the current study, it appears that at least the data range of 0-300 kPa is required to establish a KCGS model that is capable of reproducing an acceptable SWRC from oven dryness to saturation. If higher accuracy is required, soil water retention data from 0-1500 kPa are recommended.
- The FS model and W model have the advantage that existing VG model parameters can be used to extend the SWRC to oven dryness, especially for soils that with known VG fitting parameters but the original data are not available.