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Validation of the Arya and Paris Water Retention Model for Brazilian Soils

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ABSTRACT

The Arya and Paris (AP) model predicts soil water retention curves from soil particle-size distribution (PSD) data based on the similarity between these two functions. The AP model estimates pore radius (r_i) from the radius (R_i) of spherical particles by scaling pore length with a parameter α. This paper evaluates the performance of the AP model with representative Brazilian soil types using three constant α values: $\alpha = 1.38$, 0.938 (literature values), and 0.977, (obtained in the present work); and a α-variable approach, where α is determined as a function of soil water content (θ). The study was performed with 104 soil samples collected in three sites. The soil PSD curves were obtained with an automatic soil particle analyzer based on the attenuation of γ-ray by dispersed soil particles falling in a liquid medium and the soil water retention were measured with tension table and Richard chamber methods. The best mathematical representation of the $\alpha = f(\theta)$ relationship was obtained with a first-order exponential decay equation [$\alpha = 0.947 + 0.427\exp(-\theta/0.129)$] that provided values of α in the range from 1.37 ($\theta = 0$ m^3 m^{-3}) to 0.96 ($\theta = 0.6$ m^3 m^{-3}). The root mean square deviation values of estimated and measured θ were 0.062 m^3 m^{-3} for $\alpha = f(\theta)$, 0.073 m^3 m^{-3} for $\alpha = 0.977$, 0.080 m^3 m^{-3} for $\alpha = 0.938$, and 0.136 m^3 m^{-3} for $\alpha = 1.38$. Therefore, for these set of soils the α-variable approach and the constant ones using 0.977 and 0.938 presented the best estimation for the soil water retention relationships.

THE SOIL WATER retention curve or the soil water content-matric potential relationship expresses the capacity of soils to store water for plant growth, which is a very important soil property for irrigation and hydrological modeling. Several laboratory procedures are employed for the determination of soil water retention curves, but they can be basically grouped in suction-type (porous plate funnel, tension table) and pressure-type cell apparatus (Richard chamber) with both undisturbed or disturbed soil core samples.

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Due to the relatively long time involved in the determination of water retention curves, there is an increasing interest for models that estimate this property from simple taxonomic data (texture or complete particle-size distribution, bulk density, particle density, organic matter) and other basic properties (Arya et al., 1999; Pachepsky and Rawls, 1999). Prominent among these techniques are empirical equations or pedotransfer functions (PTF) that relate soil water retention and soil hydraulic conductivity to basic soil parameters available from soil surveys (Bouma 1989; Pachepsky and Rawls, 1999; McBratney et al., 2002). Another approach relies on the similarity between the shape of the particle-size distribution and water retention curves and on basic physical relationships to derive water retention curves from particle-size distribution data (Basile and D'Urso, 1997; Arya et al., 1999; Zeiliguer et al., 2000; Zhuang and Miyazaki, 2001). Among these models is the well-known AP approach (Arya and Paris, 1981).

Specific PTF have been developed for Brazilian soils (Tomasella et al., 2000; Tomasella et al., 2003) using more than 500 soil horizons. The development of PTF equations adapted for the condition of the Brazilian weathered soils allowed a better estimate of the van Genuchten (1980) retention curve parameters, when compared with the performance of PTFs derived for soils from temperate climates (Tomasella et al., 2000). However, the validity of the AP model for Brazilian soils has not been verified yet. The main limitation is the difficulty to obtain precise and detailed particle-size distribution data using the conventional sieving, pipette, and densimeter methods, mostly used in soil routine analysis. For that reason the AP method is generally performed with few soil samples (Arya and Paris, 1981; Arya et al., 1999; Basile and D'Urso, 1997), whereas studies using PTFs are performed with hundreds to thousands of soil texture data (Bouma, 1989; Pachepsky and Rawls, 1999; Tomasella et al., 2000, 2003).

Abbreviations: AP, Arya and Paris model; PTF, pedotransfer function.

Table 1. Mean, standard deviation (SD), maximum and minimum values of some physical parameters of each soil data set used in the AP model validation.†

Soil set	Statistic	ρ_s	ρ_p‡	θ_{30kPa}	$\theta_{1500kPa}$	Clay	Silt	Sand
		kg m^{-3}		m^3 m^{-3}		kg kg^{-1}		
São Carlos	mean	1.41	2.84	0.244	0.156	0.402	0.102	0.496
	SD	0.17	0.16	0.088	0.071	0.126	0.092	0.205
	maximum	1.62	3.05	0.097	0.056	0.606	0.283	0.798
	minimum	1.11	2.63	0.430	0.280	0.192	0.010	0.132
Piracicaba	mean	1.41	2.81	0.282	0.187	0.601	0.149	0.251
	SD	0.15	0.13	0.077	0.072	0.119	0.048	0.153
	maximum	1.68	2.95	0.182	0.082	0.748	0.248	0.517
	minimum	1.07	2.66	0.393	0.295	0.389	0.059	0.074
Rio Grande do Sul	mean	1.16	2.74	0.275	0.161	0.356	0.241	0.402
	SD	0.13	0.10	0.094	0.069	0.190	0.109	0.196
	maximum	1.51	2.98	0.028	0.017	0.652	0.484	0.975
	minimum	0.88	2.61	0.486	0.330	0.011	0.014	0.100

‡ Estimated from the mass attenuation coefficient measurement (Vaz et al. 1999).
† ρ_s: soil bulk density; ρ_p: soil particle density; θ_{30kPa}: soil water content at 30 or 33 kPa; $\theta_{1500kPa}$: soil water content at 1500 kPa.

As a physico-empirical model, the AP procedure contains an empirical parameter, α, used to estimate pore radius (r_i) from particle radius (R_i). Arya and Paris (1981) assumed that r_i is determined by scaling pore length, calculated from the packing of spherical particles of size R_i to natural pore length using the scaling factor α. Originally, Arya and Paris (1981) introduced α as constant ($\alpha = 1.38$) and the model proved to work relatively well for sandy soils. Later, a value of $\alpha = 0.938$ was proposed by Arya and Dierolf (1992), but it did not affect the results in any substantial way (Basile and D'Urso, 1997). However, Schuh et al. (1988) have shown the variation of α for a wide range of soil matric potentials and Basile and D'Urso (1997) derived an expression for α as a function of the soil matric potential [$\alpha = f(\psi)$]. Although Basile and D'Urso (1997) procedure improved the AP model estimates for a clay-loamy soil, the $\alpha = f(\psi)$ relationship is soil dependent and must be obtained specifically for each soil map unit and horizon or soils with similar physical properties.

In this paper we calculate an α-value for a set of 104 Brazilian soil samples and obtain also an expression for α as a function of the soil water content, $\alpha = f(\theta)$, instead of the $\alpha = f(\psi)$ proposed by Basile and D'Urso (1997), because the former relationship showed to be more useful and easy to apply in the model solution, due to the interdependence of ψ and α (see procedure to derive the α-value in the *Material and Methods* section below). The model validation was performed with both constant ($\alpha = 1.38$, 0.938, and the specific α-value determined for this set of Brazilian soils) and a variable $\alpha = f(\theta)$ approaches.

MATERIALS AND METHODS

Soil Data Set

Three sets of soil samples were collected and used for the validation of the AP model. Two sets were collected in the regions of São Carlos (24 samples) and Piracicaba (22 samples) both in the state of São Paulo. The third set was collected in 34 different locations in the Rio Grande do Sul State (58 samples). Table 1 contains the mean, standard deviation, maximum and minimum values of some physical properties of the 104 soil samples, while their texture distribution is shown in Fig. 1. The sampled soils included the following types: Typic Quartzipsamment, Typic Hapludox, Rhodic Hapludox, Rhodic Kandiudalf, Typic Hapludult, Typic Chromudert, Aquic Argiudoll, Psammentic Rhodudult, Rhodic Kandiudox, Inceptic Hapludox, Typic Hapludalf, Typic Udorthents, Vertic Ochraqualf, and Typic Kandiudalf.

Soil Water Retention Curves

Undisturbed samples for the soil water retention curves were collected with stainless steel cylinders (5-cm diam. and 5-cm height). For the two first soil sets (46 samples), retention curves were obtained in the soil analysis laboratory of the University of São Paulo, ESALQ, Piracicaba, SP. For the third soil set, retention curves were obtained in the soil analysis laboratory of the University of Santa Maria, UFSM, Santa Maria, RS. Table 2 shows the soil matric potentials applied and equipment used in each soil set for soil water retention curve determination. Equilibration time was variable according to soil texture and soil matric potential, but it was in general around 1 d for potentials up to 10 kPa, 3 to 4 d for potentials between 33 and 100 kPa and 10 to 20 d for potentials between 500 and 1500 kPa.

Experimental soil-water data were characterized with the van Genuchten equation (1980):

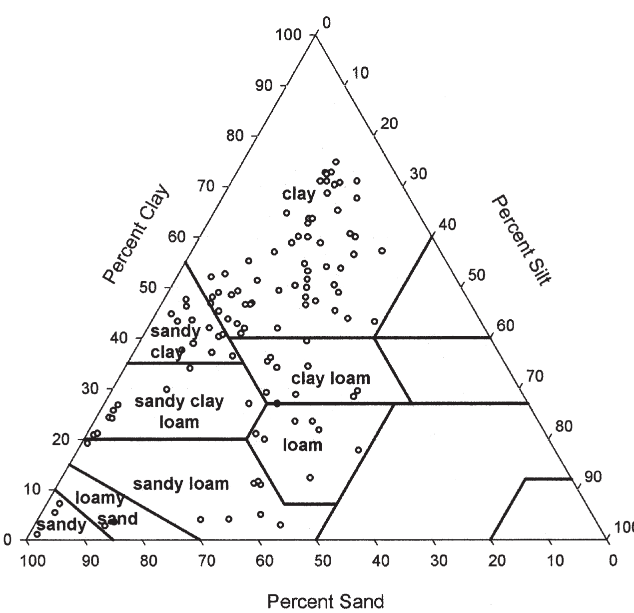

Fig. 1. Soil textural classes of the Brazilian data set.

Table 2. Soil matric potentials of each soil data set for the soil water retention curve measurements.

			Soil matric potentials, kPa	
Soil set	Location	Laboratory	Tension table	Pressure chamber
1	São Carlos	ESALQ	0.1, 2, 4, 8, 10	30, 100, 500, 1500
2	Piracicaba	ESALQ	0.1, 0.5, 1, 3, 5, 8, 10	33, 100, 500, 1500
3	Rio Grande do Sul	UFSM	0.1, 5, 10	33, 100, 500, 1500

$$\theta = \theta_r + (\theta_s - \theta_r)\left[\frac{1}{1 + (\gamma\psi)^n}\right]^{\frac{n-1}{n}} \quad [1]$$

where θ_r and θ_s (m^3 m^{-3}) are the residual and saturated soil water content, respectively, ψ (kPa) is the soil matric potential, and γ and n are fitting parameters with no physical meaning. These parameters (θ_r, θ_s, γ, and n) were obtained by nonlinear least-squares fitting (Wraith and Or, 1998), using the tool Solver of Excel from Microsoft (Microsoft Corp., Redmond, WA).

Particle-Size Distribution Analysis Procedure

Disturbed soil samples for particle-size analysis were collected in triplicate from each location. Samples (40 g of oven dried soil) were predispersed overnight with 10 mL of 1 *M* NaOH and 200 mL of distilled water. Predispersed samples were mechanically dispersed during 5 min for sandy soils, 10 min for medium texture soil and 15 min for clayey soils in a high speed shaker (model 936-2, Hamilton Beach, Washington, NC) and analyzed in groups of 10 samples with an automatic γ-ray attenuation equipment at the Embrapa Agricultural Instrumentation soil laboratory in São Carlos. (Naime et al., 2001). Time for analyzing each sample was around 18 min and therefore the analysis of each group of 10 samples was performed in about 3 h. Details of the γ-ray attenuation method for soil particle-size analysis can be found elsewhere (Vaz et al., 1992; Oliveira et al., 1997; Vaz et al., 1999; and Naime et al., 2001).

The average particle-size distribution data for each sample was fitted with a logistic Sigmoidal function (Arya et al., 1999) using the software Origin from Microcal (Northampton, MA). Other functions suggested by Hwang and Powers (2003) were also tested, but the logistic one was selected based on best performance. The logistic fitted curves were used to estimate the soil water retention with the AP model.

Arya and Paris Model

The AP model is mainly supported by two assumptions. First, the capillary equation that relates soil matric potential (ψ_i) and pore radius, r_i:

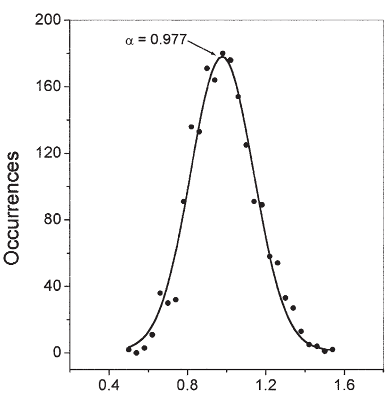

Fig. 2. Frequency distribution of the estimated α-values for the 104 soil samples. A total of 1821 α-values were obtained because each sample provide up to 20 α-values relative to the particle-size segmentation used.

$$\psi_i = \frac{2\sigma\cos\Theta}{\rho_w g r_i} \quad [2]$$

where σ (N m^{-1}) is the surface water tension in the air–water interface, Θ is the contact angle (assumed as $\Theta = 0$), ρ_w (kg m^{-3}) is the water density, and g (m s^{-2}) is the acceleration of gravity. In the international system of units, $\sigma = 0.0728$ N m^{-1}, and $g = 9.81$ m s^{-2}.

Second, the calculation of the soil water content from the soil particle-size distribution as the contribution of each fraction to soil wetting:

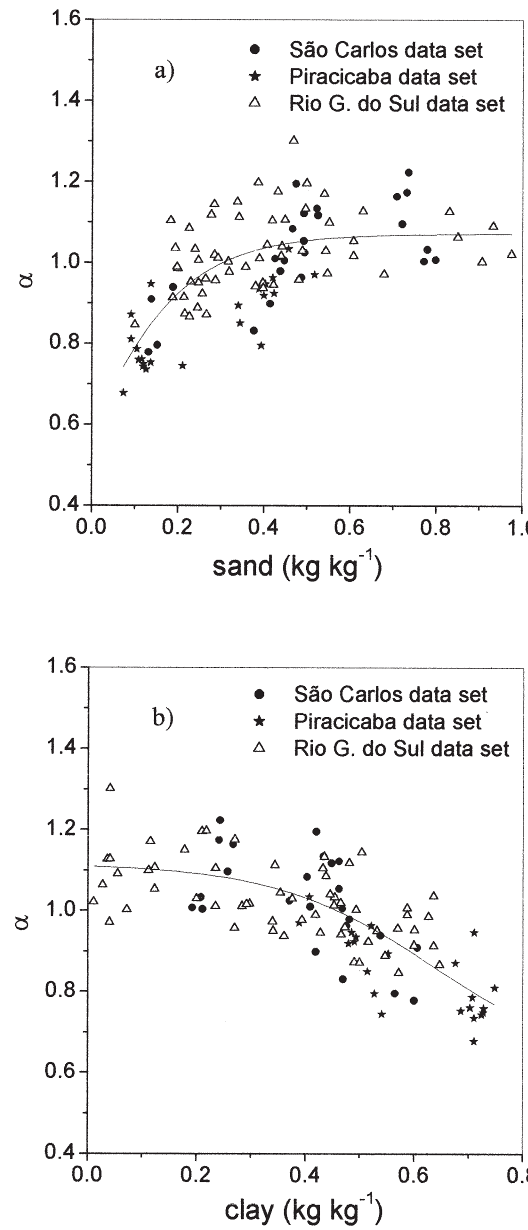

Fig. 3. Dependence of average α-values with the (a) sand and (b) clay contents for the Brazilian data sets.

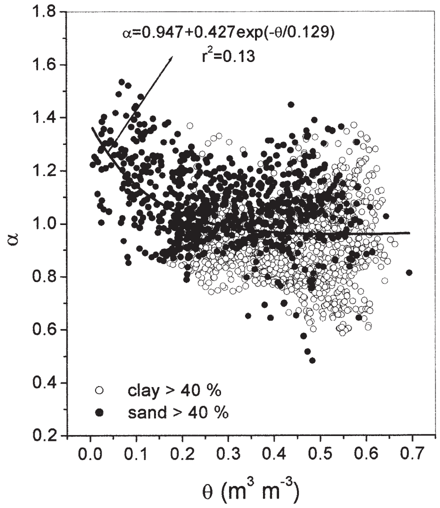

Fig. 4. Dependence of α-values with soil water content for two textural groups. The solid line is the best fit with a first-order exponential decay equation.

$$\theta_i = \phi \sum_{i=0}^{i=1} w_i \qquad [3]$$

where ϕ (m^3 m^{-3}) is the soil porosity and w_i (kg kg^{-1}) is the soil mass of the i^{th} fraction calculated with a sigmoidal model fitted to the cumulative particle-size distribution data. Soil porosity can be estimated from information on soil bulk density ρ_s (kg m^{-3}) and soil particle density ρ_p (kg m^{-3}): $\phi = 1 - (\rho_s/\rho_p)$.

Porous radius (r_i) is determined from soil particle radius (R_i) considering packing of spherical particles and a scaling factor α that corrects for structured soils (Arya and Paris, 1981; Arya et al., 1999):

$$r_i = R_i\sqrt{4en_i^{1-\alpha}/6} \qquad [4]$$

where n_i is the number of particles of a size class i and e is the void ratio (volume of pores/volume of particles), given by (Arya and Paris, 1981):

$$n_i = \frac{3w_i}{4\pi R_i^3 \rho_p} \qquad [5]$$

$$e = \frac{\rho_p - \rho_s}{\rho_s} \qquad [6]$$

The soil matric potential is then calculated with the combination of Eq. [2], [4], [5], and [6], as follows:

$$\psi_i = \frac{2\sigma}{\rho_w g R_i \sqrt{\dfrac{2(\rho_p - \rho_s)}{3\rho_s}\left(\dfrac{3w_i}{4\pi R_i^3 \rho_p}\right)^{1-\alpha}}} \qquad [7]$$

Once the scaling factor α is known, retention curves can be estimated with the AP model, pairing water content (Eq. [3]) with soil matric potential (Eq. [7]). The number of points estimated in the retention curve is defined by the segmentation of the particle-size distribution, that was originally suggested by Arya and Paris (1981) as 20 diameter classes (1, 2, 3, 5, 10, 20, 30, 40, 50, 70, 100, 150, 200, 300, 400, 600, 800, 1000, 1500, and 2000 μm). In the validation presented here these same 20 diameter classes are used.

Procedure to Derive α

The scaling factor α (Eq. [4]) is obtained through the adjustment of measured soil water retention data to the model for a great number of soil samples using a combination of Eq. [2], [4], [5], and [6], as shown in Eq. [8].

$$\alpha = 1 - \frac{\mathrm{Log}\left[\dfrac{3}{2e}\left(\dfrac{2\sigma}{\rho_w \psi_i g R_i}\right)^2\right]}{\mathrm{Log}(n_i)} \qquad [8]$$

where soil matric potential ψ_i is estimated from the van Gen-

Table 3. Application of the AP model for the estimation of the retention curve, considering both α-constant (0.977) and variable approaches for a sandy soil.

d	Σ w_i†	W_i‡	θ§	n_i¶	α Cons#	α Var††	r_i‡‡ α-cons	r_i‡‡ α-var	ψ (kPa)§§ α-cons	ψ (kPa)§§ α-var
μm			m^3 m^{-3}				m		kPa	
1	0.055	0.055	0.025	4.00×10^{-13}	0.977	1.299	5.32×10^{-7}	3.43×10^{-9}	273.77	42 455.1
2	0.055	0	0.025	0	0.977	1.299	–	–	–	–
3	0.055	0	0.025	0	0.977	1.299	–	–	–	–
5	0.055	0	0.025	0	0.977	1.299	–	–	–	–
10	0.055	0	0.025	0	0.977	1.299	–	–	–	–
20	0.056	0.001	0.025	9.08×10^{-7}	0.977	1.298	9.16×10^{-6}	4.84×10^{-7}	15.89	300.62
30	0.058	0.002	0.026	5.38×10^{-7}	0.977	1.295	1.37×10^{-5}	8.03×10^{-7}	10.66	181.38
40	0.06	0.002	0.027	2.27×10^{-7}	0.977	1.293	1.80×10^{-5}	1.24×10^{-6}	8.08	117.31
50	0.068	0.008	0.031	4.65×10^{-7}	0.977	1.283	2.27×10^{-5}	1.52×10^{-6}	6.41	95.80
70	0.09	0.022	0.041	4.66×10^{-7}	0.977	1.258	3.18×10^{-5}	2.65×10^{-6}	4.58	54.90
100	0.158	0.068	0.071	4.94×10^{-7}	0.977	1.192	4.55×10^{-5}	6.75×10^{-6}	3.20	21.57
150	0.368	0.21	0.166	4.52×10^{-7}	0.977	1.064	6.81×10^{-5}	3.15×10^{-5}	2.14	4.62
200	0.555	0.187	0.251	1.70×10^{-7}	0.977	1.008	8.98×10^{-5}	6.94×10^{-5}	1.62	2.10
300	0.794	0.239	0.359	6.43×10^{-6}	0.977	0.973	1.33×10^{-4}	1.37×10^{-4}	1.09	1.06
400	0.877	0.083	0.396	9.42×10^{-5}	0.977	0.967	1.74×10^{-4}	1.87×10^{-4}	0.84	0.78
600	0.927	0.05	0.419	1.68×10^{-5}	0.977	0.964	2.56×10^{-4}	2.77×10^{-4}	0.57	0.53
800	0.936	0.009	0.423	1.28×10^{-5}	0.977	0.963	3.31×10^{-4}	3.53×10^{-4}	0.44	0.41
1000	0.955	0.019	0.432	1.38×10^{-4}	0.977	0.962	4.14×10^{-4}	4.44×10^{-4}	0.36	0.33
1500	0.97	0.015	0.438	3.23×10^{-3}	0.977	0.961	6.11×10^{-4}	6.51×10^{-4}	0.24	0.22
2000	1	0.03	0.452	2.72×10^{-3}	0.977	0.960	8.13×10^{-4}	8.70×10^{-4}	0.18	0.17

† Cumulated particle-size distribution data.
‡ Contribution of each fraction to the particle-size distribution.
§ Calculated using Eq. [3].
¶ Calculated from Eq. [5].
# Most frequent value (mode) obtained for the Brazilian soil set.
†† α-value obtained using the equation given in Fig. 4.
‡‡ Pore radius calculated using Eq. [4], [5], and [6].
§§ Calculated using Eq. [7].

uchten (1980) equation in its inverted form (ψ as a function of θ), fitted to the experimental retention curve at several water content values, which in turn are calculated from PSD data at each of the particle radii considered.

Therefore, α can be estimated for each radius class for all soil samples and a constant α value (representative of all soils) is obtained from the mode of the frequency distribution of estimated α-values. Arya and Paris (1981) in their original formulation obtained $\alpha = 1.38$ and in a modification presented by Arya and Dierolf (1992) it was obtained $\alpha = 0.938$.

In Eq. [8], α can also be assumed as a function of ψ. This dependence was originally proposed by Basile and D'Urso (1997). However, due to the interdependence of α and ψ in the application of the AP model, the use of the $\alpha = f(\psi)$ relationship is quite complicated and requires the use of an interactive procedure. Therefore, and since α and θ are independently determined in the AP model, we propose to express α experimentally as a function of θ. For that, α is calculated with Eq. [8], using measured ψ_i values for each particle-size fraction, determined from the experimental retention curve at the water contents obtained from Eq. [3].

RESULTS AND DISCUSSION

Estimation of α

The scaling factor α allows the AP model to estimate the ψ–θ relationship for structured soils. The frequency distribution of the estimated α-values for all 104 soil samples is presented in Fig. 2. A total of 1821 α-values were obtained because each sample provided up to 20 values relative to the particle-size segmentation used. The most frequent value obtained (data fitted with a Gaussian distribution) was $\alpha = 0.977$, which is between the values proposed by Arya and Paris (1981) (1.38) and by Arya and Dierolf (1992) (0.938).

Average α-values (obtained for the 20 particle sizes used) from each of the 104 samples increased with sand content up to approximately 40% of sand (Fig. 3a), and decreased with clay content (Fig. 3b), especially for soils with more than 40% of clay.

The dependence of α with θ is presented in Fig. 4, for two groups of soils having clay contents larger than 40% and sand contents larger than 40%. In this case, each soil was included in only one group and few loam and clay loam soils were not included in the graph. For clayed soils, α-values did not show any significant tendency of variation with θ, but sandy soils exhibited a significant variation with a fast decrease at low water content values, and values stabilizing after a water content of about 0.2 $m^3\ m^{-3}$. The best fitting was obtained with the two textural groups together using a first-order decay exponential function [$\alpha = 0.947 + 0.427\exp(-\theta/0.129)$]. Using this $\alpha = f(\theta)$ dependence, α-values as low as 0.96 (for $\theta = 0.6\ m^3\ m^{-3}$) and as high as 1.37 (for

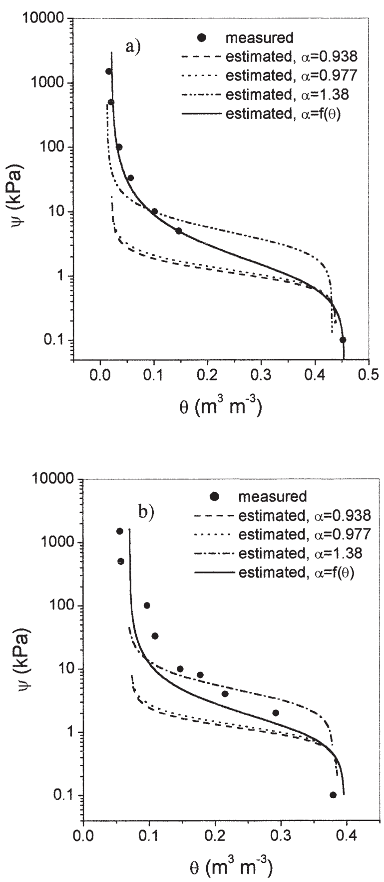

Fig. 5. Soil water retention curves for two sandy soils, measured and estimated with the Arya and Paris (AP) model using constant and variable (Fig. 4) α approaches. The continuous curves are obtained by fitting the van Genuchten (1980) equation to the discrete AP estimated values (20 points for the soil particle size segmentation used).

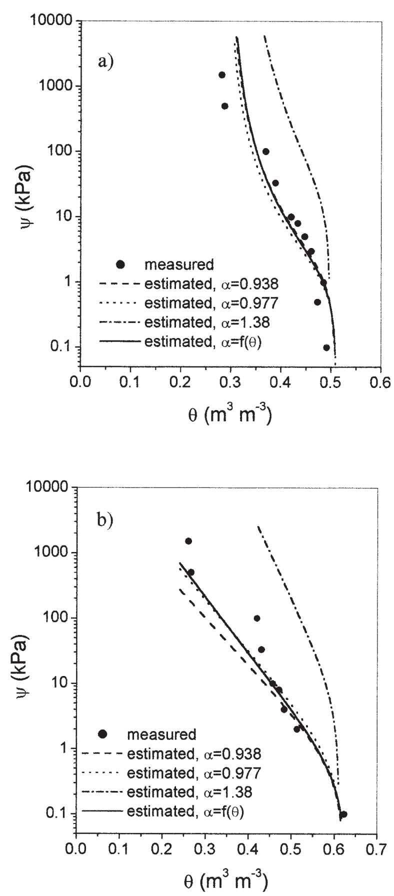

Fig. 6. Soil water retention curves for two clay soils, measured and estimated with the Arya and Paris (AP) model using constant and variable (Fig. 4) α approaches. The continuous curves are obtained by fitting the van Genuchten (1980) equation to the discrete AP estimated values (20 points for the soil particle size segmentation used).

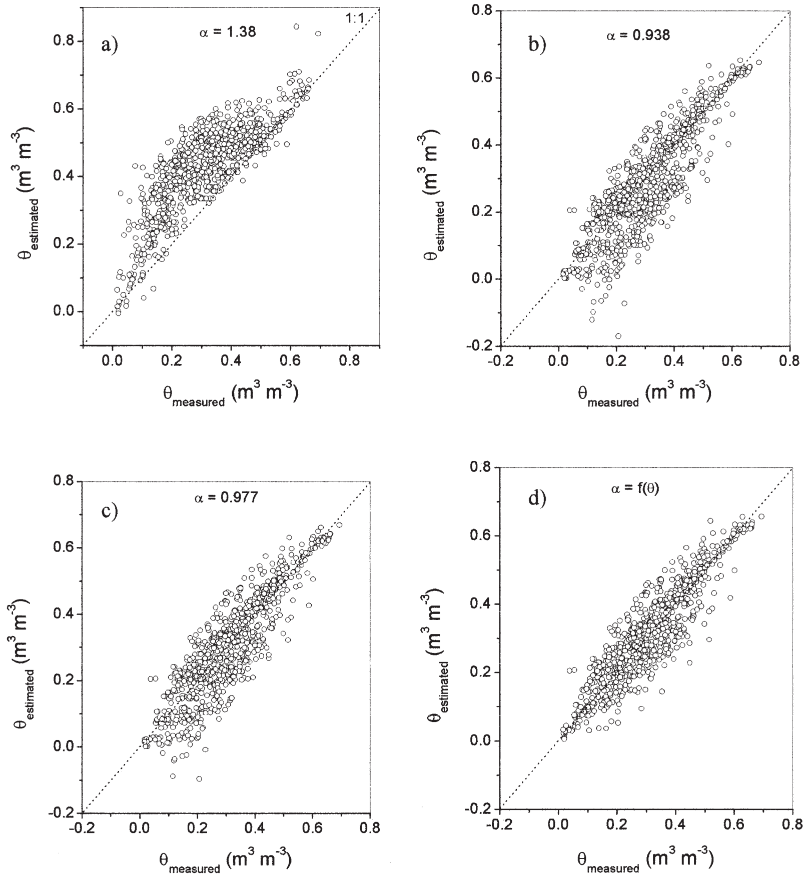

Fig. 7. Soil water content values, measured and estimated with the Arya and Paris (AP) model using constant (a-c) and variable (d) α approaches.

$\theta = 0$) are obtained with the exponential equation. This behavior is very consistent with previous works that found larger values of α for sandy than for clayey soils (Basile and D'Urso, 1997), since very low values of θ are obtained only for sandy soils in retention curves and clayed soils have higher water saturation than sandy soils. The data scatter observed in Fig. 3 may have several sources of errors from the experimental determination of the PSD and the soil water retention data and its fitting using the logistic (sigmoidal) and the van Genuchten (1980) functions, respectively.

Estimation of the Retention Curves

Table 3 shows an example of the retention curve estimation with the AP model using both α-constant (0.977) and $\alpha = f(\theta)$ approaches for a sandy soil of the Rio Grande do Sul soil set. The largest difference in the estimation of ψ occurred at the lower particle diameter values (lower water content). This is caused by the tendency of the exponential equation that relates α and θ to increase for lower values of θ (Fig. 4).

In all cases, the use of the $\alpha = f(\theta)$ approach improved the AP estimation. For the two sandy soils (Fig. 5), $\alpha = 1.38$ provided a better estimation than the estimation obtained with $\alpha = 0.938$ and 0.977, but using $\alpha = 1.38$ caused a great overestimation of ψ for the two clayed soils, especially for the lower water content range values (Fig. 6).

A complete comparison of measured and estimated retention data for all soils is presented in Fig. 7, showing measured and estimated soil water content at the specific soil matric potential used in the experimental retention curves (Table 2), considering both α-constant (0.938, 0.977, and 1.38), and α-variable approaches. Table 4 shows the root mean square deviation and coefficients of the linear fitting between measured and estimated θ at the applied matric potentials for $\alpha = 1.38$, $\alpha = 0.938$, $\alpha = 0.977$, and $\alpha = f(\theta)$.

The worst estimation was obtained with $\alpha = 1.38$, that provided RMSD of 0.136 $m^3\ m^{-3}$, which was twice as large as that of $\alpha = f(\theta)$ (0.062 $m^3\ m^{-3}$). The use of $\alpha = 1.38$ overestimated soil water content in the retention curve for the entire soil sets, although it works relatively well for very sand soils (see Fig. 5), specially at the lower water content range (see Fig. 7a). The modified α-value introduced by Arya and Dierolf (1992) ($\alpha = 0.938$) provided much better estimation of θ when

Table 4. Linear regression coefficients of θ measured and estimated by the Arya and Paris (AP) model as plotted in Fig. 7, for different α-values, where *a* and *b* are the linear and angular coefficients, r^2 is the determination coefficient and RMSD the root mean square deviation.

α	*a*	*b*	r^2	RMSD
				$m^3\ m^{-3}$
1.38	0.186	0.756	0.689	0.136
0.938	−0.012	0.973	0.755	0.080
0.977	0.001	0.977	0.781	0.073
$\alpha = 0.947 + 0.427\exp(-\theta/0.129)$	0.031	0.913	0.817	0.062

compared with $\alpha = 1.38$. The best AP model estimation was obtained with $\alpha = f(\theta)$, but it was quite similar to the estimation provided using $\alpha = 0.977$ and 0.938 and could be used with similar accuracy.

CONCLUSIONS

The characteristic α-value obtained for 104 soil samples from the most representative Brazilian soil types was $\alpha = 0.977$, which is closer to the modified α-value proposed by Arya and Dierolf (1992), ($\alpha = 0.938$), than to the original value of $\alpha = 1.38$ introduced by Arya and Paris (1981).

A first order exponential decay dependence of α with θ was obtained. For very low water content, only measured in very sandy soils in the retention curves, α increased to values as high as about 1.37, that is very close to the α-value suggested by Arya and Paris (1981) in their original formulation. The α-value presented initially a fast decrease with θ, up to θ around 0.2 m^3 m^{-3}. After that value, α presented a slight decrease with θ, reaching a value of 0.96 for θ around 0.6 m^3 m^{-3}. The exponential dependence of α with θ has improved the estimation of the retention curves with the AP model. The lowest RMSD of the estimated water content of the retention curves for all 104 soil samples were 0.062 m^3 m^{-3}, aiming to conclude that the AP model provide relatively good estimation of retention curves for the most representative Brazilian soil types.

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