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PREDICTING THE SOIL WATER RETENTION CURVE FROM READILY-AVAILABLE DATA OBTAINED DURING SOIL SURVEYS

C. Simota[1], *T. Mayr*[2]

[1]Research Institute for Soil Science and Agrochemistry, Blvd. Marasti, 61, 71331 Bucharest, Romania
[2]Soil Survey and Land Research Centre, Silsoe Campus, Silsoe, Bedford MK45 4DT, UK

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A b s t r a c t. Averages and coefficients of variation of the parameters of the van Genuchten equation were estimated, in relation to a large dataset, for soil particle-size classes differentiated according to the proportions of sand, silt, and clay particles in the inorganic fraction. For each particle-size class, three subclasses (soft, medium, and hard) were differentiated according to the values of the soil bulk density.

K e y w o r d s: model, pedotransfer functions, van Genuchten equation, soil water retention

INTRODUCTION

Spatially-distributed soil, agro-climatic and soil hydrological models for the prediction of the effects of climate change on land use over large areas, require a single method of deriving soil input parameters which characterise the soil water state. The ACCESS model is no exception to this requirement.

The pedo-transfer function which portrays the way the soil will release or retain water against the demands of crops, and upon meteorological change, is the soil water-retention curve (or its (often close) obverse - the soil water-release curve). The experimental determination of this function is difficult and time consuming, and has been done relatively rarely for large numbers of soil types and their horizons, within any specific region. In addition, soil-crop-water simulation models require the estimation of these pedo-transfer functions for a range covering all the field soil water values measured over the year (from saturation to wilting values), whereas soil water retention curve data are collected for a limited number of pressure heads. Hence, several approaches have been proposed for the analytical description of soil hydraulic properties, and for the estimation of the parameters involved in this description from readily-available, simple data, obtained during soil surveys, and thus applicable to soil map units. Use of these analytical equations for the soil water retention curve in conjunction with parameters depending on easily measured soil properties such as texture, bulk density and organic matter content, soil databases with limited data can be used to extrapolate simulation models in space for soil water dynamics and crop yield formation.

The most widely used equation for describing the soil water retention curve was proposed by van Genuchten [8]. The advantage of this closed-form equation is its ability to derive an analytical equation for the hydraulic conductivity function, which characterises the way in which water passes through the soil [3,4]. The derivation of multiple regression equations for the estimation of the parameters of the van Genuchten equation from easily measured soil physical properties (clay, silt, sand contents, bulk density and organic matter content) is reported elsewhere [6]. In this paper the parameters of the van Genuchten equation are derived for each soil particle-size class. The soil water retention curves obtained using these parameters were corrected using a translation of the curve to fit the measured soil water content at 15 bars pressure head. Therefore, the general prediction model can be tuned to site specific conditions.

THEORY

van Genuchten [8] proposed a closed form equation representing the soil water retention curve:

$$\Theta = \left[1+(\alpha\,\psi)^n\right]^{-m} \qquad (1)$$

where, α, n, and m are the model parameters, ψ is the pressure head (in bar), and Θ is the relative water content defined as:

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (2)$$

where θ, θ_r, θ_s are the gravimetric soil water content at pressure head ψ, the saturation soil water content, and the residual soil water content (all M/M), respectively.

In the general case, the parameters α, n and m are independent. For certain given combinations between the parameters n and m, the closed form van Genuchten equation can be used as an analytical equation for unsaturated hydraulic conductivity. Hence, if:

$$m = 1 - \frac{1}{n} \qquad (3)$$

then a closed-form equation is derived for the Mualem-Dagan model for the unsaturated hydraulic conductivity [4,8]. The values of θ_s are slightly different from the total porosity derived from bulk density measurements, and the values of θ_r are not zero. However, these differences are trivial. Thus, in order to simplify as much as possible the model for the prediction of the soil water retention curve, increasing its ability to be used in cases with limited soil data, it was assumed that:

$$\Theta_r = 0; \quad \theta_s = TP\left(1 - \frac{\rho_b}{\rho_p}\right) \qquad (4)$$

where, Θ_r and Θ_s represent the residual gravimetric water content and the gravimetric water content at saturation (both M/M), ρ_b is the soil bulk density (Mg m^{-3}), ρ_p is the particle density (Mg m^{-3}), and TP is the adjusted total porosity, defined as:

$$TP = \left(1.0 - \rho_b / \rho_p\right) / \rho_b \qquad (5)$$

where, ρ_p has the value 2.65 Mg m^{-3}.

Estimation of van Genuchten's equation parameters α and n (with restricting conditions of Eqs (3) and (4)), using large soil datasets provided the base to derive multiple regression equations for their estimation using easily available soil data [6]. The errors induced using the van Genuchten equation with the restrictive conditions of Eqs (3) and (4), were reduced if the estimated soil water retention curve was translated to fit the measured value of soil water content at a pressure head corresponding to the dry region of the curve. The pressure head of 15 bar was used as fitting point, because it is perhaps the most widely measured point in studies of soil water behaviour (Fig. 1). Should, however, these data be unavailable, there are direct correlations between 15 bar water content and the clay and organic carbon contents of the soil [5,7].

THE SOIL DATASET

The Soil Survey and Land Research Centre (SSLRC) has measured the soil water retention properties of undisturbed cores of mineral soils in England and Wales over the past 20 years. The sampling and laboratory techniques have remained reasonably consistent over this period and the dataset now includes over 5 000 horizons from some 1 500 soil profiles. Particle-size distribution and bulk density were measured for all samples, and organic carbon for topsoil and other selected subsoil horizons [7]. For the estimation of the parameters of the models 1 332 soil horizons were selected for which particle size distribution had been measured between the limits (in mm): 0-0.002 (clay); 0.002-0.063 (silt); 0.063-0.106, 0.106-0.212 (fine sand); 0.212-0.600

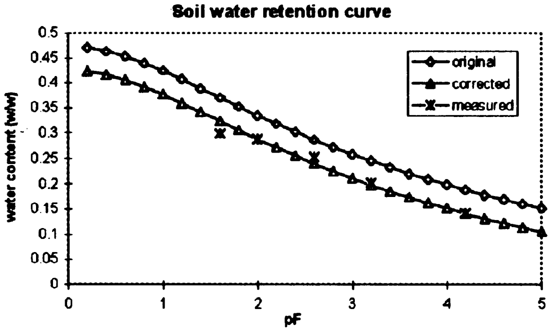

Fig. 1. An example of the effect of the 15 bar pressure head correction procedure

(medium sand); 0.600-2.00 (coarse sand). Soil water retention data are available for the following values of soil water pressure: 0.051, 0.102, 0.408, 2.04, and 15.03 bar.

RESULTS AND DISCUSSION

The parameters α and n of the van Genuchten equation were estimated for a whole range of soils with different particle-size distributions, bulk densities, and organic carbon contents, of the England and Wales soil database, using as initial data the pairs of soil water content - pressure head values computed with the Arya-Paris model [1,6].

In order to be able to use the lesser amount of quantitative information inherent in a soil map for predictions of pedo-transfer functions, the averages and the coefficients of variation of the parameters of van Genuchten's equation were estimated for each particle-size class, differentiated according to the proportions of sand (0.063-2 mm), silt (0.002-0.063 mm), and clay (0-0.002 mm) particles in the inorganic fraction <2 mm. The definition of soil particle-size classes is that used by the Soil Survey of England and Wales [2].

For each particle-size class, three subclasses (soft, medium, and hard) were differentiated according to the values of the soil bulk density. Initially, the range of the bulk density for each particle-size class was divided in three equal size subdomains. An average value of the bulk density limits between these subdomains was computed for particle-size classes with similar values of the bulk density range. Therefore, for clay, silty clay, silty clay loam, silt loam and sandy silt loam, the bulk density ranges are: <1.00 Mg cm^{-3}, 1.00-1.31 Mg cm^{-3} and >1.31 Mg cm^{-3}. For clay loam, sandy clay loam and sandy loam the ranges are: <1.20 Mg cm^{-3}, 1.20-1.42 Mg cm^{-3} and >1.42 Mg cm^{-3}, and for sandy clay, loamy sand, and sand they are: <1.27 Mg cm^{-3}, 1.27-1.42 Mg cm^{-3} and >1.42 Mg cm^{-3}, respectively.

The averages and the coefficients of variation for the α and n coefficients were calculated for all particle-size classes and bulk density ranges (Table 1). The general tendency is for average values of α and n to increase from fine to coarse textured soils, this being more visible for the values of n, and generally more evident for both loamy sand and sandy soils than for the other particle size classes. The α coefficient increases in general from soft to hard soils, whereas n tends to decrease from soft to hard soils for all particle size classes.

The values of the coefficients of variation are relatively small for α (maximum 6% for 'medium' silty clay), and very small for the n coefficient (maximum 1.2 % in the case of sandy soils). These values justify the use of the particle-size class 'average values' of the parameters of the van Genuchten equation for predicting the soil water retention curves from soil survey data. The total sum of squared errors between predicted and measured values for soil water content Σ_{error}, for all soils in the dataset, and all steps of the pressure head was used to test the prediction efficiency of

Table 1. Averages and coefficients of variation (%) for the α and n coefficients for different particle size classes and bulk density ranges

Particle size classes	Soft	(%)	Medium	(%)	Hard	(%)
			α coefficient			
clay	0.034	2.7	0.038	1.5	0.045	2.4
silty clay	0.033	3.4	0.036	2.1	0.039	2.4
silty clay loam	0.035	1.5	0.036	1.0	0.037	0.9
silty loam	0.039	5.2	0.043	2.3	0.043	2.1
clay loam	0.047	2.1	0.051	1.2	0.055	2.6
sandy silty loam	0.055	5.7	0.056	2.0	0.058	1.5
sandy clay	0.073	3.1	0.073	6.1	0.073	2.2
sandy clay loam	0.067	3.9	0.065	2.0	0.078	4.9
sandy loam	0.074	5.0	0.077	2.2	0.081	2.9
loamy sand	0.113	3.3	0.113	3.3	0.108	2.3
sand	0.136	4.5	0.136	4.6	0.150	4.5
			n coefficient			
clay	1.204	0.1	1.194	0.1	1.197	0.2
silty clay	1.213	0.3	1.214	0.2	1.204	0.2
silty clay loam	1.231	0.2	1.224	0.1	1.209	0.1
silty loam	1.251	0.6	1.243	0.3	1.233	0.2
clay loam	1.229	0.2	1.226	0.1	1.221	0.1
sandy silty loam	1.261	0.5	1.254	0.2	1.247	0.2
sandy clay	1.252	0.7	1.249	1.1	1.235	0.6
sandy clay loam	1.268	0.2	1.245	0.2	1.258	0.6
sandy loam	1.288	0.9	1.286	0.3	1.283	0.5
loamy sand	1.402	0.5	1.381	0.9	1.358	0.4
sand	1.503	1.0	1.510	1.0	1.529	2.1

the proposed algorithm. From this point of view, using the shift of the predicted curve to fit the measured soil water content for 15 bar pressure head ($\Sigma_{error} = 18.23$) improves the predictions significantly, as compared with the predicted curve using only the van Genuchten equation with coefficients obtained from Table 1 ($\Sigma_{error} = 40.61$).

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