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# Evaluation of PTFs Developed From Large Databases for Iranian Soils To Predict SMRC

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**ABSTRACT-** The majority of hydraulic processes under a natural condition in a field are carried out under unsaturated flow conditions. The soil moisture retention curve (SMRC) is the most important hydraulic characteristic of an unsaturated soil whose knowledge is of prime importance in soil-water studies such as soil conservation, soil erosion, land evaluation, soil reclamation, and water resources management. SMRC can be determined by two different direct and indirect methods. While there are noticeable developments on direct methods, they are still time- and labor-consuming. As a result, researchers are focusing more on indirect methods. The present research has evaluated some common PTFs for predicting the SMRC for a number of soils in Iran. Fifty soils, the majority of which were loam and clay loam, were taken from Karaj, Amol, and Babol in the north of Iran. Soil water contents corresponding to matric potentials of 0, -5, -33, -100, -500, and -1500 kPa were determined by a pressure plate apparatus. Four common PTFs of Rawls and Brakensiek (RB), Vereeken et al. (VMFD), Wosten (W), and Wosten et al. (WLNL) were used in this study. To evaluate these PTFs, the GMER (Geometric mean error ratio), GSDER (Geometric standard deviation of error ratio), and RMSE (Root mean square error) indices were considered. The results showed that these PTFs functioned better for loam-textured soils. VMFD and WLNL PTFs performed better, while VMFD was better than the others for clay loam soils. In general, better fit was found as the matric potential increased.

**Keywords: Soil Moisture Retention Curve, PTF, Unsaturated flow, Iran**

## INTRODUCTION

Soil moisture retention curve (SMRC) is related to soil moisture and the corresponding matric potential. SMRC is of prime importance in nearly all irrigation and drainage engineering practices. It is also required for crop water availability computations, and soil water and solute modeling in unsaturated soils. There are numerous factors, including soil pore size distribution, pore shape, pore continuity, among others, which may control the shape of SMRC. Therefore, it is not possible to define it by a definite equation. There are empirical equations, however, which describe SMRC. The most common of which are Brooks and Corey (2), Gardner (5), Campbel (3), and van Genuchten (19). Measuring soil water content corresponding to a definite soil matric potential is time- and labor-consuming. Due to above and other difficulties, there is an increasing tendency for researchers to develope indirect methods for determinating SMRC.

Pedo-transfer function (PTF) is one of the indirect methods. It is likely that the first attempts were carried out by Briggs and McLane [(reported by McBratney et al., (10)]. They successfully defined the permanent wilting point (PWP) as a function

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of soil particle size. Numerous researches were conducted by Briggs and Shantz and others, during 1950-1980 to correlate field capacity (FC) and PWP to some parameters including pore size distribution, bulk density, and organic matter (10). Such researches signify the concept of class PTF.

Different independent variables can be used in the structure of a PTF. Scheinost et al. (15) and Minasny et al. (12) used mean particle diameter and geometric standard deviation as input variables. Organic carbon and organic matter were considered as effective independent variables, in studies conducted by Rawls et al. (14) and Wosten et al. (23) during the last two decades (24). Rajkai and Varallyay (13) confirmed that $CaCO_3$ may increase the usefulness of PTF, especially at -1400 kPa potential.

There are two main categories for PTFs, i.e. classes and continuous PTF (21). The former is used for different texture classes, while the latter does not consider soil texture (18). Continuous PTF needs more time and labor, while class PTFs are less expensive to develope and are more easy to use (22). There are still other methods for categorizing PTFs, based on dependent and independent variables, as reported by McBratney et al. (10). Point PTFs are used to compute soil moisture corresponding to a specific matric potential. Two soil matric potentials corresponding to the common soil moisturte leves, FC and PWP, are important in irrigation scheduling. The clear disadvantage is that a large number of regression equations are required to quantify the complete soil moisture retention curve (1).

Iranian soils lack suitable local PTFs. In this research, some common European PTFs were evaluated for 50 soils in Iran.

## MATERIALS AND METHODS

Fifty SMRCs from previous studies were used (9). Surface (0-30 cm) disturbed and undisturbed samples were taken from different regions in the north of Iran Amol, Babol and Karaj (8). Samples were taken on grid points with equal distances during the spring of 1991. Disturbed samples were first air dried and then passed through 2-mm mesh sieves. Soil textures were determined using the standard routine method, after elimination of gypsum and organic matter (17). Dry bulk density was determined in triplicates after the samples were dried in an oven with a temperature of 105$^{o}$C until they reached a constant weight. A pressure plate apparatus was used to determine soil moisture (weight basis) corresponding to matric potentials of -5, -33, -100, -500 and -1500 kPa in triplicates for undisturbed soil samples. These soil moistures were converted to volume basis by incorporating soil bulk densities. A constant value of 2.65 (g.cm$^{-3}$) was adopted for the soils' particle density. A statistical view of the physical properties of the soils is presented in Table 1. Although relatively broad soil textures (from sandy loam to clay) are included in this data bank, the majority are loam and clay loam. The soil organic mater contents varied from a low (0.34%) to high (3.36%) values. Capillary rise equation is generally valid in non-swelling soils. Khoshnood Yazdi (8) confirmed that non-expansive clay minerals were dominant in the sample.

**Table 1. Some physical properties of soils used in this study**

| Factor | Sand | Silt | Clay | OM | ρb | Soil moisture at defined matric potential (kPa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | -5 | -33 | -100 | -500 | -1500 |
| | | | % | | $g.cm^{-3}$ | | | % | | | |
| Maximum | 65.8 | 52 | 56 | 3.36 | 1.63 | 78.5 | 55.30 | 39.70 | 35.10 | 37.60 | 26.90 |
| Minimum | 14.8 | 37.2 | 14 | 0.34 | 1.37 | 36.6 | 33 | 20 | 16.30 | 11.50 | 9.30 |
| Average | 38.32 | 34.23 | 27.45 | 1.5 | 1.47 | 47.4 | 41.8 | 30.8 | 25.1 | 19.2 | 16.3 |
| SD[+] | 8.65 | 5.46 | 7.63 | 0.7 | 0.051 | 6.66 | 4.2 | 4.1 | 3.7 | 3.1 | 3.4 |
| CV[++] | 22.57 | 15.95 | 27.8 | 46.6 | 3.5 | 11.6 | 10 | 13.3 | 14.74 | 16.15 | 20.86 |

[+] Standard deviation [++] Coefficient of variation

## PTF structures

Four common European PTFs were used. All of these PTFs are based on the 4-parameter van Genuchten (19) SMRC model, defined below:

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

where $\theta_w$ is soil moisture corresponding to soil matric head (h, cm), $\theta_r$ and $\theta_s$ are residual and saturated water contents, and $\alpha$ ($cm^{-1}$), n, and m are constant parameters which control the shape of the SMRC.

a. Rawls and Brakensiek (1989) (RB) evaluated $\alpha$, n, and m of equation (1) as follows:

$$\alpha = h_b^{-1},\ n = \lambda + 1,\ m = \lambda/n \qquad (2)$$

where $h_b$ (air entry suction head, cm), and $\lambda$ (pore size distribution index) can be computed based on equations (3-4) and $\theta_r$ (Equation 1) is found by equation (5), as follows:

$$\begin{aligned} h_b = \exp(&5.3396738 + 0.1845038 clay - 2.48394546\theta_s - 0.00213853 clay^2 \\ &- 0.04356349 sand\,\theta_s - 0.61745089 clay\,\theta_s + 0.00143598 sand^2\theta_s^2 \\ &- 0.00855375 clay^2\,\theta_s^2 - 1.282\times10^{-5}\,sand^2\,clay + 0.00895359 clay^2\theta_s \\ &- 7.2472\times10^{-4}\,sand^2\theta_s + 5.4\times10^{-6}\,clay^2\,sand + 0.50028060\theta_s^2\,clay) \end{aligned} \qquad (3)$$

$$\begin{aligned} \lambda = \exp(&0.7842831 + 0.0177544 sand - 1.062498\,\theta_s - 5.304\times10^{-5}\,sand^2 \\ &- 0.00273493 clay^2 + 1.11134946\theta_s^2 - 0.03088295 sand\,\theta_s \\ &+ 2.6587\times10^{-4}\,sand^2\,\theta_s^2 - 0.00610522 clay^2\,\theta_s^2 - 2.35\times10^{-6}\,sand^2\,clay \\ &+ 0.00798746 clay^2\,\theta_s - 0.00674491\theta_s^2\,clay) \end{aligned} \qquad (4)$$

$$\begin{aligned} \theta_r = &-0.0182482 + 8.7269\times10^{-4}\,sand + 0.00513488 clay + 0.02939286\theta_s \\ &- 1.5395\times10^{-4}\,clay^2 - 1.0827\times10^{-3}\,sand\,\theta_s - 1.8233\times10^{-4}\,clay^2\,\theta_s^2 \\ &+ 3.0703\times10^{-4}\,clay^2\theta_s - 2.3584\times10^{-3}\,\theta_s^2\,clay \end{aligned} \qquad (5)$$

where clay and sand are percentages of clay and sand contents of the soil respectively.

b. Based on Vereeken et al. (20) (VMFD), $\theta_r$, $\theta_s$, $\alpha$, and n can be calculated as follows:

$$\theta_r = 0.015 + 0.005\ clay + 0.014\ om \quad (6)$$

$$\theta_s = 0.81 - 0.283\ D + 0.001\ clay \quad (7)$$

$$Ln\left(\alpha\right) = -2.486 + 0.025\ sand - 0.351\ om - 2.617\ D - 0.023\ clay \quad (8)$$

$$Ln\left(n\right) = 0.053 - 0.009\ sand - 0.013\ clay + 0.00015\left(sand\right)^2 \quad (9)$$

where D is apparent soil bulk density (gr $cm^{-3}$), om is the percentage of organic matter, and sand and clay were defined before.

c. By Wosten (21) (W), $\alpha$, and n can be computed as follows:

$$\alpha = \exp\left(\alpha^*\right),\ n = \exp\left(n^*\right) + 1 \quad (10)$$

where $\alpha^*$ and $n^*$ are:

$$\alpha^* = 11 - 2.298 D^2 - 12.41 D^{-1} + 0.838 om + 0.343 om^{-1} + 2.03 Ln\left(om\right) - 1.263 D\, om \quad (11)$$

$$n^* = -0.34 + 1.224 D^{-1} - 0.7952 Ln\left(clay\right) - 0.3201 Ln\left(om\right) + 0.0651 D\, om \quad (12)$$

d. Wosten et al. (23) (WLNL) computed $\alpha^*$ and $n^*$ differently from Wosten (21) as:

$$\begin{aligned}\alpha^* = &-14.96 + 0.03135 clay + 0.0351 silt + 0.646 om + 15.29 D - 0.192 topsoil \\ &- 4.671 D^2 - 0.000781 clay^2 - 0.00687 om^2 + 0.0449 om^{-1} + 0.0663 Ln\left(silt\right) \\ &+ 0.1482 Ln\left(om\right) - 0.04546 D\, silt - 0.4852 D\, om + 0.00673 topsoil\, clay\end{aligned} \quad (13)$$

$$\begin{aligned}n^* = &-25.23 - 0.02195 clay + 0.0074 silt - 0.194 om + 45.5 D - 7.24 D^2 \\ &+ 0.0003658 clay^2 + 0.002885 om^2 - 12.81 D^{-1} - 0.1524 silt^{-1} - 0.01958 om^{-1} \\ &- 0.2876 Ln\left(silt\right) - 0.0709 Ln\left(om\right) - 44.6 Ln\left(D\right) - 0.02264 D\, clay \\ &+ 0.0896 D\, om + 0.00718 topsoil\, clay\end{aligned} \quad (14)$$

where topsoil is a parameter whose value depends on soil sampling depth (topsoil=1 for top surface-up to 30 cm-, and topsoil=0 for deeper sampling depth) and silt is the percentage of silt fraction in the soil.

## PTF Evaluation

Geometric mean error ratio (GMER, equation 15), geometric standard deviation error ratio (GSDER, equation 16) (16) and root mean square error (RMSE, equation 17) were used to evaluate the performances of the selected PTFs:

$$GMER = \exp\left(n^{-1}\sum_{i=1}^{n} Ln\left(\varepsilon_i\right)\right) \quad (15)$$

$$GSDER = \exp\left[\left(\left(n-1\right)^{-1}\sum_{i=1}^{n}\left[Ln\left(\varepsilon_i\right) - Ln\left(GMER\right)\right]^2\right)^{1/2}\right] \quad (16)$$

$$\mathrm{RMSE} = \left[ n^{-1} \sum_{1}^{n} \left( y_i - \hat{y}_i \right)^2 \right]^{1/2} \qquad (17)$$

where n is the total data points, and $\varepsilon$ for each data pair corresponding to a definite matric potential is defined as $\theta_p / \theta_m$ ($\theta_p$ and $\theta_m$ are predicted and measured soil moisture contents, respectively). The governing criteria are (a) as GMER approaches 1, the performance of a PTF increases, (b) a low value for GSDER is assumed for a good PTF, and (c) a good PTF is considered if its corresponding RMSE has a low value.

## RESULTS AND DISCUSSION

### Predicting SMRC

Loam and clay loam textures covered 43 of the soil samples. Therefore these two soil textures were studied more carefully. The average was calculated for all parameters of each soil texture class. Then van Genuchten parameters were computed by RETC, for each PTF model. Figure 1 shows the computed SMRC for loam and clay loam textures. It seems that loam textured soil is better fitted by PTFs. The RB model while underestimating the soil moisture at a given matric potential, is relatively insensitive to matric potential at $\psi_p > -50$ kPa. It appears that Rawls PTF changes water content values as the potential changes. Thus this model may not compute a fair prediction for soil moisture contents between FC and PWP. While the RB model underestimates soil moisture, the other three PTFs over-predict the soil moisture.

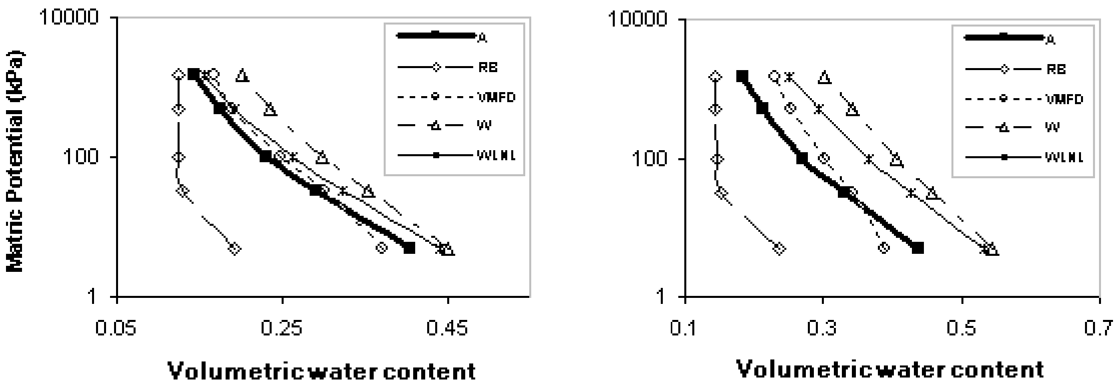


**Figure 1. SMRCs constructed by different PTFs for loam (left) and clay loam (right) soil textures**

Figure 2 presents a comparison between predicted versus measured soil moistures at two matric potentials of -33 and -1500 kPa. The RB model is highly underestimating, especially at -33 kPa matric potential. On the other hand, W and WLNL models over-predict soil moisture, especially for clay loam soils. The best fit for both matric potentials of -33 and -1500 kPa under loam soils seems to be estimated from the WLNL model. The RB model is highly underestimating, especially at -33 kPa. Alternatively, W and WLNL over-predict soil moistures, especially for clay loam soils. It seems that the best fit is for WLNL for clay loam soil textures for both matric potentials of -33 and -1500 kPa. Excluding different soil textures, one may reach a conclusion for adopting the VMFD model that has an overall good fit. Previous literature (11) supports the fact that the VMFD model also has the best performance for the silt loam soil texture.

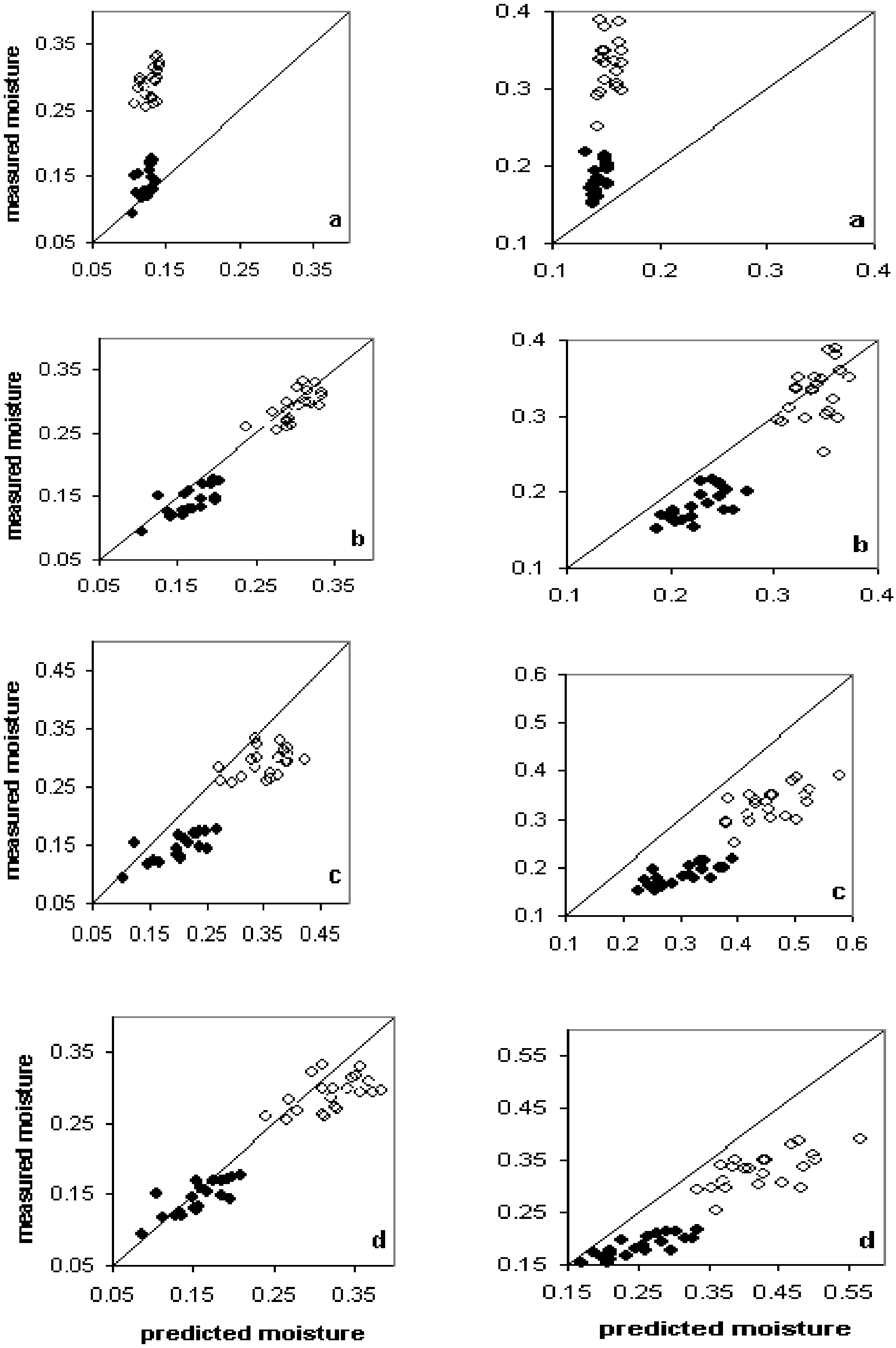


**Figure 2. Comparison of measured and predicted soil volumetric water content ($cm^3$ $cm^{-3}$) at -33 kPa (hollow marks) and -1500 kPa (filled marks) for loam (left column) and clay loam (right column) by (a) RB, (b) VMFD, (c) W, and (d) WLNL PTF**

## Statistical Measures

Table 2 presents GMER values for all PTF models and for two different soil textures. Based on the table, both VMFD and WLNL perform reasonably for both soil texture classes. However, loam soils have a GMER value which is as close to 1 as possible. This result is verified by Figure 1. GSDER values are also reported in Table 2. The lowest GSDER is attributed to the WLNL model for loam soil texture. However, the results for VMFD and WLNL are considered to be good and are in harmony with Table 2. Figure 3 presents RMSE values corresponding to different PTFs and different matric potentials.

**Table 2. The GMER and GSDER values for all PTF models and for two different soil textures**

| Texture | Rawls and Brakensiek | Vereecken et al | Wosten | Wosten et al |
|---|---|---|---|---|
| | | ***GMER*** | | |
| **Loam** | 0.679 | 0.9568 | 1.215 | 1.082 |
| **Clay Loam** | 0.6469 | 1.058 | 1.3759 | 1.2562 |
| | | ***GSDER*** | | |
| **Loam** | 1.4043 | 1.1708 | 1.1473 | 1.0816 |
| **Clay Loam** | 1.2927 | 1.2576 | 1.2115 | 1.1356 |

For clay loam textured soils, RB and W models present a marked decrease in RMSE as matric potential decreases (suction head increases), while the decrease in RMSE for WLNL is relatively mild. The behavior for the other PTF (VMFD model) is not well-defined. As the potential matric decreases, performances of all models converge each others, while RMSE is minimum for all of them, except for VMFD. Lam soils performed slightly differently than clay soils (Figure 2). RMSE for the W model is nearly insensitive to matric potential, while the others are sensitive, although with different rates. The maximum performance for VMFD, however, was due to matric potential of -33 kPa, which is supported by Cornelis et al. (4). Excluding the RB model, the other PTFs perform nearly equally under -33 and -1500 kPa. There was a significant correlation between measured and predicted soil moisture values at -33 and -1500 kPa, as reported by Khodaverdi Lou and Homaee (7). Givi et al. (6) also reported good soil moisture prediction for some soils in the central part of Iran (Chaharmahal and Bakhtiary province) under the VMFD model.

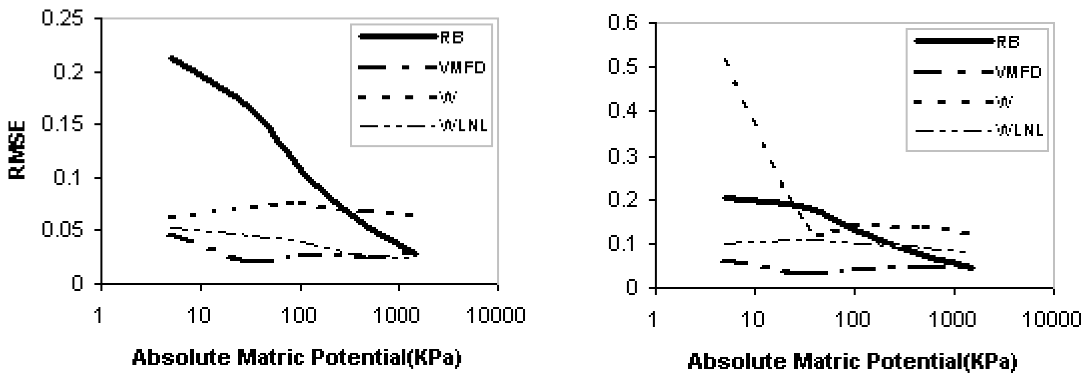


**Figure 3. The values of RMSE corresponding to different PTFs and different matric potentials for loam (left) and clay loam (right)**

The VMFD model is developed for Belgian soils with a clay content around 13%. This may explain why loam textured soils have performed better than clay soil textures (Table1) under this PTF (RMSEs for loam soils are smaller than those of clay loam soils).

## CONCLUSIONS

Soil moisture retention curve is of prime importance in soil-water-plat relationships. Forty three Iranian soils (loam, and clay loam) were used for evaluating four common European pedotransfer functions. The VMFD (20) and the WLNL (23) performed better than the others under loam textured soils, while for clay soils, the VMFD model is more acceptable. FC and PWP were successfully predicted by VMFD and WLNL for loam soils, and VMFD and RB models were good for clay loam soils. Overall, RB under-predicted and the other three models over-predicted soil moisture contents. Soil moisture prediction increased markedly as the matric potential decreased. As a final conclusion, the VMFD model had the best pedotransfer function for the soils under study.

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# ارزیابی چند تابع انتقال متداول اروپایی برای تخمین منحنی رطوبتی خاک در چند خاک ایران

**روزبه موذن‌زاده[1*] و بیژن قهرمان[1**]**

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**چکیده-** عمده‌ی فرآیندهای هیدرولیکی در شرایط طبیعی در یک مزرعه در شرایط غیراشباع انجام می‌شود. منحنی مشخصه‌ی رطوبتی، SMRC، مهم‌ترین ویژگی هیدرولیکی یک خاک غیراشباع است که دانستن آن در مطالعات آب و خاک از قبیل حفاظت خاک، فرسایش خاک، ارزیابی اراضی و مدیریت منابع آب از اهمیت بالایی برخوردار است. SMRC را می‌توان به دو روش مستقیم و غیر مستقیم به‌دست آورد. گرچه توسعه‌های فراوانی در روش‌های مستقیم به‌وجود آمده است، این روش‌ها کماکان زمان‌بر و هزینه‌بر به شمار می‌آیند. در نتیجه، روش‌های غیر مستقیم همواره در کانون توجهات قرار دارد. این مقاله چند تابع انتقال (PTF) متداول اروپایی را برای تخمین SMRC در چند خاک ایران ارزیابی کرده است. از ۵۰ خاک از مناطق کرج، آمل و بابل واقع در شمال ایران که بافت عمده‌ی آن‌ها لوم و لوم رسی بود، استفاده شد. مقدار رطوبت متناظر با پتانسیل‌های ماتریک ۰ ، -۵، -۳۳، -۱۰۰، - ۵۰۰ و ۱۵۰۰ kPa- با استفاده از دستگاه صفحات فشاری تعیین شد. در این بررسی چهار PTF متداول اروپایی راولز و براکنزیک (RB)، وریکن و همکاران (VMFD)، وستن (W) و وستن و همکاران (WLNL) مدنظر قرار گرفت. برای ارزیابی این PTF ها از معیارهای GMER، GSDER و RMSE استفاده شد. نتایج نشان داد که کارایی این PTF ها برای خاک‌های لومی بالاتر بود. عملکرد مدل‌های VMFD و WLNL بهتر بود در حالی‌که مدل VMFD تنها در خاک‌های لوم رسی از بقیه بهتر بود. به‌طور کلی هرچه پتانسیل ماتریک افزایش می‌یافت، عملکرد نیز بهتر می‌شد.

**واژه های کلیدی : منحنی مشخصه‌ی رطوبتی، PTF، ارزیابی، ایران**

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** مکاتبه کننده