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Full Length Research Paper

Pedotransfer functions for point estimation of soil moisture characteristic curve in some Iranian soils

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Soil moisture characteristic (SMC) curve is a basic soil property. Since its direct measurement is costly and time-consuming, an alternative to measurement is to estimate this property indirectly, using the more easily available soil properties. These methods are called pedotransfer functions (PTFs). Point PTFs estimate the water content of the soil at different matric potentials. For this study, twenty soil samples from the topsoils (A horizons) were selected from different locations in Fars province, South of Iran, and SMC curve of each soil was measured with the combination of hanging column for matric potentials of 0 (saturated soil moisture content), 3, 6, 9 and 12 kPa and pressure plate methods for matric potentials of 30, 100, 500, 1000 and 1500 kPa. Also, the particle size distribution curve of each soil was measured and the percentages of clay, silt and sand, and the geometric mean particle-size diameter of each soil was determined. Then, three PTFs were derived based on clay or sand fraction of the soil or geometric mean particle- size diameter, saturated soil moisture content and bulk density for point estimation of SMC curve. To evaluate the proposed PTFs another five independent soils were used. The results showed that, the PTFs for point estimation of SMC curve based on clay content were appropriate for soils with clay, silty clay and silty clay loam textures, and the PTFs based on sand content were appropriate for soils with loam and sandy loam textures.

Key words: Soil moisture characteristic curve, pedotransfer functions, clay, sand, saturated soil moisture content.

INTRODUCTION

Soil moisture characteristic (SMC) curve is a basic soil property necessary for the study of plant-available water, infiltration, drainage, and solute movement. Many soil physicists desribed in detail the SMC curve such as Brooks and Corey (1964), Campbell (1974) and van Genuchten (1980). The proposed model by van Genuchten (1980) is the most common equation for describing the SMC curve, but this method needs the measured data of SMC curve. However, direct measurement of the SMC curve is costly and time-consuming. Therefore, an alternative to measurement is to estimate this property using more easily available soil properties such as particle size distribution curve, particle density, bulk density, pore size distribution, mineralogy, and soil morphology (Arya and Paris, 1981; Saxton et al., 1986; Arya et al., 1999; Zhuang et al., 2001; Fooladmand et al., 2004; Buczko and Gerke, 2005; Vaz et al., 2005; Fooladmand, 2007; Fooladmand, 2011). Most of these methods can be called pedotransfer functions (PTFs) (Bouma and van Lanen, 1987), because they translate existing surrogate data into soil hydraulic data (Schaap et al., 2001). However, since PTFs are often developed empirically, their applicability may be limited to the data set used to define the method (Wosten et al., 1999). Moreover, the available pedotransfer procedures can produce substantially different estimates. Thus, users have a difficult task in selecting a more appropriate PTF for their application (Acutis and Donatelli, 2003).

Pedotransfer procedures are classified as point pedotransfers and function pedotransfers (Cornelis et al., 2001; Acutis and Donatelli, 2003). Point pedotransfer estimates the water content of the soil at certain matric potentials. This kind of PTFs can be used for most conditions based on linear or nonlinear regressions. For an example, Givi et al. (2004) evaluated the PTFs for predicting the soil water contents at field capacity and wilting point for 16 soil samples of fine clay or clay loam soil profiles in a semiarid region in Iran. Also, Fooladmand (2009) used soil specific surface area and mean geometric soil diameter for estimating the water content of the soil at different certain matric potentials for some Iranian soils. Furthermore, many studies have done about point PTFs such as the proposed PTFs by Gupta and Larson (1979), Ahuja et al. (1984) and Saxton et al. (1986). Function pedotransfer predicts the parameters of a closed-form analytical equation, such as the model of Brooks and Corey (1964) or the van Genuchten (1980) equation. Also, this kind of PTFs can be used for most conditions based on linear or nonlinear regressions. For example, Vereecken et al. (1989) and Scheinost et al. (1997) developed PTFs for van Genuchten parameters, separately, which were used in other studies such as the study of Loos et al. (2007).

The objective of this study was to obtain and evaluate the PTFs for point estimation of SMC curve at nine soil matric potentials for twenty soils in the South of Iran, based on clay or sand fraction of soil or geometric mean particle-size diameter, saturated soil moisture content and bulk density.

MATERIALS AND METHODS

For this study, twenty soil samples from the topsoils (A horizons) were selected from different locations in Fars province, South of Iran. All soil samples with strucute were gathered in depths of 0 to 30 cm. The selected soils have similar organic matter content and similar mineralogy. Some measured characteristics of the soils used in this study by normality distribution are presented in Table 1. For this study, SMC curve of each soil was measured with the combination of hanging column (for matric potentials of 0, 3, 6, 9 and 12 kPa) and pressure plate (for matric potentials of 30, 100, 500, 1000 and 1500 kPa) apparatus methods. The value of bulk density of each soil was measured by using undisturbed samples. The particle size distribution curve of each soil was accomplished with a combination of the hydrometer and the wet sieving methods as described by Gee and Bauder (1986), and then the percentages of clay, silt and sand of each soil were determined, according to the USDA system for particle size range (Clay: 0 to 0.002 mm; Silt: 0.002 to 0.05 mm; sand: 0.05 to 2 mm). Furthermore, the geometric mean particle-size diameter for each soil was determined by using the Shirazi and Boersma (1984) method as follows:

$$a = 0.01\left(f_c \mathrm{Ln}M_c + f_{si}\,\mathrm{Ln}M_{si} + f_{sa}\,\mathrm{Ln}M_{sa}\right) \quad (1)$$

$$d_g = \exp(a) \quad (2)$$

where: d_g is the geometric mean particle-size diameter (mm), f_c, f_{si} and f_{sa} are the clay, silt and sand fraction of soil, respectively, and M_c, M_{si} and M_{sa} are the mean values diameter of clay, silt and sand, respectively (M_c = 0.001 mm; M_{si} = 0.026 mm; M_{sa} = 1.025 mm).

In this study, it was assumed that the saturated soil moisture content and soil bulk density of each soil were available. Therefore, the three following equations were derived by using multiple linear regression to obtain PTFs at soil matric potentials of 3, 6, 9, 12, 30, 100, 500, 1000 and 1500 kPa as follows:

$$_h = a + b\mathrm{Clay} + c\,_s + d\,_b \quad (3)$$

$$_h = a + b\mathrm{Sand} + c\,_s + d\,_b \quad (4)$$

$$_h = a + bd_g + c\,_s + d\,_b \quad (5)$$

where θ_h is the soil water content at different soil martic potentials (m^3/m^3), clay and sand in fraction, d_g is the geometric mean particle-size diameter (mm), θ_s is the saturated soil moisture content (m^3/m^3) and ρ_b is the soil bulk density (g/cm^3), and a, b, c and d are the coefficients of each equation. Also, the proposed method by Saxton et al. (1986) was used for evaluating the developed PTFs in this study. This method for soil martic potentials between 10 and 1500 kPa is as follows (Saxton et al., 1986):

$$= \left(\frac{h}{A}\right)^{\frac{1}{B}} \quad (6)$$

$$A = \exp\left[w + x(\%\mathrm{Clay}) + y(\%\mathrm{Sand})^2 + z(\%\mathrm{Clay})(\%\mathrm{Sand})\right] \times (100) \quad (7)$$

$$B = e + f(\%\mathrm{Clay})^2 + g(\%\mathrm{Sand})^2 + g(\%\mathrm{Clay})(\%\mathrm{Sand})^2 \quad (8)$$

where θ is the soil water content (m^3/m^3), h is the soil martic potentials (kPa), %clay and %sand are the percentages of clay and sand, respectively, and w = -4.396, x = -0.0715, y = -4.88×10^{-4}, z = -4.285×10^{-5}, e = -3.14, f = -2.22×10^{-3} and g = -3.484×10^{-5}. On the other hand, the proposed method for soil martic potentials between air entry and 10 kPa is as follows (Saxton et al., 1986):

$$= _{10} + \frac{(10-h)(_s - _{10})}{10 - h_e} \quad (9)$$

$$_{10} = \exp\left(\frac{2.302 - \ln A}{B}\right) \quad (10)$$

$$_s = t + j(\%\mathrm{Sand}) + k\log(\%\mathrm{Clay}) \quad (11)$$

$$h_e = 100(m + n\theta_S) \quad (12)$$

where θ_s is the saturated soil moisture content (m^3/m^3), h_e is the soil martic potential at air entry (kPa), and t = 0.332, j = -7.251×10^{-4}, k = 0.1276, m = -0.108 and n = 0.341.

To evaluate the developed PTFs, another five independent soils from the topsoils (A horizons) with different textures were considered from the Fars and Boushehr provinces, South of Iran with measured SMC curve (Keshmiripour and Niazi, 2000). Some soil characteristics of these soils are presented in Table 2. Standard error (SE) and mean absolute error (MAE) were used to evalute the obtained results as follows:

$$SE = \left[\frac{\sum_{i=1}^{N}(_m - _p)^2}{N-1}\right]^{0.5} \quad (13)$$

$$MAE = \frac{\sum_{i=1}^{N}\left|_m - _p\right|}{N} \quad (14)$$

where: θ_p is estimated soil water content at different soil matric potentials with three proposed PTFs and Saxton et al. (1986) method, separately, and θ_m is the measured soil water content at different soil matric potentials, and N is the number of measured soil moisture content at different soil matric potentials in each soil

Table 1. The characteristics of the soils used in this study for obtaining PTFs.

Clay (%)	Sand (%)	d_g (mm)	Saturated soil moisture content (m^3/m^3)	bulk density (g/cm^3)
26	18	0.022	0.5473	1.17
46	4	0.007	0.4556	1.43
30	8	0.013	0.4580	1.39
28	10	0.015	0.5231	1.30
39	8	0.010	0.4532	1.34
34	6	0.011	0.4460	1.35
4	80	0.431	0.4306	1.55
9	63	0.196	0.4498	1.67
4	79	0.416	0.3729	1.61
6	76	0.349	0.4562	1.63
26	24	0.027	0.4412	1.45
24	20	0.025	0.4247	1.33
30	12	0.015	0.4673	1.18
28	18	0.020	0.4568	1.18
34	12	0.013	0.4772	1.17
27	18	0.021	0.4705	1.16
42	8	0.009	0.4443	1.18
32	12	0.014	0.4992	1.24
7	63	0.210	0.4655	1.60
12	36	0.066	0.4312	1.37

Table 2. The characteristics of the soils used for evaluating PTFs.

Texture	Clay (%)	Sand (%)	d_g (mm)*	Saturated soil moisture content (m^3/m^3)	Bulk density (g/cm^3)
C**	53.2	8.6	0.006	0.425	1.65
SiC**	49.2	8.6	0.007	0.411	1.72
SiCL**	36.6	18.0	0.015	0.455	1.33
L**	20.6	36.0	0.050	0.365	1.60
SL**	16.7	67.6	0.181	0.332	1.41

*Geometric mean particle-size diameter, ** C: clay, SiC: silty clay, SiCL: silty clay loam, L: loam, SL: sandy loam.

(N = 9). The best condition will give a smaller SE and MAE and bigger R^2.

RESULTS AND DISCUSSION

The constant coefficients and R^2 values of Equations (3) to (5) for different soil matric potentials are presented in Table 3. All obtained equations were significant ($P < 0.05$). The results showed that for matric potential of 3, 6, 9, 12, 30, 100 and 500 kPa the maximum value of R^2 depend on sand percentage. While, for matric potentials of 1000 and 1500 kPa, the maximum value of R^2 depend on clay percentage, which is in agreement with the fact that in high matric potentials, soil moisture content have strong dependency with the value of clay content in the soil. The mean value of R^2 for matric potential of 3, 6, 9, 12, 30, 100, 500, 1000 and 1500 kPa in three proposed PTFs were 0.769, 0.608, 0.606, 0.580, 0.645, 0.643, 0.637, 0.621 and 0.615, respectively. The maximum values of R^2 were obtained in matric potential of 3 kPa. The reason is that in this matric potential, the soil moisture content is near the saturated soil moisture content which is one of the parameters of the proposed linear regressions. The coefficient of clay and sand in all equations were positive and negative, respectively, which is in agreement with the fact that the soil moisture content will increase by increasing clay content and will increase by decreasing sand content of the soil. Furthermore, the results showed that using the geometric mean particle-size diameter was not as effective as using clay or sand content for proposed PTFs.

Then, in another five independent soils, and in each soil matric potential, the measured soil moisture contents

Table 3. The constant coefficients and R^2 values of Equations (1) to (3) for different soil matric potentials.

Matric potential (kPa)	a	b (Eq. 3: Clay)	c	d	R^2
3	-0.2324	0.0606	1.0889	0.0867	0.769
6	-0.3838	0.1383	1.1503	0.1438	0.601
9	-0.4977	0.2306	1.2307	0.1663	0.577
12	-0.5351	0.2857	1.2326	0.1706	0.536
30	-0.4220	0.2952	0.9693	0.1428	0.653
100	-0.3786	0.3028	0.8346	0.1191	0.654
500	-0.2959	0.3306	0.5691	0.1043	0.677
1000	-0.2971	0.3459	0.5109	0.1090	0.678
1500	-0.2611	0.3178	0.4881	0.0877	0.670
	a	b (Eq. 4: Sand)	c	d	R^2
3	-0.2236	-0.0445	1.0664	0.1080	0.781
6	-0.3614	-0.0995	1.0999	0.1899	0.637
9	-0.4616	-0.1672	1.1460	0.2448	0.648
12	-0.4936	-0.2098	1.1263	0.2712	0.629
30	-0.3403	-0.1828	0.8757	0.2057	0.692
100	-0.2938	-0.1866	0.7391	0.1825	0.694
500	-0.1906	-0.1926	0.4701	0.1601	0.689
1000	-0.1803	-0.1956	0.4101	0.1603	0.668
1500	-0.1534	-0.1795	0.3957	0.1345	0.659
	a	b (Eq. 5: d_g)	c	d	R^2
3	-0.1903	-0.0380	1.0673	0.0766	0.758
6	-0.3044	-0.1228	1.0820	0.1418	0.586
9	-0.3858	-0.2499	1.0927	0.1893	0.593
12	-0.4045	-0.3267	1.0525	0.2091	0.575
30	-0.2489	-0.2546	0.8274	0.1340	0.589
100	-0.2004	-0.2596	0.6899	0.1092	0.581
500	-0.0933	-0.2662	0.4203	0.0835	0.546
1000	-0.0805	-0.2683	0.3606	0.0812	0.517
1500	-0.0603	-0.2427	0.3521	0.0599	0.516

were compared with estimated soil moisture contents by using three proposed PTFs and Saxton et al.'s (1986) method. The values of SE and MAE for each soil are shown in Table 4. According to this table, the results showed that the PTFs based on clay content were appropriate for soils with clay, silty clay and silty clay loam textures. Therefore, in soils with high clay content the PTFs containing clay were appropriate for point estimation of SMC curve. Also, the results showed that the PTFs based on sand content were appropriate for soils with loam and sandy loam textures. Therefore, in soils with high sand content the PTFs containing sand were appropriate for point estimation of SMC curve. Also, the results showed that using the Saxton et al.'s (1986) method for estimating SMC curve was not appropriate for selected soils. Furthermore, the developed PTFs in this study can be used for estimating the SMC curve for the soils in the South of Iran, and cannot be used for other soils in different regions of the world with high certainty.

Conclusions

The results of this study showed that, PTFs for point estimation of SMC curve for matric potentials of 3, 6, 9, 12, 30, 100, 500, 1000 and 1500 kPa had positive relationship with clay fraction of the soil, and negative relationship with sand fraction of the soil. The obtained results agreed with the fact that, the soil moisture content will increase by increasing clay content and will increase by decreasing sand content of the soil. Also, the results showed that using the geometric mean particle-size

Table 4. The values of SE and MAE for evaluating PTFs.

	Texture	**Eq. (3)**	**Eq. (4)**	**Eq. (5)**	**Saxton et al. (1986)**
SE	C*	0.016	0.108	0.192	0.106
	SiC*	0.023	0.102	0.187	0.106
	SiCL*	0.019	0.070	0.122	0.096
	L*	0.095	0.051	0.099	0.085
	SL*	0.077	0.052	0.064	0.063
MAE	C*	0.013	0.097	0.173	0.092
	SiC*	0.017	0.089	0.166	0.077
	SiCL*	0.018	0.064	0.110	0.063
	L*	0.083	0.040	0.087	0.066
	SL*	0.061	0.045	0.045	0.043

* C: Clay, SiC: silty clay, SiCL: silty clay loam, L: loam, SL: sandy loam.

diameter of the soil was not appropriate for point estimation of SMC curve at different soil matric potentials.

On the other hand, the results of evaluating the proposed PTFs showed that, PTFs based on clay content were appropriate for three soils with high clay content (clay, silty clay and silty clay loam textures), and PTFs based on sand content were appropriate for two another soils with loam and sandy loam textures. According to the obtained values of standard error and mean absolute error, the results indicated that proposed PTFs in this study can be used for point estimation of SMC curve for soils in the South of Iran by using the values of saturated soil moisture content, clay or sand fraction of the soil and soil bulk density. Furthermore, the results showed that using the proposed method by Saxton et al. (1986) was not appropriate for the selected soils in the South of Iran.

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