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Transposability of pedotransfer functions for estimating water retention of Algerian soils

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ABSTRACT

Testing the efficiency of a pedotransfer function (PTF) outside of its development data-set is one of the best ways for assessing its robustness. An important question which remains unanswered is how transposable are PTFs to other agropedoclimatic contexts? Models developed and validated in a particular pedoclimatic context have been relatively little tested in other contexts. Particularly, no studies have been conducted until now to evaluate the PTFs for Algerian soils. In this study, eight (8) PTFs most frequently cited were considered. We used them to evaluate soil water retention at field capacity (FC) and wilting point (WP) on a set of 134 samples collected in the low Cheliff. The calculated Akaike information criterion and root mean square errors values showed that the Rawls, and Ghorbani Dashtaki et Homaee type 1 models were the best in estimation of soil water retention at FC (–709.795, 0.070 $cm^3\,cm^{-3}$) and WP (–733.480, 0.064 $cm^3\,cm^{-3}$). The poorer performances were presented by the PTFs developed on soils from Europe or United States where the organic matter values were much higher than the Algerian soils. However, the transposability of the PTFs formed from data spread from a wider area, produce more accurate predictions than those built from local data.

Keywords: Pedotransfer function; Water retention; Field capacity; Wilting point; Transposability

1. Introduction

Water is considered a scarce resource in many parts of the world due to the competition between different uses such as irrigated agriculture, industry, domestic use, and recreation. Agriculture accounts for about 70% of freshwater withdrawals, even up to 95% in some developing countries (FAO). Thereby improving water use in irrigated agriculture has become a major concern.

In fact, knowledge of the soil water state has become essential for agriculture, hydrology,

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meteorology, and in general for all applications requiring environmental monitoring. To better manage and understand the hydrological functioning of the soil cover, it is necessary to know the soil hydraulic properties (water retention, hydraulic conductivity). These properties are generally known for a limited number of soils due to the laborious experimental protocols used for their determination (expensive and time consuming). Therefore, prediction tools have been developed, called "pedotransfer functions" (PTFs) which relate soil water retention properties with soil properties easily obtained such as the sand, silt, and clay content, the organic carbon content or bulk density [1,2].

Despite the very elevated number of PTFs proposed in the literature, few studies have discussed their evaluation within agropedoclimatic contexts. Researchers have been focusing on the discussion of their capacities to estimate with more or less accuracy the water contents which are measured for samples having relatively the same nature in terms of the soil's components [3–13]. Hence, Nemes et al. [14] have shown that the use of PTF established on a given scale leads to low-quality predictions when they are applied on a limited scale that is to say on soils which correspond to a range of larger variability. Tomasella et al. [15] have also shown that when PTFs, established on a given scale, are applied on soils of different nature the predictions' quality is lower than that obtained when they are applied on soils of related nature. Therefore, we may ask ourselves about the appropriateness of PTFs established from soils localized within a different pedoclimatic context when they are used to predict the water retention specifications of the Algerian territory soils. The aim of the current study was to evaluate the application of PTFs to predict soil water retention at field capacity (FC; −33 kPa) and wilting point (WP; −1,500 kPa) on a set of 134 samples collected in the low Cheliff region.

2. Materials and methods

2.1. The database

The database encompassed 134 samples taken from the low Cheliff soils in Algeria. The grain size distribution, the bulk density, the organic matter (OM), and the water contents density with two values of potential −33 kPa (pF = 2,5), and −1,500 kPa (pF = 4,2), are known (Table 1). This collection contains 58 layers of surface A or L (from 0 to 30 cm of depth) and 76 layers of surface E, B and C (>30 cm of depth).

The soil water retention equation of van Genuchten [16] was employed:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1 + |\alpha h|^n)^{1-1/n}} \tag{1}$$

The van Genuchten's model parameters were computed by fitting the third Rosetta (H3) model to the measured data [9], with $m = 1 - 1/n$. (Table 2).

2.2. Description of selected PTFs

Basically, two main types of PTFs can be distinguished; point and parametric PTFs. Point PTFs estimate values of soil moisture at fixed pressure head values (e.g. [17,18]), whereas parametric PTFs estimate parameters of functions that describe the observed data across a range of pressure heads (e.g. [19–22]).

This study is about the evaluation of the eight PTFs which takes into account only characteristics of soils' constitution, which are the most mentioned in the literature, were essentially point PTFs; Rawls and Brakensiek [17], Ghorbani Dashtak and Homaee [23] Type 1 [GH-1 (2004)] and those of parametric PTFs of Campbell [24], Saxton et al. [25], Rawls and Brakensiek [26], Vereecken et al. [22], Rosetta [9], Ghorbani Dashtak and Homaee [23] Type 3[GH-3 (2004)] [23],

Table 1
Characteristics of selected soils

	Grain size distribution (%)					Water content (cm^3cm^{-3})	
	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)	OM (%)	pF 2,5	pF 4,2
Average	17.88	41.65	40.47	1.63	0.98	0.40	0.22
Standard-deviation	14.59	9.27	14.24	0.21	0.62	0.10	0.08
Minimum	0.0	17.00	4.00	0.60	0.20	0.13	0.05
Maximum	63.00	67.00	70.00	2.00	6.10	0.61	0.45

Table 2
van Genuchten parameters of selected soils

	van Genuchten parameters				
	Θr	Θs	α	n	m
Average	0.0696	0.4333	0.0060	1.5175	0.3285
Standard-deviation	0.0178	0.0498	0.0111	0.2287	0.0852
Minimum	0.0290	0.3078	0.0002	1.1078	0.0973
Maximum	0.1191	0.6141	0.0842	2.3856	0.5808

Table 3
Input parameters of evaluated PTFs

Authors	Number of samples	The origin of soils	Model inputs					
			Pressure	Sa	Si	Cl	OM	BD
Campbell [24]	1,400	United States	pF 2.5	+		+		+
			pF 4.2	+		+		+
Rawls and Brakensiek [17]	2,541	United States	pF 2.5	+		+	+	
			pF 4.2			+	+	
Saxton et al. [25]	ns	United States	pF 2.5	+		+		
			pF 4.2	+		+		
Rawls and Brakensiek [26]	5,320	United States	pF 2.5	+		+		+
			pF 4.2	+		+		+
Vereecken et al. [22]	182	Belgium	pF 2.5	+	+	+	+	+
			pF 4.2	+	+	+	+	+
Rosetta-H3 (Schaap et al. [9])	24,691	North of America and Europe	pF 2.5	+	+	+		+
			pF 4.2	+	+	+		+
Ghorbani Dashtak and Homaee [23] Type 1 [GH-1 (2004)]	234	Iran	pF 2.5	+	+	+		+
			pF 4.2			+		
Ghorbani Dashtak and Homaee [23] Type 3 [GH-3 (2004)]	234	Iran	pF 2.5	+		+		+
			pF 4.2	+		+		+

Note: OM: the organic matter, BD: the bulk density, Cl; Si; Sa: the clay. The silt and the sand, and ns: not specified.

PTF on a physical basis have not been retained in the evaluation made during this work because they require knowledge about the detailed particles size distribution. So, it is data which are generally not available. Table 3 gives an overview about the inputs data which are necessary for PTFs used.

2.3. Evaluation criteria

PTFs are regularly evaluated by making a comparison between the values that they predict and the measured values [27]. For PTFs used in this study, the root mean square error (RMSE) has been used:

$$\mathrm{RMSE} = \left\{\frac{1}{n}\sum_{i=1}^{n}(\theta_p - \theta_m)^2\right\}^{1/2} \tag{2}$$

The estimation improves when the RMSE value diminishes. The Akaike information criterion (AIC) and the geometric mean error (GMER) are also applied to assess the validity of PTF.

$$\mathrm{GMER} = \exp\left\{\frac{1}{n}\sum_{i=1}^{n}\ln\left(\frac{\theta_p}{\theta_m}\right)\right\} \tag{3}$$

$$\mathrm{AIC} = n\ln\left\{\frac{1}{n}\sum_{i=1}^{n}(\theta_p - \theta_m)^2\right\} + 2k \tag{4}$$

with k—the model inputs number. The smallest values of AIC (the most negative) is the best model. The GMER value more or less than 1 shows an under or over estimation orderly.

3. Results and discussion

The results show that most of methods underestimate sensibly the soil water retention at the two levels of potential, (FC and WP). The statistical parameter,

Table 4
Calculated statistical criteria employed to evaluate water retention estimation on FC and in WP by PTF selected in current study

	Θ (–33 kPa)			Θ (–1,500 kPa)		
	cm^3cm^{-3}					
	GMER	RMSE	AIC	GMER	RMSE	AIC
Campbell [24]	0.315	0.264	−352.856	0.382	0.118	−568.299
Rawls and Brakensiek [17]	1.001	0.077	−683.434	1.139	0.067	−719.537
Saxton et al. [25]	0.976	0.082	−669.143	1.081	0.071	−707.501
Rawls and Brakensiek [26]	0.392	0.248	−371.790	0.714	0.121	−550.310
Vereecken et al. [22]	0.874	0.117	−566.157	1.235	0.080	−668.066
Rosetta (Schaap et al. [9])	0.685	0.169	−467.210	0.665	0.101	−603.703
GH-1 (2004)	0.661	0.157	−492.779	0.924	0.064	−733.480
GH-3 (2004)	0.655	0.157	−45.171	0.786	0.076	−672.374

GMER (Table 4) has confirmed that only PTFs of Rawls and Brakensiek [17], Vereecken et al. [22], and Saxton et al. [25] have overestimated the soil water retention at −1,500 kPa. The GMER values of Rawls and Brakensiek [17], GH-1 [23], are estimated at 1.001 and 0.924, at FC and WP, orderly, what gives a good appropriateness between the estimated and measured values of the water content (Figs. 2(a) and 2(b)). In fact, the RMSE values overflow those of GMER. The lowest values are observed for Rawls and Brakensiek [17], at 0.077 $cm^3\ cm^{-3}$ and GH-1 [23] at 0.064 $cm^3\ cm^{-3}$. When results of the RMSE agree with GMER values, these statistics indicate that the point PTFs predicted better than the parametric PTFs.

The AIC value which considers the model inputs shows that the best PTF to estimate the soil water content at FC was Rawls and Brakensiek [17] and Saxton et al. [25] (Table 4). Ghanbarian-Alavijeh and Liaghat [28] and Abbasi et al. [29] noticed that the model of Saxton et al. [25] estimates the soil water contents on the Iranian soils better than the other PTF such as Campbell [30].

Although the PTF of Ghorbani Dashtak and Homaee Type 1 [23] have been developed for the Iranian soils in a pedoclimatic context similar to those of the soils selected in this study. Their estimations at WP are better; the statistical criteria values confirm that the model developed for soils of a pedoclimatic context similar to the study area are more efficient.

The Rosetta model (H3) includes an approach on artificial neural networks in order to predict the parameters of the water retentions curve of van Genuchten (Table 2) using four levels the percentage of clay (C), silt (Si), sand (S), and bulk density (BD). Many authors like Schaap et al. [9], Minasny and McBratney [31], Ghorbani Dashtaki and Homaee [23], and Khodaverdiloo and Homaee [32] have shown that the Rosetta model underestimates the water retention. This was confirmed in this study by the GMER value being <1.

The causes of the weak precisions relative to the evaluated PTF are probably due to different factors. The application data, all the samples used in this study, have been taken in a context totally different from the context of the evaluated PTF development data except for the Ghorbani Dashtak and Homaee Type 1 model [23]. That may indicate that the efficiency of PTF may be influenced by the geographical origin of the data used in its construction [33,34]. Then, it can be concluded that the application of the PTF derived from a wide range of soils (heterogeneity) is more robust than the models derived from data of particular pedoclimatic contexts. However, a large number of records of soil hydraulic data and corresponding predictive soil properties were obtained from three databases [9,35] were used to drive the five models of Rosetta (H1–H5). The inferior performance of third

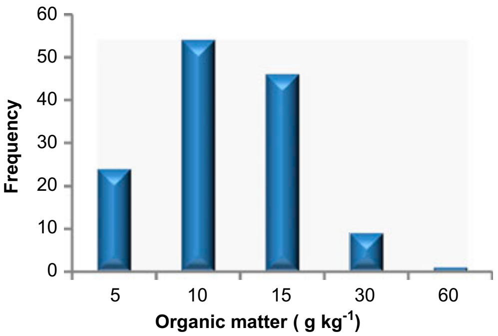

Fig. 1. Frequency representation of the used samples organic matter.

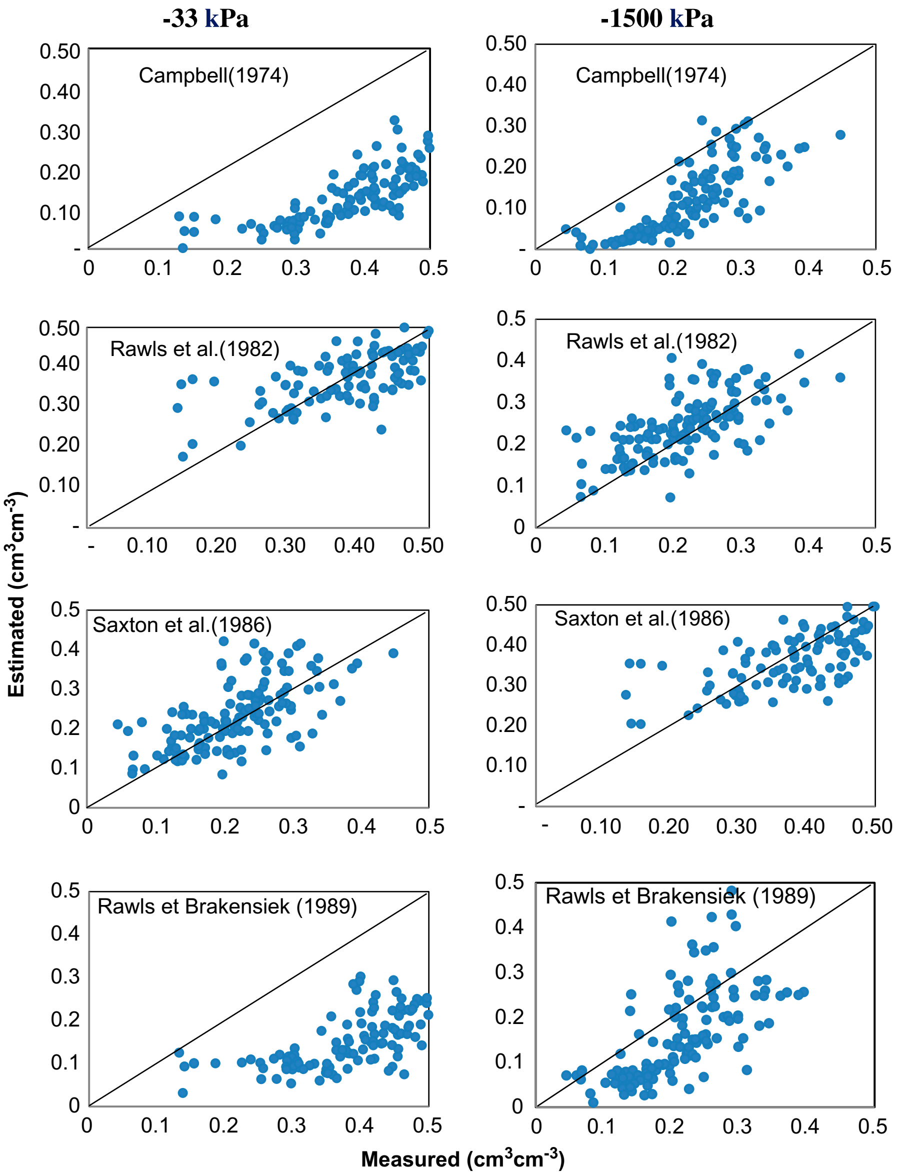

Fig. 2a. Predictions of water retention at field capacity and in wilting point by the selected PTFs.

model of Rosetta (H3) in view of the fact that the soils used in its development were different from North African soils. The most of the samples derived from the PTFs of Rosetta were collected from soils in temperate to subtropical climates of North America and Europe.

The results show the low degree of uncertainty at –33 and −1,500 kPa observed by Rawls and Brakensiek PTF [26] (RMSE = 0.25–0.121 $cm^3\,cm^{-3}$) and Campbell PTF [24] (RMSE = 0.26–0.118 $cm^3\,cm^{-3}$). It can be argued that this is due to the fact that the texture and bulk density of the low Cheliff soils are not in the range of those which were used to develop these models [36].

The majority of the soil samples used in this study are poor in OM. The value of the OM was less than 16 g kg^{-1} (Fig. 1). Nevertheless, all the evaluated PTFs except for Ghorbani Dashtaki and Homaee [23] were based on the soils of Europe or United States, where the values of the OM are higher than those of Algerian soil. Nemes et al. [37] have estimated the values of the OM at 0.9–78.9, 1.0–64.8, and 1.0–44.0 g kg^{-1} for all the European, Hungarian, and American data, respectively. OM affects the pore size distribution through the development of the soil structure. The presence of organic debris and the concentration of OM encourage the development of a biological activity in the soil that

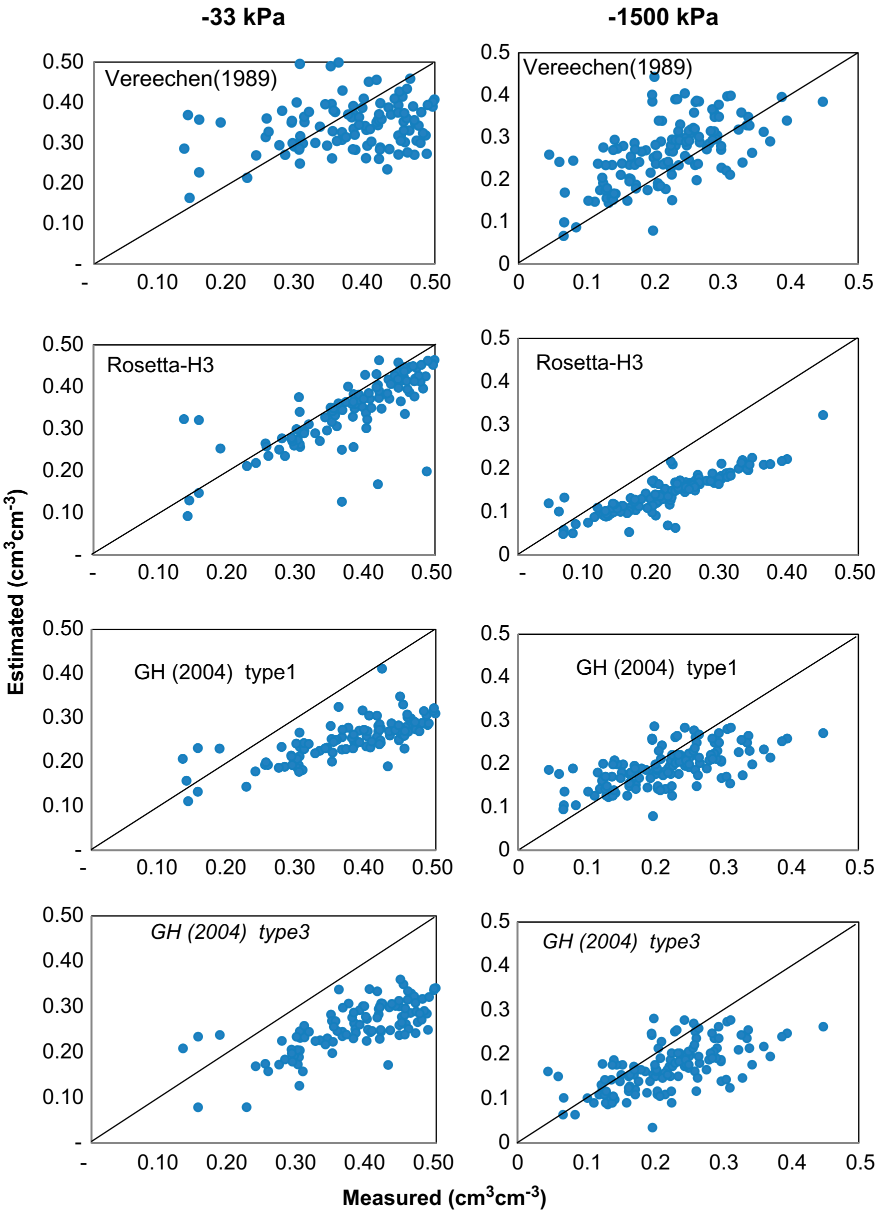

Fig. 2b. Predictions of water retention at field capacity and in wilting point by the selected PTFs.

leads to an evolution of tortuous paths and consequently the establishment of a continuous porosity which receives and stores water. Rawls et al. [38] concluded that the organic carbon and the bulk density improve the estimations of the soils water retention. Jamison and Kroth [39], Petersen et al. [40], Rawls and Brakensiek [17], Rawls et al. [41], de Jong and Loebel [16], Ambroise et al. [42], and Kern [43] have all observed that the inclusion of the organic carbon content in the water content as an input was useful for improving the estimations of soil water at −33 and −1,500 kPa. Indeed, in this work, the point PTFs predict a little better than the parametric PTFs and confirm that soil water retention is controlled by different independent variables as OM at different potential points, and not directly related to the parameters of the water retention curve as the van Genuchten model [15]. Furthermore, whatever the fixed pressure points, soil water content at FC is certainly not an inherent property of the soil, but is a parameter of production process water runoff and drainage (leakage) out the root zone in the entire soil profile [44].

The mathematical formalism as the choice of inputs and adopted methods in modeling (e.g. multiple

Table 5
Coefficients of determination (R^2) of studied soils

Variables	Sand (%)	Silt (%)	Clay (%)	OM (%)
ϴ (–330 kPa)	**0.529**	**0.077**	**0.318**	0.028
ϴ (–15,000 kPa)	**0.490**	0.017	**0.399**	**0.038**

Note: The values which are in bold are different from 0 to a level of signification α = 0.05

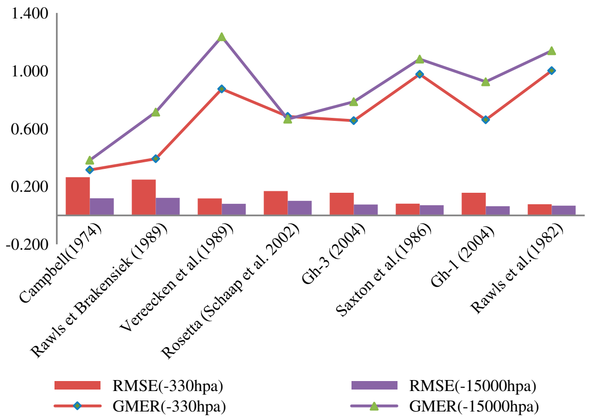

Fig. 3. Graphic representation of evaluation criteria.

regressions linear or non-linear and artificial neural networks) has a decisive role in the improvement of PTF estimation. According to Table 4, the statistical evaluation obtains the best efficiency for PTF of Rawls and Brakensiek [17] and a good classification Vereecken et al. [22] PTF compared with other methods, that may be explained by the fact that they are the only models that need OMs as an input at −33 kPa. The PTFs that use the OM contents as predictive variables to estimate FC and permanent WP have good predictive ability [45].

The quality estimation of Saxton et al. [25] PTF to pF 4.2 and G-1 [23] PTF to pF 2.5 for the reason that these two models are based on the content of clay and sand as inputs. The variation of water quantity retained by the low Cheliff soils is explained firstly by the variation of clay content. The variance increases when the potential decreases. Also, the clay content explains 32 and 40% of the water content variability, when we pass from −33 to –1,500 kPa (Table 5). The similar results were finding in Mitidja (North of Algeria) plain confirms that the clay content is among factors that contribute most to the water retention of soils, usually to low potential [46].

The methods of modeling adopted in the development of PTFs reveal that the RMSE value associated with GMER (Fig. 3) decreases when we pass from a multiple non-linear regression [24,26] and a regression based on the artificial neural networks [9] to a multiple linear regression [17,23].

4. Conclusion

The evaluation criteria have shown that the best models for estimating of soil water retention are Rawls and Ghorbani Dashtaki and Homaee Type 1 at FC and WP. The results suggest that the performance of GH-1 PTF is due to the fact that has been developed from data-set collected in similar pedoclimatic context then our soils. It is important to consider the range of soils on which the PTFs have been derived. In a different context, the PTFs can lead to poor precision (Rawls and Brakensiek (RMSE = 0.25–0.121 $cm^3 cm^{-3}$), Rosetta (RMSE = 0.16–0.101 $cm^3\ cm^{-3}$), and Campbell (RMSE = 0.26–0.118 $cm^3 cm^{-3}$ at −33 and −1,500 kPa, respectively). The points produce less error compared with parametric PTFs and confirm that the soil water retention can be well explained by different independent variables at fixed pressure points and cannot be accurately described by parametric models. The choice of inputs as OM and clay content as well as adopted methods in modeling have a decisive role in the improvement of PTF estimation of soil water retention properties.

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