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MINIMUM NUMBER OF POINTS FOR A RELIABLE SOIL WATER RETENTION CURVE USING RICHARDS' PRESSURE CHAMBER

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ABSTRACT

The soil hydro-physical characteristics are very important for studies about soil water dynamics. The soil water retention curve is a soil characteristic sometimes expensive and time-consuming to be done and could be a problem for farmers. The numbers of points and their tension evaluated are normally choosen arbitrarily. This study aimed to define the fewest pairs of soil moisture and soil water potential points which result in a reliable water retention curve in two different soils (sandy and clay). Using different tensions by the suction table and Richards' pressure chamber, nine replications were adjusted by van Genuchten's equation. Curves with 4, 5, 7, 8, 9, 10, and 13 points were studied and the curve with 13 points was adopted as standard. The obtained parameters for different pairs of soil moisture and their corresponding soil water potential were compared to the equivalent standard curve and submitted to analysis of variance (F test), and their values were compared by the Scott-Knott test (5% of probability). The curve with 7 points, using the tensions of 0; 40; 100; 300; 1,000; 5,000 e 15,000 hPa, was the lower number of points that did not show a statistical difference in any parameters of the model and the point with 15,000 hPa showed to be important and should be used on the combination of points to obtain a good adjustment.

Palavras-chaves:
manejo da irrigação
física de solo
umidade do solo

NÚMERO MÍNIMO DE PONTOS PARA A CONSTRUÇÃO DE UMA CONFIÁVEL CURVA DE RETENÇÃO DE ÁGUA NO SOLO UTILIZANDO A CÂMARA DE PRESSÃO DE RICHARDS

RESUMO

O conhecimento do comportamento físico-hídrico do solo é fundamental para sua caracterização. A determinação da curva de retenção de água é um processo que costuma ser oneroso e demorado, tornando-se de difícil execução por alguns produtores. A escolha do número de pontos utilizados para a determinação da curva de retenção, normalmente é feita de forma arbitrária, sem um critério específico. O objetivo deste trabalho foi definir o menor número de pontos que resulte na descrição de uma curva de retenção de água do solo confiável para dois tipos de solos (arenoso e argiloso). Foram realizadas nove repetições para cada solo, as quais foram submetidas a diferentes tensões pelo método da câmara de Richards e ajustadas pelo modelo de van Genuchten. Realizaram-se curvas contendo 4, 5, 7, 8, 9, 10 e 13 pontos de tensão, sendo que a curva que contem 13 pontos foi adotada como referência na comparação com as demais. Os parâmetros obtidos foram comparados aos seus equivalentes da curva referência e submetidos à análise de variância (teste F), e suas médias comparadas pelo teste de Scott-Knott a 5% de probabilidade. A curva de retenção de água no solo com 7 pontos, e com as tensões 0, 40, 100, 300, 1.000, 5.000 e 15.000 hPa, foi o menor número de pontos que não apresentou diferença estatística em nenhum dos parâmetros do modelo e o ponto de 15.000 hPa se mostrou importante e deve ser utilizado na combinação de pontos para que se consiga um bom ajuste.

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INTRODUCTION

The soil water retention curve expresses the relation between the soil moisture and its corresponding matric potential (YANG; YOU, 2013). The knowledge of this parameter is very important in soil water studies. Among the methods used to construct the soil water retention curve, the one proposed by Richards (1965) is considered the standard and it is the most used. The lab procedure to determine the soil water retention curve using Richard's pressure chamber uses several points with one tension and its corresponding soil moisture to plot the curve.

Many soil attributes can influence directly their water retention, however some of them have more intensity than others. We highlight the relative distribution, the form, and the arrangement of soil particles (REEVE *et al*., 1973; SALTER *et al*., 1966; SHARMA; UEHARA, 1968) available water (Av. Another important attribute is the soil texture, responsible for a great influence on the soil water retention curve. Carvalho and Lima (2000); Martinez *et al*. (1995) and Severiano *et al*. (2013) and texture of Latosols in the Brazilian Cerrado, container-title: Soil Research, page: 193-202, volume: 51, issue: 3, source: CSIRO Publishing, abstract: In the Brazilian Cerrado Biome, Latosols (Oxisols consider the soil texture as the most relevant. Geroy *et al*. (2011) comparing two different spots (south and north face slopes) showed 25% more water retention at the north face that have more silt content and organic matter than the south face. Other factors, such as the temperature and the hysteresis were analyzed in some studies and may also affect the results.

An important factor that some studies do not show in their soil water retention curve characterization is the minimum number of points (pairs of soil moisture and soil water tension). In general, it is used from 6 to 8 pairs of points, including the point in the saturation soil (SILVA *et al*., 2006). Embrapa (1997) recommends 6 pairs of points to construct the water retention curve using Richards' pressure chamber with the tensions 0 (saturation), 100, 330, 1,000, 5,000, and 15,000 hPa.

Dexter *et al*. (2007) and Machado *et al*. (2008) used 11 pairs of points in their water retention curve studies and Blainski *et al*. (2008) and Silva *et al*. (2008) used 12. However, there are many doubts about the number of points necessary to construct one reliable soil water retention curve with the capacity to represent different kinds of soils. Silva *et al*. (2006) analyzing one soil in the Brazilian Savanna "Cerrado biome" concluded that it is necessary 8 pairs of points to determine the water retention curve to this soil. Increasing the number of points also increases the time to finalize the analyses and its cost (HODNETT; TOMASELLA, 2002; SILVA *et al*., 2006)chemical and soil water-retention data suitable for the derivation of a Pedo-Transfer Functions (PTF. Some studies have prioritized the points on the low tensions, because the time to obtain the physic-hydric balance it is lowest to the tensions below 1,000 hPa (MACHADO *et al*., 2008; SILVA *et al*., 2008; TORMENA *et al*., 2008).

Determining the minimum number of points that result a reliable soil water retention curve can be useful to save time and reduce the process cost. Therefore, this study aimed to analyze statistically the fewest pairs of points (soil moisture x soil water potential) that promote such conditions in two different soils: sandy and clay.

MATERIAL AND METHODS

The research was performed on the soil physics lab, Biosystems Engineering Department, College of Agriculture "Luiz de Queiroz" University of São Paulo, Brazil. Two different soils were studied, clay soil (Alfisol Eutroferric) and sandy soil (Oxisol). The clay soil was collected in the university experimental area on the coordinates 22º41´58,91" south e 47º38´44,15" west, with an altitude of 518 m. The sandy soil was collected in the university experimental area on the coordinates 22º 43´02,26" south e 47º 37´06,41" west, with an altitude of 573 m.

Disturbed samples were collected for both soils in enough quantity to create the soil water retention curve and analyze its granulometry. A surface soil layer was removed (0.05 m) and samples up to 0.3 m were collected. The samples were transferred to metal trays for air dry, milled, and sieved, obtaining fine dry soil (FDS). After this, the samples were placed on the electric oven with temperature 105 to

110 ºC, obtaining fine dry soil in the oven (FDSO).

For the soil granulometric characterization, three replicates and the method proposed by Bouyoucos (densimeter) was used, according to methodology standardized by Embrapa (1997). On this research 18 stainless rings with 0.030 m tall and 0.047 m diameter were used, 9 replicates for each soil. In one ring side a synthetic material was placed to hold the soil and increase the contact between the soil inside the ring and the porous plate.

In the process to accommodate the soil inside the rings FDSO was used with care to keep the same level of compaction on all samples. Thus, the soil was compacted inside the rings in three layers, whose final density was 1.26 and 1.12 g cm^{-3} respectively to sandy and clay soils. Even this is not a standard procedure for the soil water retention curve, it was adopted to ensure the elimination of the density as a soil variable.

The sample saturation was done by increasing the water level gradually in a plastic tray up to the soil saturation. These samples were weighted to obtain the water content in the saturation condition (0 hPa of suction pressure). The soil water retention curves for both soils were obtained with continuous drying to reduce the hysteresis effect on the process, i.e. every time the samples reached a stabilized suction pressure they were removed for weighing and returned to the system to increase the pressure until the next point. The soil samples were submitted to different suction pressures (10; 20; 40; 100; 200; 300; 500; 700; 1,000; 5,000, 10,000 and 15,000 hPa), and for each one the correspondent moisture was obtained. Suction table for the pressure up to 40 hPa and Richard's pressure chamber for pressures higher than 40 hPa were used in the process. The temperature was controlled in 20ºC and before getting the last point at 15,000 hPa, the samples were drying in the stove for 24 hours to determine the soil residual moisture.

The parameters $q_{r,}$ n, and α were obtained by using the software Retention Curve – RETC, (VAN GENUCHTEN *et al*., 1991) (equation 1). The parameter m is dependent on n and was calculated by equation 2. Using the parameters from RETC, the soil moisture for all points was estimated, obtaining the error between observed and estimated soil moisture.

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + \left(\alpha\left|\psi_m\right|\right)^n\right]^m} \qquad (1)$$

$$m = 1 - \frac{1}{n} \qquad (2)$$

Where:
θ = Soil moisture (cm^3 cm^{-3});
Ψ_m = Matric potential (hPa);
q_r = Residual moisture (cm^3 cm^{-3});
q_s = Saturation moisture (cm^3 cm^{-3}); and
α, m e n = Adjust parameters.

We opted for 6 combinations of points (Table 1) chosen without any specific criteria, including the curve with 10 points that is normally used in physic soil lab in the Biosystems Engineering Department at ESALQ/USP and a curve with 13 points as a standard for its large number of points.

Jorge *et al*. (2010) mention that it is necessary to include one point with 15,000 hPa when the van Genuchten's model is used to construct the water retention curve. If not, it is possible to get wrong results in the soil water retention curve and consequently miscalculation in the soil moisture. In order to analyze this condition, one point combination was used including only points up to 1,000 hPa (number 8, Table 1).

Table 1. Number and points distribution in the soil water retention curve evaluated

Number of points	Tension points evaluated (hPa)
4	0; 100; 700 e 15,000
5	0; 100; 300; 1,000 e 15,000
7	0; 40; 100; 300; 1,000; 5,000 e 15,000
8	0; 10; 20; 40; 100; 300; 700 e 1,000
9	0; 20; 40; 100; 300; 700; 1,000; 5,000 e 15,000
10	0; 10; 20; 40; 100; 300; 500; 1,000; 5,000 e 15,000
13	0; 10; 20; 40; 100; 200; 300; 500; 700; 1,000; 5,000; 10,000 e 15,000

The estimated data were determined by the statistics parameters: average; maximum;

minimum, standard deviation (Equation 3), standard error of the average (Equation 4), and the coefficient of variation (Equation 5).

$$ó = \left[\frac{\sum \left(x_{i} - \bar{x} \right)^2}{n-1} \right]^{0,5} \quad (3)$$

$$SE_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \quad (4)$$

$$CV = \frac{\sigma}{\bar{x}} \times 100 \quad (5)$$

Where:
σ = Standard deviation;
x_i = Observed data;
$\bar{x}$ = Average of observed data;
n = Number of sample points;
$SE_{\bar{x}}$ = Average Standard Error; and
CV = Coefficient of variation.

To compare observed moisture with estimated moisture different analysis were used: coefficient of determination "r^2" (equation 6); coefficient of correlation "r" (equation 7); accuracy index "d" (equation 8) (Willmott *et al.*, 1985); agreement index "c" (equation 9) (CAMARGO; SENTELHAS, 1997); and standard error of estimative "SEE" (equation 10).

$$r^2 = \frac{a\sum y + b\sum xy - n\left(\bar{y}\right)^2}{\sum y^2 - n\left(\bar{y}\right)^2} \quad (6)$$

Where:
r^2 = coefficient of determination;
a, b, n = replication number;
x = number of points observed;
y = number of points estimated; and
$\bar{y}$ = average of estimated data.

$$r = \frac{\sum \left(x_i - \bar{x} \right)\left(y_i - \bar{y} \right)}{\sqrt{\left[\sum \left(x_i - \bar{x} \right)^2 \right] \times \left[\sum \left(y_i - \bar{y} \right)^2 \right]}} \quad (7)$$

Where:
r = correlation coefficient;
y_i = estimated data.

$$d = 1 - \left[\frac{\sum_{i=1}^{n} \left(y_i - x_i \right)^2}{\sum_{i=1}^{n} \left(\left| y_i - \bar{x} \right| + \left| x_i - \bar{x} \right| \right)^2} \right] \quad (8)$$

Where:
d = accuracy index.

$$c = r \times d \quad (9)$$

Where:
c = agreement index.

$$SEE = \sqrt{\frac{\sum \left(x_i - y_i \right)}{n-1}} \quad (10)$$

Where:
SEE = Standard Error of Estimative.

Each parameter estimate by van Genuchten's model was compared to a correspondent on the standard curve. The parameters were analyzed with variance analysis (F test) and your average comparing by the Scott-Knott test at 5%.

RESULTS AND DISCUSSION

The soil granulometric distribution used in this study is shown in Table 2. As we can observe very distinguished soils were used to try to amplify the differences at the results.

In Table 3 is presented the parameters for both soils and the combination points observed. The CV for the parameters qs, m, and n is considered low according to Pimentel-Gomes (1990), and for the parameters qr and α the CV it is totally variable when we compare between the soils and among the different point combinations.

Table 2. Soil Granulometric distribution using in this study

Soil	% Clay	% Silt	% Sand
Clay soil	56.55	20.12	23.33
Sandy soil	11.42	8.24	80.34

Table 3. Van Genuchten's model parameters for both soils

Nº of pars	Soil		Parameters				
			θs	θr	α	n	m
13	sandy	average	0.5095	0.0497	0.0410	1.6807	0.4047
		CV (%)	3.06	5.52	10.80	2.32	3.41
	clay	average	0.6051	0.0006	0.1171	1.2291	0.1864
		CV (%)	1.44	44.48	21.84	0.66	2.89
10	sandy	average	0.5100	0.0483	0.0414	1.6724	0.4017
		CV (%)	3.00	6.73	10.02	2.46	3.66
	clay	average	0.6201	0.0002	0.1156	1.2207	0.1808
		CV (%)	1.41	54.08	18.54	0.50	2.25
9	sandy	average	0.5171	0.0500	0.0412	1.6918	0.4085
		CV (%)	2.83	6.93	8.72	2.61	3.78
	clay	average	0.6174	0.0004	0.1275	1.2146	0.1767
		CV (%)	1.31	84.65	16.79	0.47	2.19
8	sandy	average	0.5129	0.0234	0.0445	1.5768	0.3649
		CV (%)	2.91	65.301	9.44	3.92	6.87
	clay	average	0.5985	0.0003	0.1287	1.1906	0.1601
		CV (%)	2.46	111.42	21.76	0.90	4.74
7	sandy	average	0.5178	0.0511	0.0409	1.6959	0.4102
		CV (%)	2.63	4.81	10.96	1.91	2.76
	clay	average	0.6201	0.0004	0.1209	1.2245	0.1833
		CV (%)	1.29	61.73	16.13	0.63	2.79
5	sandy	average	0.5186	0.0581	0.0268	1.9355	0.4823
		CV (%)	2.54	4.37	18.24	4.66	5.10
	clay	average	0.6234	0.0003	0.1055	1.2188	0.1795
		CV (%)	1.33	82.16	10.97	0.33	1.51
4	sandy	average	0.5186	0.0541	0.0303	1.8273	0.4517
		CV (%)	2.54	4.62	20.14	4.51	5.61
	clay	average	0.6171	0.0006	0.1084	1.1906	0.1599
		CV (%)	1.32	55.26	7.25	1.54	8.05

When we compare the soils, the qr CV is lower on sandy soil. However, in both soils, the curve that presented the largest value of CV for this parameter is the number 8, where it is not included the point with 15,000 hPa. Other authors like Jorge *et al*. (2010) mentioned that the point with 15,000 hPa must be included in the soil water retention curve when using van Genuchten's model. The parameter α is totally variable between the soils and among the point combinations but presented the lowest values than Grego and Vieira (2005). Therefore, using just the parameter CV was not possible to find the best number of points necessary to construct a reliable soil water retention curve.

The values of statistical indices calculated for both soils are presented in Figure 1. In most indices, we can detect expressive variation, except to SEE that presented the highest values in the curve with 8, 5, and 4 pairs of points. One more time we can observe the importance of the point with 15,000 hPa (curve 8), especially for clay soil.

When we compare the observed with estimated values of soil moisture (Figure 2) it is possible to see that the curves with 13, 10, 9 and 7 pair of points are more precise than curves with 8, 5 and 4 pairs of point, i.e. presented the lowest deviation for the line 1:1 (Figure 2).

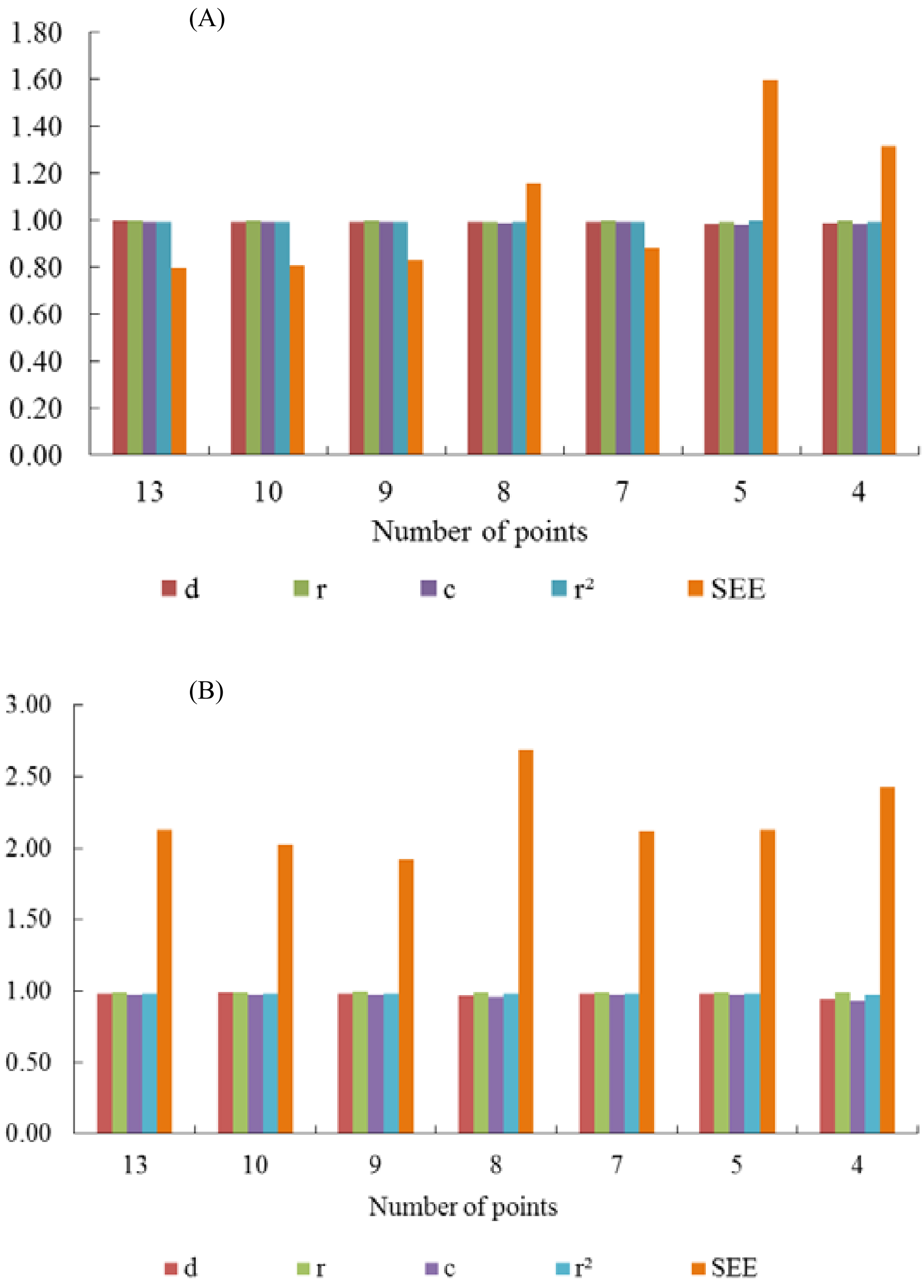
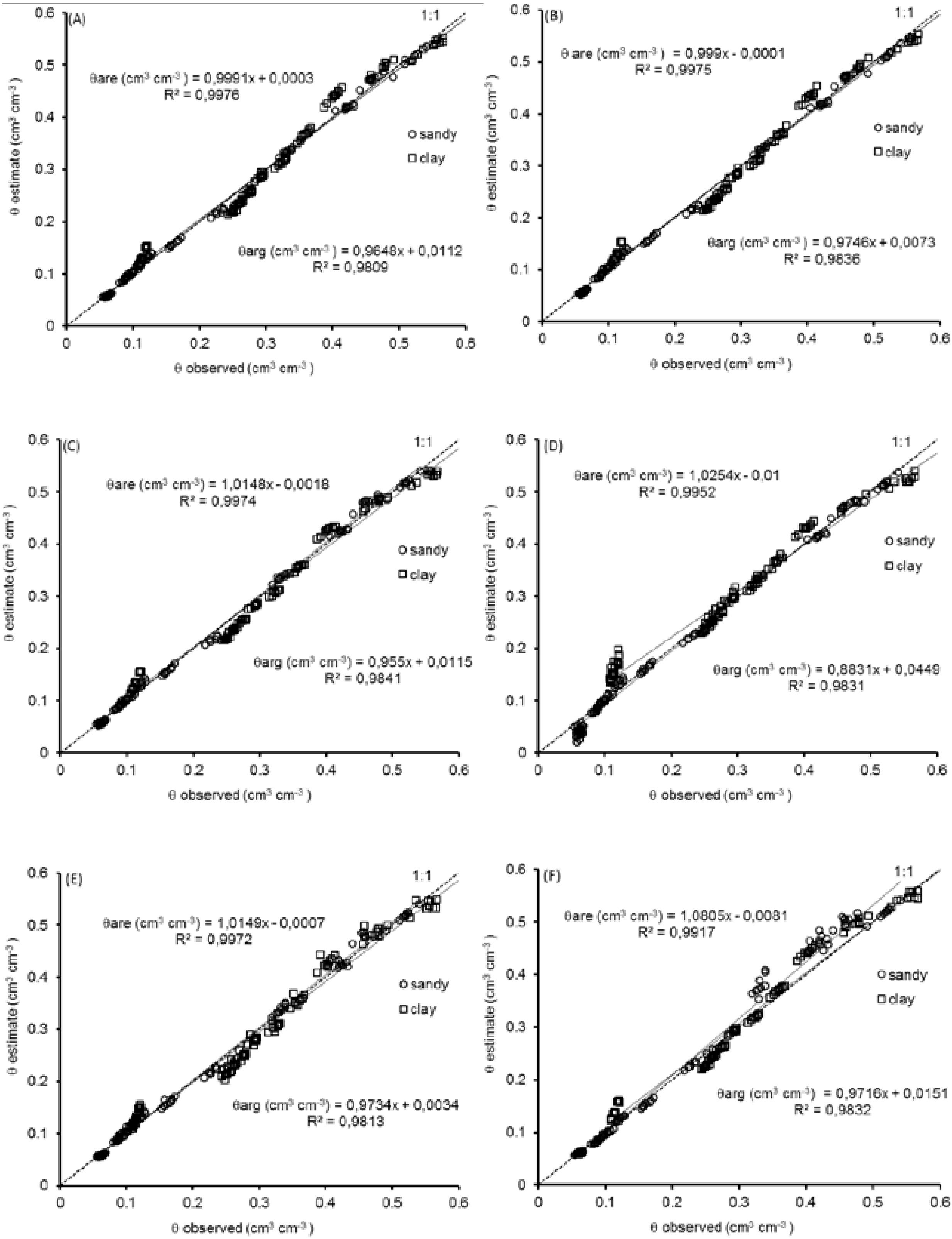


Figure 1. Statistical indices calculated for both soils (A) sandy and (B) clay. Y axis in different scale for better visualization


(A)
1:1
θare (cm³ cm⁻³) = 0,9991x + 0,0003
R² = 0,9976
θarg (cm³ cm⁻³) = 0,9648x + 0,0112
R² = 0,9809
(B)
1:1
θ are (cm³ cm⁻³) = 0,999x - 0,0001
R² = 0,9975
θarg (cm³ cm⁻³) = 0,9746x + 0,0073
R² = 0,9636
(C)
1:1
θare (cm³ cm⁻³) = 1,0148x - 0,0018
R² = 0,9974
θarg (cm³ cm⁻³) = 0,955x + 0,0115
R² = 0,9841
(D)
1:1
θare (cm³ cm⁻³) = 1,0254x - 0,01
R² = 0,9952
θarg (cm³ cm⁻³) = 0,8831x + 0,0449
R² = 0,9831
(E)
1:1
θare (cm³ cm⁻³) = 1,0149x - 0,0007
R² = 0,9972
θarg (cm³ cm⁻³) = 0,9734x + 0,0034
R² = 0,9813
(F)
1:1
θare (cm³ cm⁻³) = 1,0805x - 0,0081
R² = 0,9917
θarg (cm³ cm⁻³) = 0,9716x + 0,0151
R² = 0,9832
sandy
clay
θ estimate (cm³ cm⁻³)
θ observed (cm³ cm⁻³)

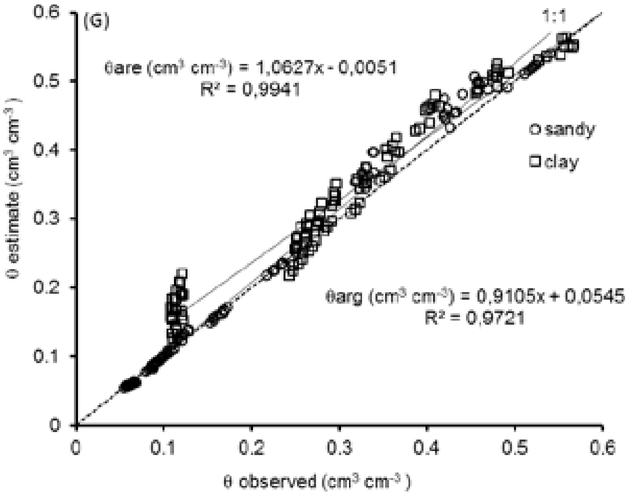


Figure 2: Correlation between observed and estimated soil moisture for each soil water retention curve. A = 13; B = 10; C = 9; D = 8; E = 7; F = 5, and G = 4 pairs of points

The results showed on Figure 2 can be confirmed for both soils by statistical analyses of van Genuchten's parameters. When we analyze the sand soil (Table 4) and the clay soil (Table 5), curves with 13, 10, 9, and 7 pairs of points not presented statistical difference among them in any parameter of the model. Similar results were observed by Jorge *et al*. (2010), which used undisturbed samples collected in no-till field condition.

Table 4. Average values of van Genuchten's parameters to sandy soil

Number of pars of points	Model parameters			
	θr (cm^3 cm^{-3})	α (kPa^{-1})	n	m
13	0.0497 b	0.0410 a	1.6807 c	0.4047 c
10	0.0483 b	0.0414 a	1.6724 c	0.4017 c
9	0.0501 b	0.0412 a	1.6918 c	0.4085 c
7	0.0511 b	0.0409 a	1.6959 c	0.4102 c
8	0.0234 c	0.0445 a	1.5768 d	0.3649 d
5	0.0581 a	0.0268 b	1.9355 a	0.4823 a
4	0.0541 a	0.0303 b	1.8273 b	0.4517 b
Average	0.0478	0.0381	1.7258	0.4177
CV (%)	13.26	12.12	3.46	4.66
F test	28.45**	18.75**	35.12**	34.45**

Averages followed by the same letter on the column do not present statistical difference (Scott-knott p > 0.05); **significant at 1 %.

The curve with 8 pairs of points was statistically different from the standard curve but the curve with 7 pairs of points was not. This result can be explained by the absence of the point with 15,000 hPa in the curve with 8 points and its presence in the curve with 7 points. Therefore, we can reinforce the importance of this point to achieve a good fit to van Genuchten's model.

Table 5. Average values of van Genuchten's parameters to clay soil

Number of pars of points	Model parameters			
	θr (cm^3 cm^{-3})	α (kPa^{-1})	n	m
13	0.589 10-3 a	0.1171 a	1.2291 a	0.1864 a
10	0.222 10-3 a	0.1156 a	1.2207 a	0.1807 a
9	0.411 10-3 a	0.1275 a	1.2146 a	0.1767 a
7	0.444 10-3 a	0.1209 a	1.2245 a	0.1833 a
8	0.289 10-3 a	0.1287 a	1.1906 b	0.1601 b
5	0.333 10-3 a	0.1055 b	1.2188 a	0.1795 a
4	0.578 10-3 a	0.1084 b	1.1906 b	0.1598 b
Average	0.495 10-3	0.1134	1.2127	0.1752
CV (%)	69.07	17.13	1.80	3.84
F test	2.20ns	5.08**	23.75**	23.41**

Averages followed by the same letter on the column do not present statistical difference (Scott-knott p > 0.05); **significant at 1 %.

Results of different simulations are presented on Figure 3 for both soils. It is possible to observe that the points plotted on Figure 3A and 3C (curves without statistical difference) are much more precise that Figure 3B and 3D (curves with statistical difference) when compared with the standard curve (13 points).

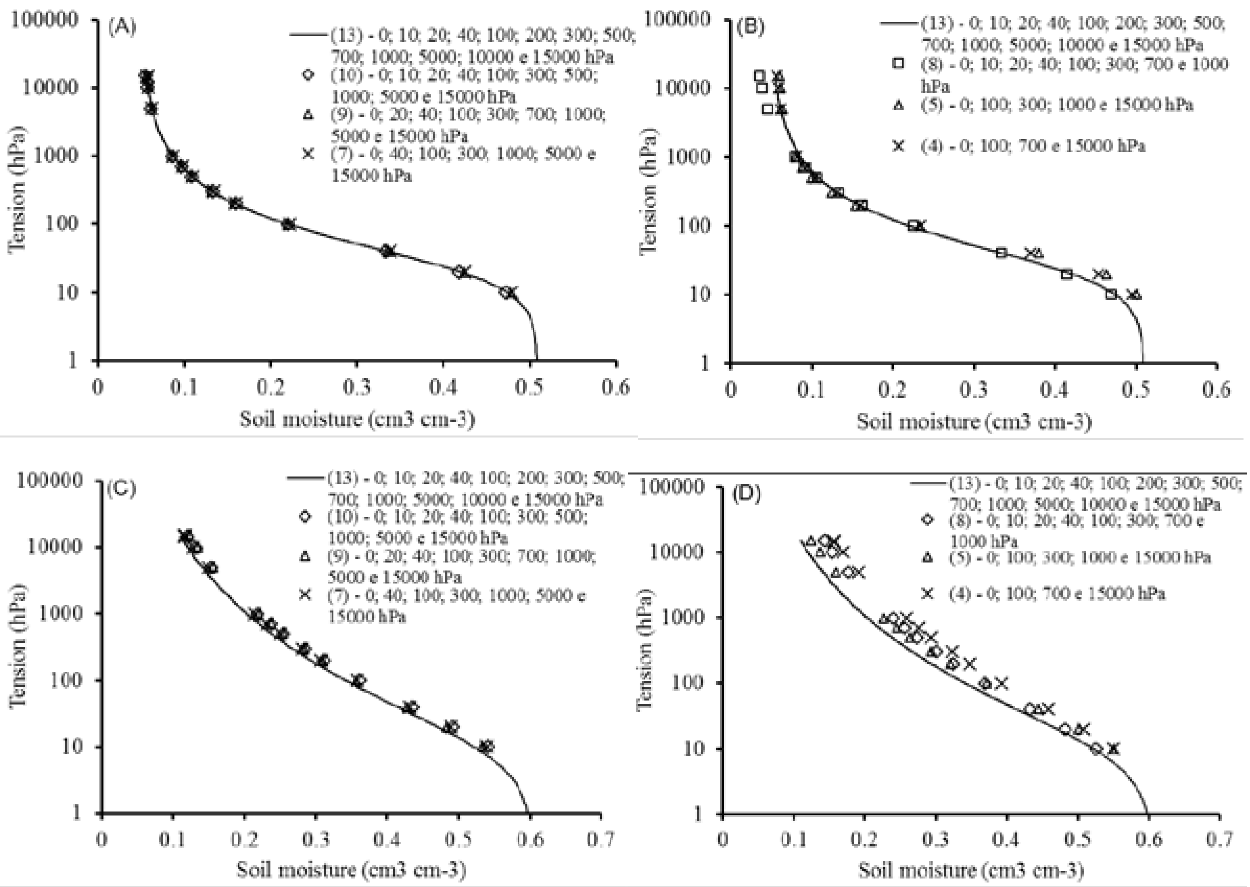


Figure 3. Soil water retention curve without statistical difference (A – sandy soil and C – Clay soil) and with statistical difference (B - Sandy soil and D – Clay soil) among the standard curve (13 pairs of points)

In this scenario, we can affirm that the curve with 7 pairs of points and with the tensions 0, 40, 100, 300, 1.000, 5,000 e 15,000 hPa includes the minimum of points to represent the reliable soil water retention curve. This result is similar to that showed by Silva *et al*. (2006) that found 8 points analyzing a soil (Oxisol) in the Brazilian Cerrado Biome and higher than the one of Jorge *et al*. (2010) that found curves with 4 to 6 points. However, one important observation is necessary: there is not possible to say that the other curve with any 7 pairs of points can offer the same result. The results obtained in this study are valid just if we use the same point combinations. We emphasize that studies that seek to improve the techniques for obtaining a water retention curve in the soil are fundamental for the evolution of this methodology. In addition, it is important that this topic be addressed again, since there is a huge lack of information on the topic and this approach is very relevant for the irrigated agriculture, in the sense of making accurate water management. Having a retention curve that accurately expresses the tension with which the water is retained in the soil, means, above all, applying the correct irrigation blade to supply the water demands of agricultural crops.

CONCLUSION

- In this study, the curve with 7 pairs of points was enough to represent one reliable soil water retention curve for both, sandy and clay soils. However, it is necessary to respect the same point combinations, since it was possible to generate one curve with more points (8), but with inferior results.
- The point with 15,000 hPa must be used on the point combinations to obtain a good fit to van Genuchten's model, in agreement with other studies.

- Using 7 pairs of points will make it possible to reduce the time consuming and the cost to obtain the soil water retention curve, against the actual one used by Biosystems Engineering Department ESALQ/USP.

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