Estimation of the Hydrodynamic Parameters of Soils Subjected to Water Scarcity: Application of BEST and Introduction of a Specific Methodology

Marco Aurélio Calixto Ribeiro de Holanda[1*], Diogo Botelho Correa de Oliveira[2], Willames de Albuquerque Soares[3]

[1]Post Graduate Program in Nuclear and Energetic Technologies – PGPNET, Department of Nuclear Energy – DEN, Center of Technology and Geosciences – CTG, Federal University of Pernambuco – UFPE, Recife, Pernambuco, Brazil, ORCiD:0000-0002-0860-2458.*
[2]Post Graduate Program in Nuclear and Energetic Technologies – PGPNET, Department of Nuclear Energy – DEN, Center of Technology and Geosciences – CTG, Federal University of Pernambuco – UFPE, Recife, Pernambuco, Brazil, ORCiD: 0000-0003-1556-5664.
[3]Post Graduate Program in Civil Engineering – PEC, Department of Civil Engineering, Polytechnic School of Pernambuco – POLI, Recife, Pernambuco, Brazil, ORCiD: 0000-0003-3268-7241.

ABSTRACT

Propose a specific method (Junction Between Arya and Heitman and Haverkamp - JAHH), similar to BEST, to obtain the hydrodynamic parameters of soils in Pernambuco, Brazil. Sample: Department of Civil Engineering, Polytechnic School of Pernambuco – POLI, between March 2019 and February 2021. For this, BEST and JAHH were used to obtain the hydrodynamic characteristics of the collected materials, and the results of both methods were compared with simulations performed in Hydrus-1D. Sorptivity and K_s, acquired using both methods, presented differences reached 68.38% regarding K_s. The characteristic radius of the pores (λ_m) and capillary length (λ_c) obtained with BEST are not coherent, and this can be explained because during the evaluation of one sandy soil, λ_m values were the highest and λ_c were the lowest, when the opposite was expected. The use of JAHH to estimate soil parameters could generate more coherent estimates than BEST-slope, even though both of them have presented results of the same proportion, such as sorptivity and saturated hydraulic conductivity, for exemple. Therefore, the proposed method presented more pertinent results when compared to BEST regarding the studied soils.

Keywords: Beerkan; infiltration tests; soil columns; Hydrus-1D.

1. INTRODUCTION

The study of physical-water processes that occur in the soil, such as water infiltration, requires the estimation of its hydrodynamic parameters [1-3]. For this purpose, semi-physical methods have been used over the years, such as the Beerkan and Beerkan Estimation of Soil Transfer (BEST). They rely on the textural composition of the soils, are more simple, robust and cheaper than the Reverse and Evaporation methods [4-5].

[6] used the Beerkan methodology to predict shape and normalization parameters of water retention curves in the soil and also, the hydraulic conductivity to avoid flooding in urban areas, concluding that the implementation of permeable pavements on tunnel entrances using this method is a feasible alternative.

Aiming the validation of BEST-slope in Yellow Latosols and Fluvial Neosols of Northeastern Brazil, [7] compared the values of the estimated hydrodynamic parameters with results obtained by other authors and observed that both are similar.

Though, this method (BEST) may not be suitable for Brazilian soils, and authors like [8] have proposed some optimizations in BEST-slope for new urban soils, composed for several anthropogenic materials, since this method did not provide coherent results. The changes made by these authors have focused on obtaining normalization parameters of the hydraulic conductivity curves and, as a result, this method started being known as BEST-intercept.

[9] have applied BEST-slope and BEST-intercept methods to evaluate the interference that the height in which the water is poured during the infiltration test has on soils from Sicily. It was demonstrated that the BEST-intercept which contains the modifications proposed by [8] presented better results than the BEST method which was originally proposed by [10]. According to [11], the K_s values estimated by BEST-intercept and BEST-slope are different. Regarding Sandy Loam and Loamy Sand soils, BEST-intercept estimates were higher than BEST-Slope's. Other authors such as [12] and [13] also presented similar results for these types of soil.

[14], while performing infiltration tests on transparent acrylic columns, using the same soils from Sicily used by [9], have observed that BEST-slope presented plausible results of saturated hydraulic conductivity (K_s) in only 57% of the tests, while BEST-intercept had positive K_s values in all infiltration tests, without exception. Therefore, specific soils and conditions may impair the use of some BEST variants (slope, steady and intercept) [15].

Therefore, knowing that BEST-slope may not present coherent results for all soils, this study proposes a method that could obtain parameters of the normalization and shape of hydraulic conductivity curves and water retention in soils from Pernambuco, Northeastern Brazil.

2. MATERIAL AND METHODS

2.1 Area of study

Four cities in the state of Pernambuco (Recife, Caruaru, Custódia and Santa Cruz da Baixa Verde), Brazil, were chosen in order to contemplate the three climatic regions of the state, Zona da Mata, Agreste and Sertão, Figure 1. All cities are near the main access road (BR-232) that connects the coast to the countryside.

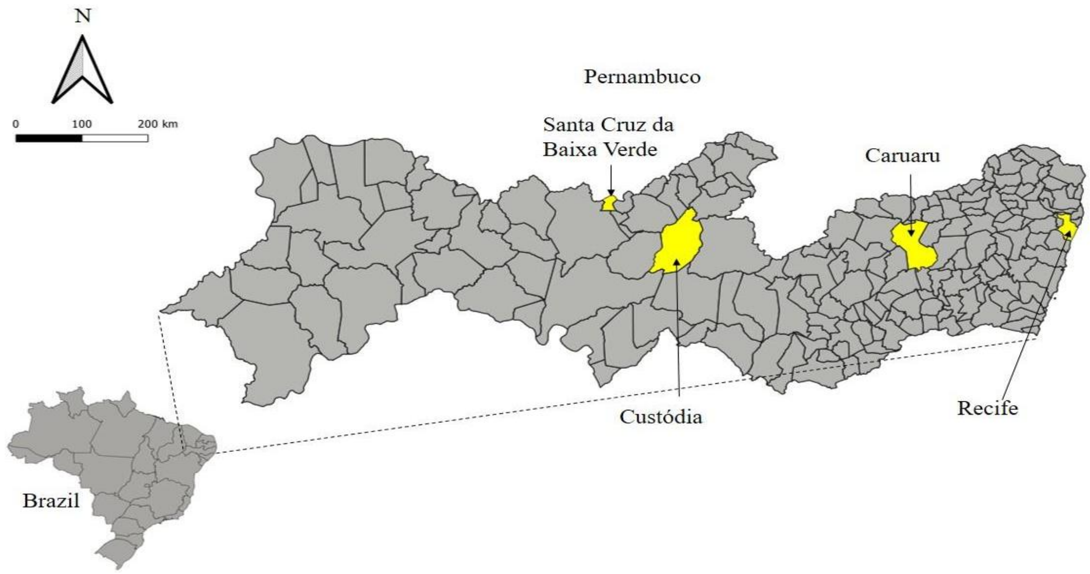

Fig. 1. Cities chosen for soil collections

In these locations, disturbed soil samples were collected to determine the granulometric composition through the sedimentation method and laboratory infiltration tests using the Beerkan methodology. From each of the four cities, approximately 80 kg of soil were collected. For this, a shovel, a hoe, a pickaxe and raffia bags were used for material transportation.

From the 80 kg collected, 62.5% was actually soil, whereas the other 37.5% were rocks and roots, those were segregated during sample preparation. Besides that, the information on georeferenced coordinates of sampling sites ware also collected, Table 1.

Table 1. Geolocation of soil collection points

City	Latitude	Longitude	Altitude (m)
Recife	S 8° 1' 12.675"	W 34° 57' 8.80704"	13,24
Caruaru	S 8° 18' 22.0338"	W 35° 55' 59.32236"	574,38
Custódia	S 8° 4' 56.7534"	W 37° 39' 25.3242"	556,36
Santa Cruz da Baixa Verde	S 7° 51' 7.53336"	W 38° 10' 15.68676"	977,05

2.2 Laboratory Tests

In order to determine the granulometric composition of each of the four collected soils, sedimentation and sieving tests were performed using the densimeter method [16, 17], as described by the Brazilian Technical Standards, NBR 7181 [18].

Water infiltration tests in the soil have generated ordered pairs between time and cumulative infiltration as results, once equal and known volumes (15 ml) are added to the infiltrometer and the time it takes for water to infiltrate is counted [19]. These were performed in 140 mm diameter, 330 mm height transparent acrylic columns. The columns had hollow bottoms to ensure free drainage [20] and they were filled with a 55 mm high gravel layer; a geotextile blanket to prevent the intrusion of soil into the voids of the drainage layer, and a 220 mm high soil layer (Figure 2). All tests were performed in triplicate and their averages were calculated.

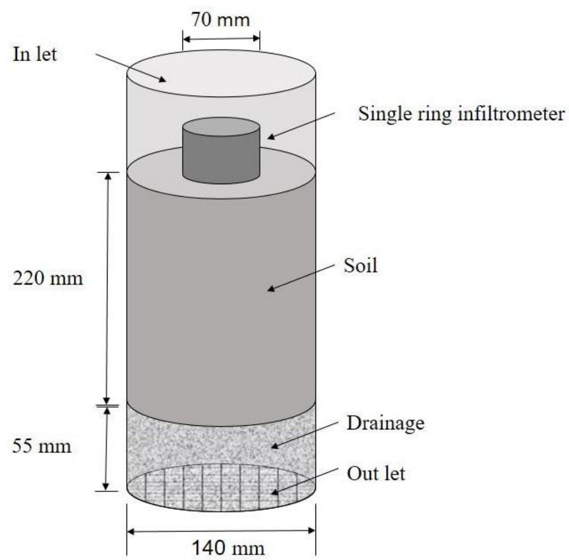

Fig. 2. Schematic representation of the soil columns (Adapted from Holanda et al., 2020).

In this case, the soil was gradually placed every 150 g, and compacted with a rubber stopper to ensure that the column had a uniform density [21, 22]. Besides that, the single ring infiltrometer positioned in the center of the column measured 70 mm diameter and the amounts of water used during the test were identical (15 mL).

2.3 Three-dimensional Conditions of the Infiltration Test

In order to guarantee the three-dimensionality of the infiltration tests, the cumulative infiltration of water into the soil was calculated (*I(t)*) using the horizontal infiltration rate (ϑ) according to the equation proposed by [23], Equations 1 and 2, respectively.

$$I(t) = S\sqrt{t} \quad (1)$$

$$\vartheta = \frac{S}{(2\sqrt{t})} \quad (2)$$

S represents the sorptivity in mm $s^{-0.5}$ and *t*, the time in seconds. Since the diameter of the single ring infiltrometer and the acrylic tube measure 70 and 140 mm, respectively, there is a distance of 35 mm between both of their walls. Therefore, if *I(t)* is not equal to, or greater than the distance between the walls of both pieces (35 mm), then it was ensured that the infiltration test was three-dimensional.

2.4 Obtaining the Hydrodynamic Parameters of the Soil Through BEST

The Beerkan of Estimation Soil Transfer (BEST) proposed by [10], also known as BEST-slope, can be subdivided into two stages. The first consists in analyzing the particle size distribution (PSD), which uses the adjustment model of the granulometric curve proposed by [24], and the second is composed of the infiltration tests according to the Beerkan methodology.

The shape parameters (*n*, *m* and *η*) of the water retention curve in the soil were determined using the Equation 3,

$$F(D) = \left(1 + \left(\frac{D_g}{D}\right)^N\right)^{-M} \qquad \text{in which } M = 1\text{-}2/N \qquad (3)$$

where $F(D)$ represents the particle size distribution, D the particle size (mm), D_g the particle size scale parameter (mm) and M and N shape parameters of the particle size distribution curve. The middle shape index (p_m) was obtained through Equation 4.

$$p_m = \frac{MN}{1+M}(1+k)^{-1} \qquad \text{in which } k = \frac{2s-1}{2s(1-s)} \qquad (4)$$

Where K is the coefficient defined by [25] and *s* the fractal dimension (0.5 < *s* < 1). The parameters n, m and η were obtained through Equations 5-7,

$$n = \frac{2}{1-m} \qquad (5)$$

$$m = \frac{1}{p_m}\left(\sqrt{1+{p_m}^2} - 1\right) \qquad (6)$$

$$\eta = \frac{2}{nm} + 2 + p \qquad (7)$$

where p is the tortuosity factor, which assumes unitary value.

For the normalization parameters, saturated volumetric moisture, (θ_s) saturated hydraulic conductivity (K_s) and scale parameter for water pressure (h_g) were initially calculated θ_s, Equation 8,

$$\theta_s = W_s \rho_d \qquad (8)$$

where W_s is the saturated gravimetric moisture and ρ_d the specific soil mass. The three-dimensional infiltration of water into the soil for the steady ($I_{+\infty}(t)$) and transient states ($I(t)$), were calculated according to the Equations 9 and 10,

$$I_{+\infty}(t) = (aS^2 + K_s)t + c\frac{S^2}{K_s} \qquad (9)$$

$$I(t) = S\sqrt{t} + (aS^2 + bK_s)t \qquad (10)$$

where a, b and c are auxiliary variables based on the initial conditions described by [26], and are defined in Equations 11-13,

$$a = \frac{\tau}{r\Delta\theta} \qquad (11)$$

$$b = \frac{2-\beta}{3}\left(1-\left(\frac{\theta_0}{\theta_s}\right)^{\eta}\right)+\left(\frac{\theta_0}{\theta_s}\right)^{\eta} \qquad (12)$$

$$c = ln\left(\frac{1}{\beta}\right)\frac{1}{2\left(1-\left(\frac{\theta_0}{\theta_s}\right)^{\eta}\right)(1-\beta)} \qquad (13)$$

Where β equals 0.6, τ equals 0.75, θ_0 and θ_s are the initial and saturated volumetric moisture values, respectively, and r stands for the infiltrometer radius. In this case, according to [26], the premise that θ_0 must be less than 25% of θ_s must be respected. Equation 14 was used to obtain the scale parameter for water pressure.

$$h_g = \frac{S^2}{c_p(\theta_s-\theta_0)\left(1-\frac{\theta_0}{\theta_s}\right)^{\eta}K_s} \qquad (14)$$

Where c_p is defined by Equation 15,

$$c_p = \Gamma\left(1+\frac{1}{n}\right)\left(\frac{\Gamma\left(m\eta-\frac{1}{n}\right)}{\Gamma(m\eta)}+\frac{\Gamma\left(m\eta+m-\frac{1}{n}\right)}{\Gamma(m\eta+m)}\right) \qquad (15)$$

where Γ stands for the gamma function. To get to the K_s value, it has to be considered the value of b, from Equation 12, and an adjustment made to the object function for the accumulated infiltration, $f_I(S, K_s, l)$, which was minimized according to Equation 16,

$$f_1(S, K_s, l) = \sum_{i=1}^{l}\left(I^{exp}(t_i) - I(t_i)\right)^2 \qquad (16)$$

where l stands for the number of considered points in the transitory state, and $I^{exp}(t_i)$ represents the experimental cumulative infiltration. Equations 17 and 18 were used to obtain the capillary length scale (λ_c) and the characteristic radius of the pores (λ_m), respectively,

$$\lambda_c = \frac{qS^2}{K_s(\theta_f-\theta_i)} \qquad (17)$$

$$\lambda_m = \frac{\sigma}{g\rho_w\lambda_c} * 10^2 \qquad (18)$$

where σ stands for the water surface tension; q is a constant equal to 0.55, and ρ_w the water density.

2.4 Obtaining the Hydrodynamic Parameters of the Soil Through JAHH

Just like BEST-slope, Junction Between [27] and [26] (JAHH) was created in two stages. The first, responsible for the particle size distribution analysis, is based on the model proposed by [27], and as an adjustment of the particle size curve, it used the model of three adjustment parameters proposed by [28], Equation 19,

$$F(D) = P_0 + \frac{100 - D_m}{\left(1 + \left(\frac{\mu}{D}\right)^{\nu}\right)^{\lambda}} \quad (19)$$

where D corresponds to the diameter of the soil particles, *F(D)* the percentage of particles with a diameter less than D; μ, v and λ are the adjustment parameters, D_m the minimum diameter of the soil particles, and P_0 the percentage of particles with a diameter less than or equal to D_m.

The model proposed by [27] assumes that soil particles are considered spherical. Besides these, authors suggested that in order to obtain the radius of the pores (r_i), it must be performed beforehand, the conversion to the equivalent water pressure in the soil (h_i) through the radius of the particles (R_i) and the capillarity, Equations 20 and 21,

$$r_i = R_i \sqrt{\frac{2}{3} n_i{}^{1-\alpha} e} \quad (20)$$

$$h_i = \frac{2\gamma \cos \Theta}{Q_w g r_i} \quad (21)$$

where r_i is the radius of the cylindrical pore, n_i the amount of particles present in the i-th fraction, h_i the water pressure in the soil, *Θ* is the contact angle, Q_w and γ the density and surface tension of the water, respectively, and g the gravity acceleration.

From the values of the water potential in the soil, the values of the volumetric moisture used in obtaining the water retention curves [$h(\theta)$] in the soil were captured. The values of the shape parameters, m, n and η, and the parameter h_g, were also obtained using the values of the potential, or the equivalent pressure of water in the soil.

The second stage of JAHH was exactly the same as the second stage of BEST-slope, i.e. the model proposed by [26] was used to obtain the parameters for normalizing the hydraulic conductivity curve ($K(\theta)$).

2.5 Simulation

To simulate the water flow in the soil, Hydrus-1D was used considering the Van Genuchten-Mualem model, described by Equations 22 and 23. As upper boundary conditions, the atmospheric conditions were adopted, while for the lower boundary condition, the free drainage was considered.

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left(1 + \left|\frac{h}{h_g}\right|^{n}\right)^{1-\frac{1}{n}}} & h \leq 0 \\ \theta_s & h \geq 0 \end{cases} \quad (22)$$

$$K(\theta) = \begin{cases} K_s \left(\dfrac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\eta} \left\{1 - \left[1 - \left(\dfrac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\frac{1}{m}}\right]^{m}\right\}^{2} & h \leq 0 \\ K_s & h \geq 0 \end{cases} \quad (23)$$

θ corresponds to the volumetric soil moisture ($cm^3\ cm^{-3}$), h to the matric potential (cm), θ_r to the volumetric residual moisture ($cm^3\ cm^{-3}$) and θ_s to the volumetric saturated moisture ($cm^3\ cm^{-3}$). As initial conditions, the parameters obtained with the infiltration tests and with BEST-slope and JAHH were used.

3. RESULTS AND DISCUSSION

From the sedimentation tests, the granulometric compositions of the four soils studied were obtained. The amounts of sand, silt and clay, as well as the textural classification of each of the soils are presented in Table 2, where it can be observed that the soil from Custódia is the sandiest and the one from Santa Cruz da Baixa Verde, the most clayey among them.

Table 2. Granulometric composition and textural classification of the soils from Pernambuco

City	Sand (g Kg^{-1})	Silt (g Kg^{-1})	Clay (g Kg^{-1})	Classification
Recife	816.3	36.4	147.2	Sandy loam
Caruaru	790.6	52.4	157.1	Sandy loam
Custódia	835.3	44.3	120.4	Loamy sand
Santa Cruz da Baixa Verde	559.1	82.4	358.5	Sandy clay loam

As a result of the granulometry tests, it was also possible to assemble the particle size distribution curves obtained with the fitting model proposed by [24] used at BEST-slope, and with the fitting model proposed by [28] used at JAHH, respectively (Figures 3 and 4). In this case, it is possible to observe that the Particle Size Distribution Curves (PSD) of the model used in JAHH have a better fit than those obtained with the model used in BEST-slope.

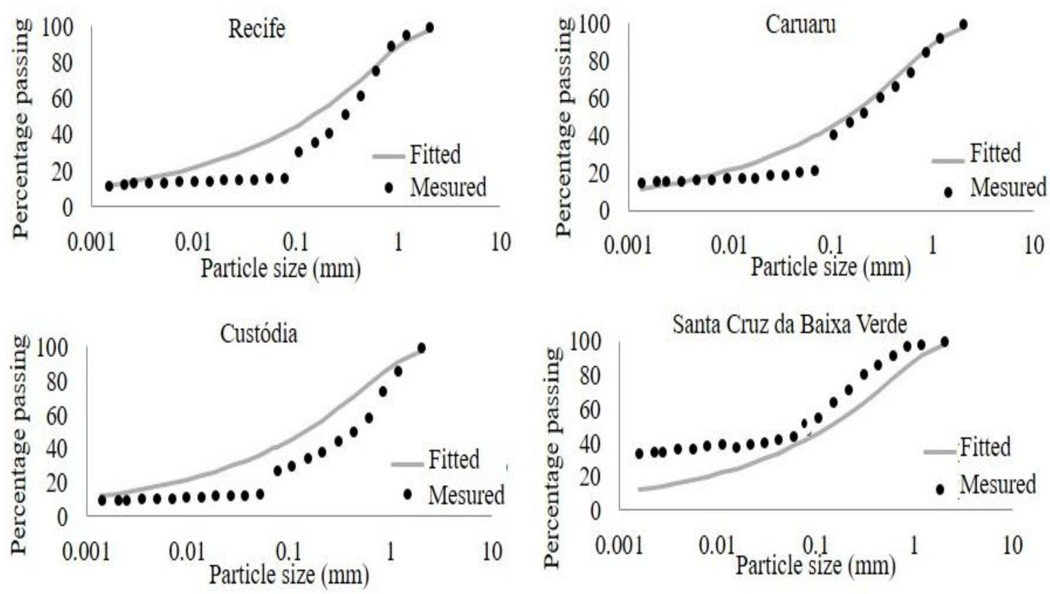

Figure 3. Particle size distribution curves obtained with the [24]

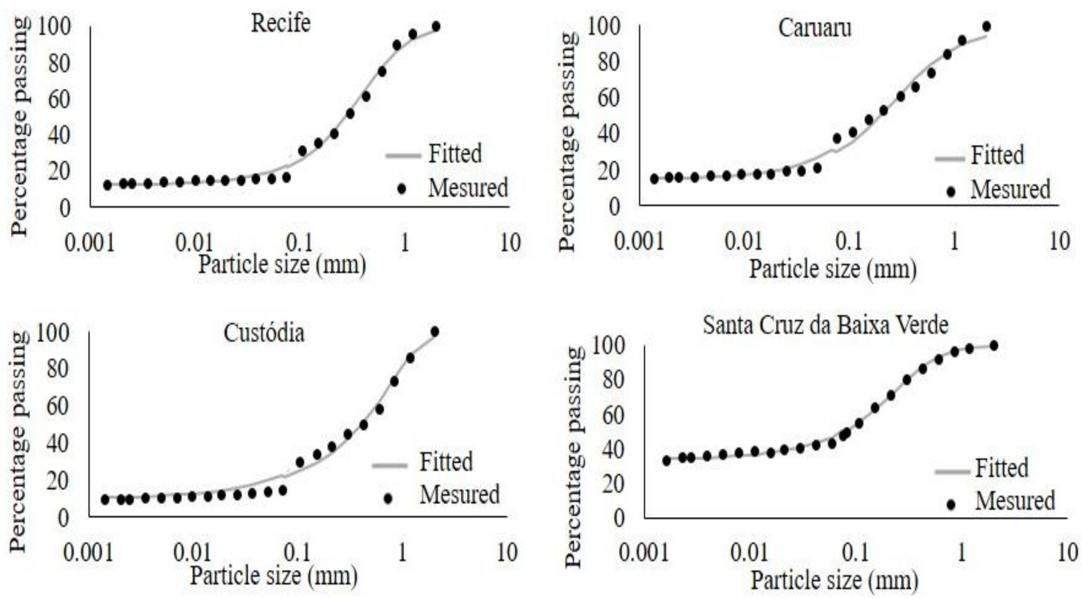

Figure 4. Particle size distribution curves obtained with [28]

[29], when analyzing PSD curve adjustments from 12 different models of 201 different soils in Brazil, have observed that the model for three fitting parameters used in the design of BEST-slope proposed by [24], was the one that presented one of the worst results. On the other hand, the model of [28], also with three adjustment parameters, presented the best result. This result corroborates with the choice of another adjustment model of particle size distribution curves in Brazil, proposed in this study, and consequently, applied to the state of Pernambuco.

Through the infiltration tests carried out on the soil columns, the times were taken in which each volume of water (15 ml) took to infiltrate and, consequently, also the accumulated infiltration values. [30] showed that the amount of water inserted into the infiltrometer influences K_s estimates, which can generate results that vary by approximately one order of magnitude, because of the pressure exerted by the height of the column of water placed on the soil. The initial and final values of volumetric moisture and porosities of the soils were also obtained and are presented in Table 3.

Table 3. Values of initial and final volumetric moisture and soil porosity

City	θ_i (x10^{-2} cm^3 cm^{-3})	θ_f (cm^3 cm^{-3})	ε
Recife	2.83	0.38	0.41
Caruaru	2.54	0.39	0.48
Custódia	1.76	0.27	0.38
Santa Cruz da Baixa Verde	5.26	0.44	0.45

The values of moisture present in Table 3 demonstrate that the ratio between θ_i and θ_f are under 25% for all four soils analyzed, agreeing with the premise imposed by [26]. Besides that, the results of the infiltration tests, i.e., time and cumulative infiltration, as well as the values of the initial and final volumetric moisture were used to assemble the water infiltration curves in the soil, represented in Figure 5.

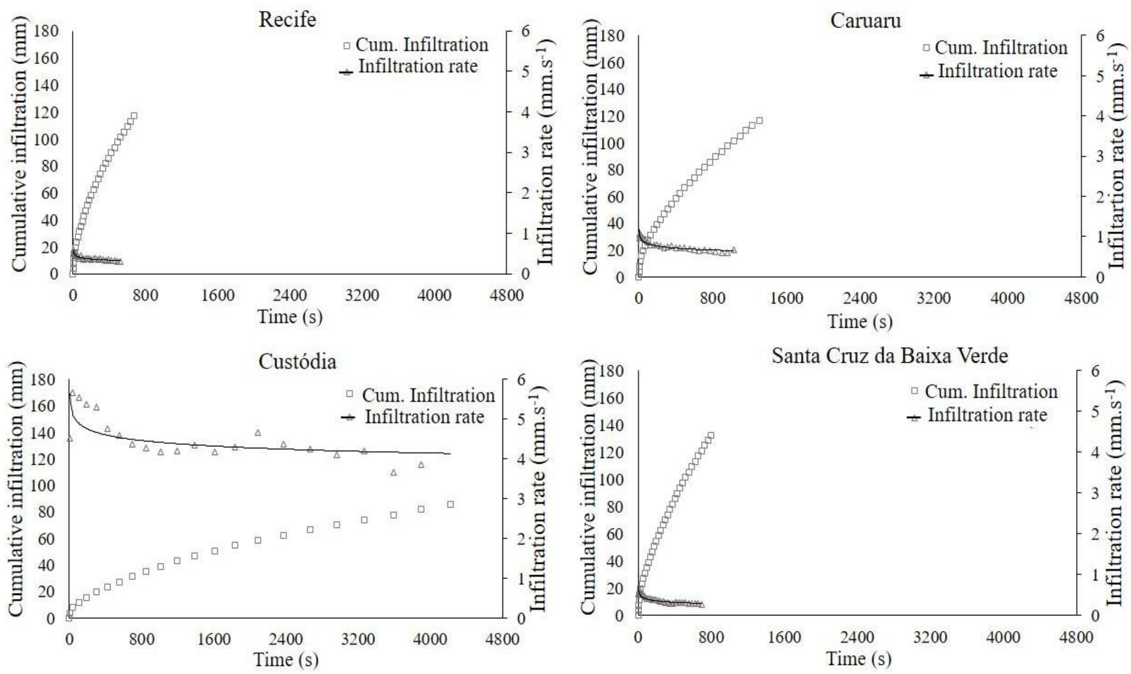

Figure 5. Curves of cumulative infiltration and infiltration rates in soils from Pernambuco.

The infiltration curves present in Figure 5 show that the shortest test (Recife soil) does not exceed 800 s of duration, while the longest (Custódia soil) reaches almost 4400 s of duration. However, depending on the horizontal cumulative infiltration, which cannot exceed 35 mm, it is only possible to guarantee that the water infiltration tests in these soils are three-dimensional until certain fractions of time (Table 4).

Table 4. Values of the time limits in which the infiltration tests are three-dimensional.

Soil	Time limit (s)	
	BEST-slope	JAHH
Recife	409.30	218.09
Caruaru	850.69	332.30
Custódia	5789.22	5102.04
Santa Cruz da Baixa Verde	369.82	235.65

To obtain the hydrodynamic parameters of the soils using BEST-slope and JAHH, the time limits present in Table 4 were considered to be the endpoints of the infiltration tests. In order to prevent that the tests cease to be three-dimensional and be able to detect the effects of water disturbances in the soil more precisely, some researchers such as [9] and [14] used single ring infiltrometers of small diameters (50 mm) or a proportion of 1:4 in the dimensions of the infiltrometer's diameter and the acrylic tube's diameter.

The hydrodynamic parameters of the soils, such as sorptivity and saturated hydraulic conductivity; the parameter values n, m and η; the capillary length scale (λ_c), and the characteristic radius of the pores (λ_m), obtained with BEST-slope and JAHH are described in Table 5.

According to the results presented in Table 5, it can be observed that the values of S and K_s obtained with BEST-slope have the same magnitude as those obtained with JAHH, as well as the parameters of shape, n. Nevertheless, the values of saturated hydraulic conductivity and sorptivity, obtained with the two methods, present significant differences for all soils, except for Custódia, where the sorptivity does not present a significant difference (a: 0.1).

However, BEST-slope underestimated the results of some parameters such as K_s, reaching differences of 29.93 to 68.38%, for the soils of Recife and Custódia, respectively.

Table 5. Saturated hydraulic conductivity values, K_s, (x10^{-2} mm s^{-1}), sorption, S, (mm s$^{-0,5}$), capillary length, λ_c, (mm) characteristic radius of the pores, λ_m, (mm) parameter values m, n and η obtained with BEST-slope and JAHH

Parameter	Method	Recife	Caruaru	Custódia	Santa Cruz da Baixa Verde
n	BEST-slope	2.18	2.17	2.18	2.17
	JAHH	2.64	2.51	2.50	2.55
m	BEST-slope	0.08	0.08	0.08	0.08
	JAHH	0.24	0.20	0.20	0.22
η	BEST-slope	14.47	14.52	14.47	14.52
	JAHH	6.16	6.98	7.00	6.56
S	BEST-slope	1.73[a]	1.20[b]	0.46	1.82[c]
	JAHH	2.37[a]	1.92[b]	0.49	2.28[c]
K_s	BEST-slope	9.74[d]	4.78[e]	0.37[f]	7.75[g]
	JAHH	13.90[d]	9.32[e]	1.17[f]	12.84[g]
λ_c	BEST-slope	48.89	44.46	148.13	45.75
	JAHH	64.24	65.99	46.10	56.57
λ_m	BEST-slope	0.15	0.17	0.05	0.14
	JAHH	0.12	0.12	0.16	0.13

a, b, c, d, e, f and g – Results obtained followed by this symbols differ by Student's t test for a significance level of 10%.

Even if the results of K_s did not show a significant difference for the soil from Custódia, it should be taken into account that other parameters, such as the capillary length scale and the characteristic radius of the pores, must be evaluated to predict whether the models are suitable or not for the soils of this location.

In addition, sorptivity values obtained with BEST-slope were underestimated when compared to those obtained with JAHH, showing divergences between 6.12 and 37.50% for Custódia and Caruaru, respectively. However, when comparing the values of η obtained with the two methods, it is possible to infer that the results provided by BEST-slope are greater than those from JAHH, while for m, the opposite occurs.

It is also possible to observe that the values of m obtained with BEST-slope are the same for all soils and the values of n are practically the same. These two parameters are derived from the first stages of the methods used, either BEST-slope or JAHH, which leads us to believe that the model proposed by [24] for the adjustment of the particle size distribution curves is not the most suitable for soils in the state of Pernambuco.

Furthermore, it was noted that all K_s values obtained with BEST were positive, as it was observed by [14] for BEST-slope when performing infiltration tests on soil columns where the water used in the test was poured from a small height and its impact on the soil was cushioned by pouring the water over the hand.

When comparing λ_c and λ_m values of both methods (BEST-slope and JAHH), it can be noted that for the soil from Custódia, the results have a discrepancy of 102.03 mm for λ_c and 0.1 mm for λ_m. Thus, the results obtained with BEST-slope indicate that the permeability of this soil would be the highest among the four, but this was not observed in the laboratory, since these tests were the longest. These observations corroborate with what was stated by [31] and [5], who demonstrated that the higher the values of λ_c and λ_m, the smaller are S and K_s, meaning that the amount of water this soil allows to infiltrate tends to be greater.

[5] stated that, usually, the higher the value of the capillary length scale, the higher will be the

amount of fine particles in the granulometric composition of the soil. However, it was noted that the values of the capillary length scale obtained with BEST-slope do not respect this premise, because the soil from Custódia is the one with the highest percentages of sand in its composition. However, for JAHH, this soil was the one with the lowest value among the four tested soils, i.e., 46.10 mm.

Thus, the results obtained with BEST-slope can give a false connotation of coherence. Other authors such as [14] have also identified some inconsistencies in the results obtained with BEST-slope, leading to the conclusion that BEST-intercept and BEST-steady variations presented more accurate values for most of the soils studied in Sicily. However, [32] observed that for some soils in the Mediterranean, BEST appears to be adequate enough since it presented estimates that seemed reasonable.

This can still be endorsed by the water infiltration curves in the soil obtained with the simulations performed in Hydrus-1D. In this case, it is possible to verify that the curves obtained through the simulations that used as initial condition the parameters obtained with JAHH, are more similar to the curves obtained through the laboratory infiltration tests than the curves originated from the simulations that used BEST-slope parameters (Figure 6).

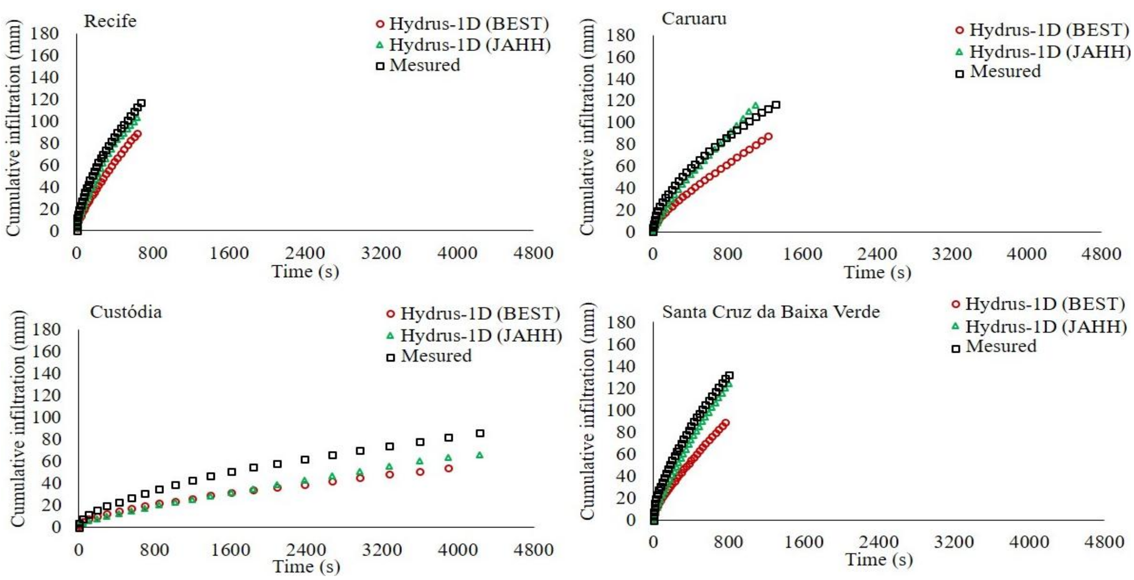

Figure 6. Water infiltration curves in the soil obtained through simulations performed in Hydrus-1D and with infiltration tests.

The use of JAHH to estimate soil parameters has been considered more coherent than BEST-slope, even though both have presented results of the same magnitude, as it is the case of sorptivity and saturated hydraulic conductivity. This is related to the fact that the model of particle size curves adjustment proposed by [24] does not generate really well-adjusted curves to the values measured in the laboratory in comparison to the model proposed by [28]. Furthermore, the particle size curve adjustment model proposed by [28] has already been successfully used for soils in the region [29].

4. CONCLUSION

The use of JAHH to estimate soil parameters could generate more coherent estimates than BEST-slope, even though both of them have presented results of the same proportion, such as sorptivity and saturated hydraulic conductivity.

BEST-slope underestimated results of the parameter K_s for the soils in Recife and Custódia, respectively. Besides, the size of the characteristic radius of the pores (λ_m) of the soil from Custódia obtained with BEST-slope was lower than the measured with JAHH. The sorptivity values obtained with BEST-slope were also underestimated when compared to those obtained with the JAHH model for the soils in Custódia and Caruaru.

The results of the simulations performed with Hydrus-1D reinforce that the parameter values obtained with BEST-slope are less coherent than the values obtained with JAHH for soils in the state of Pernambuco. Therefore, regarding this model, it is suggested that another one, such as JAHH, can be used to obtain the parameters of shape (m, n and η) and of K_s and S, since the adjustment model of the particle size distribution curves used in BEST-slope does not present reliable results for the studied soils. This is explained because the values of the parameters m and n obtained with BEST-slope for the four soils studied are practically the same.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

Author 1 – Marco Aurélio Calixto Ribeiro de Holanda' designed the study, Experiment setup and data collection, performed the statistical analysis, wrote the manuscript. 'Author 2 - Diogo Botelho Correa de Oliveira' Proofreading the text and adding relevant parts, and 'Author 3 - Willames de Albuquerque Soares' creator of the research project and managed the analyses of the study. All authors read and approved the final manuscript.

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