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*Full Length Research Paper*

# Parametric pedotransfer functions of a simple linear scale model for soil moisture retention curve

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**Soil moisture retention (SMR) curve is a basic soil property. Since, direct measurement of the SMR curve is costly and time-consuming; it can be estimated using pedotransfer functions (PTFs) based on more easily available soil properties. Parametric PTFs estimate the parameters of a closed-form analytical equation for representation of SMR curve. In this study, we derived parametric PTFs for the model of Groenevelt and Grant (2004) which include three adjustable fitting parameters ($K_0$, $K_1$ and n). Our results tended to consider the constant value of 5 for the parameter of $K_0$, and the parameters $K_1$ and n were estimated based on more easily available soil properties by using twenty-two soils. The value of soil water content at matric potential of 1500 kPa ($\theta_{wp}$) must also be available for this model. In this study, we considered two conditions for entering the $\theta_{wp}$ in the model: using measured $\theta_{wp}$ and estimated $\theta_{wp}$ with more easily available soil properties considering sand fraction of the soil, organic matter content, geometric mean particle-size diameter and geometric standard deviation of the particle-size diameter. Finally, the derived PTFs were evaluated for eight independent soils. The results indicate that there was no considerable difference between the two mentioned conditions for using $\theta_{wp}$ to estimate the SMR curve. Also, the results demonstrated that the proposed model in this study can be used for estimating the SMR curve with acceptable accuracy.**

**Key words:** Model of Groenevelt and Grant, soil moisture retention curve, pedotransfer functions.

## INTRODUCTION

Soil moisture retention (SMR) curve is a basic soil property necessary for the study of plant-available water, infiltration, drainage, solute movement, and it has an important role in soil water studies. However, its direct measurement is costly and time-consuming. Therefore, an alternative for its measurement is to estimate this property using more easily available soil properties such as particle size fractions that is, clay, silt and sand contents, bulk density and organic matter content. Most of these methods can be called pedotransfer functions (PTFs), because they translate existing surrogate data into soil hydraulic data. PTFs are classified as point and parametric PTFs (Cornelis et al., 2001; Acutis and Donatelli, 2003). Point PTFs estimate the water content of the soil at certain matric potentials such as field capacity and wilting point. Many studies have used PTFs to evaluate only points of the SMR curve. Givi et al. (2004) compared thirteen PTFs for estimating wilting point for fine-textured soils. Nourbakhsh et al. (2004) estimated wilting point in a arid region, and they obtained a strong linear correlation between wilting point and cation exchange capacity and silt content of the soil. Also, Dashtaki et al. (2010) derived equations for estimating wilting point using some soil samples, and Merdun (2010) derived the point PTFs for estimating wilting point using some soil samples from UNSODA soil databases, based on sand and silt content and bulk density of soil. Parametric PTFs predict the parameters of a closed-form analytical equation, such as the model of Brooks and Corey (1964) and van Genuchten (1980). The proposed model by van Genuchten (1980) is the most common method for describing the SMR curve, and many studies have used this model (Vereecken et al., 1990; Wösten et al., 1999; Sepaskhah and Bondar, 2002; Rajkai et al., 2004; Merdun, 2006; Dashtaki et al., 2010). However, since PTFs are often developed empirically,

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their applicability may be limited to the data set used to define the method (Wosten et al., 1999). Moreover, the available PTFs can produce substantially different estimates. Thus, users have a difficult task in selecting a more appropriate PTF for their application (Acutis and Donatelli, 2003).

Groenevelt et al. (2001) fitted an equation to the SMR curve in a new approach. Then, Groenevelt and Grant (2004) presented a simple linear scale equation for the SMR curve. This model includes the value of the volumetric soil water content at –1500 kPa and three adjustable fitting parameters ($K_0$, $K_1$ and n) with no physical meaning. However, a few studies can be found in literature about this model. In one of these studies, Grant et al. (2010) used this model to predict the soil hydraulic conductivity. Although, many parametric PTFs of the model of van Genuchten (1980) were derived in different locations of the world and have been accepted; however, there is no study reported in the literature for parametric PTFs of the model of Groenevelt and Grant (2004). Therefore, the objective of this study was to derive and validate the PTFs for the parameters of this model.

## MATERIALS AND METHODS

For this study, thirty soils from the topsoils (A horizons) were selected from different locations in Fars province, south of Iran. All soil samples were gathered at the depth of 0 to 30 cm. The selected soils have similar mineralogy. The values of organic matter content of each soil was measured. Also, the values of clay, silt and sand fractions of each soil were measured according to the United State Department of Agriculture (USDA) system (Clay: 0 to 0.002 mm; Silt: 0.002 to 0.05 mm; sand: 0.05 to 2 mm) with combination of the hydrometer and the wet sieving methods as described by Gee and Bauder (1986). The geometric mean particle-size diameter ($d_g$), and geometric standard deviation of the particle-size diameter ($\square_g$) for each soil were determined by using the following equations (Shirazi and Boersma, 1984):

$$a = 0.01(f_c \mathrm{Ln}0.001 + f_{si} \mathrm{Ln}0.026 + f_{sa} \mathrm{Ln}1.025) \quad (1)$$

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

$$b^2 = 0.01\{f_c (\mathrm{Ln}0.001)^2 + f_{si} (\mathrm{Ln}0.026)^2 + f_{sa} (\mathrm{Ln}1.025)^2\} - a^2$$
(3)

$$\delta_g = \exp(b) \quad (4)$$

where $d_g$ is geometric mean particle-size diameter in mm, and $f_c$, $f_{si}$ and $f_{sa}$ are the clay, silt and sand fractions (g $g^{-1}$), respectively.

The SMR 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 appratus (for matric potentials of 30, 100, 500, 1000 and 1500 kPa) methods.

The simple linear scale equation proposed by Groenevelt and Grant (2004) for the SMR curve including three adjustable fitting parameters ($K_0$, $K_1$ and n) in the plant-available range of soil water (up to matric potentials of 1500 kPa corresponded to the wilting point) is as follows:

$$\theta(h) = \theta_{wp} + K_1 \left\{ \exp\left( \frac{-K_0}{15000^n} \right) - \exp\left( \frac{-K_0}{h^n} \right) \right\} \quad (5)$$

where θ(h) is the volumetric soil water content ($m^3$ $m^{-3}$) in each matric potential (h, cm) and $\theta_{wp}$ is the measured water content at matric potentials of 1500 kPa corresponding to the wilting point ($m^3$ $m^{-3}$).

The parameters $K_0$, $K_1$ and n and $\theta_{\omega\pi}$ must be available to represent the SMR curve. However, the objective of this reaserch was to estimate SMR curve without appealing to measurements. To do so, at first we determine the parameters of Equation 5 for each soil, separately. Our results tended to consider the constant value of 5 for the parameter of $K_0$, and the parameters of $K_1$ and n were determined using the Solver menu of Microsoft Excel. To do this, the minimum differences between measured and estimated SMR curve were established by using the available $\theta_{wp}$ for each soil. The reason for selecting a constant value for the parameter of $K_0$ was to better fit Equation 5 to measured SMR curve, and the value of 5 for this paremeter was obtained by trial and error. Therefore, for each soil the parameters of $K_1$ and n were determined. On the other hand, $\theta_{wp}$ is not an easily available soil property, and as mentioned before it can be estimated with point PTFs. Dashtaki et al. (2010) derived two equations for estimating $\theta_{wp}$, linear equation based on clay content, and multiple linear equation based on $d_g$ and $\theta_g$. However; in this study, we used the combination of soil fraction contents, organic matter content, $d_g$ and $\theta_g$ to derive the best point PTFs for estimating $\theta_{wp}$ based on the multiple linear regression method.

Therefore, we propose three PTFs for estimating the parameters of $K_1$ and n, and $\theta_{wp}$ based on soil texural data, $d_g$, $\theta_g$ and soil organic matter content. We also supposed two conditions for estimating SWR as follows:

PTF1: Considering PTFs for estimating $K_1$ and n and available measured $\theta_{wp}$ for using in Equation 5.

PTF2: Considering PTFs for estimating $K_1$, n and $\theta_{wp}$ for using in Equation 5.

To do this, twenty-two soils were used in the calibration stage, and the other eight remaining soils were used for validating the obtained results. To evaluate the obtained results in the validation stage, the root mean square error (RMSE), geometric mean error ratio (GMER) and geometric standard deviation of the error ratio (GSDER) were used as follows (Tietje and Hennings, 1996):

$$\mathrm{RMSE} = \left[ \frac{\sum_{i=1}^{N} (\theta_m - \theta_e)^2}{N} \right]^{0.5} \quad (6)$$

$$e = \frac{\theta_e}{\theta_m} \quad (7)$$

$$\mathrm{GMER} = \exp\left( \frac{1}{N} \sum \mathrm{Ln}(e_i) \right) \quad (8)$$

**Table 1.** Characteristics and parameters of Iranian soils used in this study in calibration stages.

| Clay (%) | Sand (%) | Organic matter content (%) | $d_g$ (mm) | $\delta_g$ | $K_1$ | n |
|---|---|---|---|---|---|---|
| 42 | 8 | 1.51 | 0.009 | 8.12 | 0.26 | 0.33 |
| 26 | 18 | 1.95 | 0.022 | 9.69 | 0.48 | 0.28 |
| 13 | 35 | 2.63 | 0.064 | 10.11 | 0.62 | 0.19 |
| 15 | 31 | 3.20 | 0.051 | 10.21 | 0.56 | 0.22 |
| 27 | 18 | 1.61 | 0.021 | 9.88 | 0.35 | 0.39 |
| 13 | 31 | 1.89 | 0.053 | 9.50 | 0.37 | 0.32 |
| 30 | 8 | 1.91 | 0.013 | 7.02 | 0.35 | 0.30 |
| 32 | 12 | 2.08 | 0.014 | 8.65 | 0.48 | 0.31 |
| 28 | 10 | 2.18 | 0.015 | 7.44 | 0.47 | 0.31 |
| 39 | 8 | 1.14 | 0.010 | 7.89 | 0.42 | 0.26 |
| 28 | 18 | 1.91 | 0.020 | 10.08 | 0.41 | 0.52 |
| 34 | 12 | 2.01 | 0.013 | 8.91 | 0.41 | 0.39 |
| 4 | 80 | 0.34 | 0.431 | 6.21 | 0.50 | 0.46 |
| 4 | 79 | 0.24 | 0.416 | 6.33 | 0.38 | 0.44 |
| 1 | 75 | 1.17 | 0.396 | 9.14 | 0.50 | 0.34 |
| 9 | 63 | 0.34 | 0.196 | 10.16 | 0.41 | 0.33 |
| 6 | 54 | 1.01 | 0.151 | 8.94 | 0.41 | 0.30 |
| 26 | 24 | 1.61 | 0.027 | 11.58 | 0.37 | 0.42 |
| 14 | 39 | 1.17 | 0.067 | 11.21 | 0.46 | 0.25 |
| 15 | 43 | 2.63 | 0.076 | 12.24 | 0.62 | 0.23 |
| 13 | 38 | 2.34 | 0.070 | 10.47 | 0.55 | 0.30 |
| 9 | 51 | 1.30 | 0.127 | 10.02 | 0.45 | 0.27 |

**Table 2.** Characteristics of Iranian soils used in this study in validation stages.

| Soil number | Clay (%) | Sand (%) | Organic matter content (%) | $d_g$ (mm) | $\delta_g$ |
|---|---|---|---|---|---|
| 1 | 46 | 4 | 1.11 | 0.007 | 6.66 |
| 2 | 24 | 20 | 1.15 | 0.025 | 9.88 |
| 3 | 12 | 36 | 1.38 | 0.066 | 9.92 |
| 4 | 34 | 6 | 1.31 | 0.011 | 6.72 |
| 5 | 30 | 12 | 2.05 | 0.015 | 8.38 |
| 6 | 6 | 76 | 0.44 | 0.349 | 7.67 |
| 7 | 7 | 63 | 0.37 | 0.210 | 10.16 |
| 8 | 10 | 40 | 3.35 | 0.082 | 9.84 |

$$\mathrm{GSDER} = \exp\left[\left(\frac{1}{N-1}\sum\left[\mathrm{Ln}\left(e_i\right) - \mathrm{Ln}\left(\mathrm{GMER}\right)\right]^2\right)^{0.5}\right] \tag{9}$$

Where $\theta_m$ and $\theta_e$ are the measured and estimated volumetric soil water content at each soil matric potential (h), and N is the number of data for each soil. A GMER value equal to one corresponds to an exact matching between measured and predictive data; GMER less than one indicate that estimated values are generally underestimated, and GMER greater than one points to a general over-estimation. GSDER equal to one corresponds to a perfect matching and it grows with deviation from measured data. The best model will, therefore, give a GMER close to one and a small GSDER (Wagner et al., 2001). Also, the lower RMSE value show better agreement between measured and estimated SMR curve.

## RESULTS AND DISCUSSION

The values of clay, sand, organic matter content, the calculated values of $d_g$ and $\theta_g$ and the obtained values of the parameters of $K_1$ and n for twenty-two soils used in calibration stage are shown in Table 1. The mentioned soil characteristics except the parameters of $K_1$ and n for soils used in the validation stage are shown in Table 2.

The best derived PTFs for the parameters of $K_1$ and n, and $\theta_{wp}$ based on twenty-two soils in calibration stage are

**Table 3.** Values of RMSE, GMER and GSDER for each soil in validation stage for models of PTF1 and PTF2.

| Soil number | SE | SE | GMER | GMER | GSDER | GSDER |
|---|---|---|---|---|---|---|
| | PTF1 | PTF2 | PTF1 | PTF2 | PTF1 | PTF2 |
| 1 | 0.02 | 0.02 | 0.94 | 0.94 | 1.05 | 1.05 |
| 2 | 0.08 | 0.07 | 0.77 | 0.83 | 1.17 | 1.18 |
| 3 | 0.04 | 0.03 | 0.88 | 0.94 | 1.09 | 1.10 |
| 4 | 0.06 | 0.06 | 0.85 | 0.87 | 1.09 | 1.10 |
| 5 | 0.02 | 0.03 | 0.93 | 1.14 | 1.07 | 1.10 |
| 6 | 0.08 | 0.10 | 0.76 | 0.61 | 1.18 | 1.12 |
| 7 | 0.10 | 0.13 | 0.72 | 0.55 | 1.21 | 1.13 |
| 8 | 0.08 | 0.10 | 1.15 | 1.23 | 1.13 | 1.10 |
| Average | 0.06 | 0.07 | 0.88 | 0.89 | 1.12 | 1.11 |

as follows:

$$K_1 = 0.16 + 0.11\text{OM} + 0.003\text{S} \quad \text{and}$$

$(R^2 = 0.67)$ (10)

$$n = -2.47 - 0.28\text{OM} + 0.61\text{OM}^{0.5} - 0.05\text{Sand} + 7.85 d_g^{0.5} + 0.75\delta_g^{0.5}$$

$(R^2 = 0.70)$ (11)

$$\theta_{wp} = 1.17 + 0.02\text{OM} + 0.02\text{Sand} - 2.85 d_g^{0.5} - 0.31\delta_g^{0.5}$$

$(R^2 = 0.64)$ (12)

Where Sand is in %, OM is the soil organic matter content in %, and $d_g$ and $\theta_g$ have been defined before.

The values of RMSE, GMER and GSDER for each soil in the validation stage based on two conditions for estimating the SMRcurve are presented in Table 3, separately. As shown in this table, the mean values of RMSE for all soils for PTF1 and PTF2 were 0.06 and 0.07, respectively. Merdun (2006) reported RMSE values of 0.067 and 0.082 for parametric PTFs of the models of van Genuchten (1980) and Brooks and Corey (1964), respectively. In another study the RMSE values of 0.067, 0.080 and 0.093 were reported for three PTFs (Ghanbarian-Alavijeh and Liaghat, 2009). Therefore, the results of this study showed that the obtained mean RMSE value for all soils had an appropriate value for estimating the SMRcurve. On the other hand, the mean values of GMER for all soils for PTF1 and PTF2 were 0.88 and 0.89, respectively, close to one. Therefore, the results indicate that the estimated values of SMR curve based on PTF1 and PTF2 were generally underestimated in relation to measured values. Ghanbarian-Alavijeh and Liaghat (2009) reported GMER values of 0.910, 0.801 and 0.786 for three PTFs, which were close to the obtained GMER value for all soils in this study. Furthermore, the mean values of GSDER for all soils for PTF1 and PTF2 were 1.12 and 1.11, respectively, which were small and close to one. Therefore, the results of this study show that the proposed PTFs based on the model of Groenevelt and Grant (2004) can be used for estimating SMRcurve with acceptable accuracy by using some easily soil measured properties. On the other hand, the results indicate that there was no considerable difference between the PTF1 and PTF2 models for estimating SMR curve. Rajkai et al. (2004) reported that using one measured moisture content tended to improve the SMR estimation; however, the results of this study demonstrated that using $\theta_{wp}$ no considerable effect was observed to improvs SMR curve. Since, the measurement of $\theta_{wp}$ is to some extent costly and time-consuming; it's estimation through Equation (12) can be suggested for estimating SMR curve with proposed model in this study.

## Conclusions

Many parametric PTFs can be found for estimating soil moisture retention (SMR) curve especially those based on the model of van Genuchten (1980). However, in this study we derived parametric PTFs for the model of Groenevelt and Grant (2004). This model includes three adjustable fitting parameters ($K_0$, $K_1$ and n) and the value of volumetric soil water content at –1500 kPa ($\theta_{wp}$). We suggested the constant value of 5 for the parameter of $K_0$, and we estimated the parameters of $K_1$ and n. Also, we use measured and estimated $\theta_{wp}$ for estimating SMR curve by the model of Groenevelt and Grant (2004), separately. The results indicated that using $\square_{wp}$ had no considerable effect in improving SMR curve, which was in contrast with the reported results by Rajkai et al. (2004). Finally, the results of this study showed that the proposed PTFs based on the model of Groenevelt and Grant (2004) can be used for estimating SMR curve with acceptable accuracy for selected soils in South of Iran. Up to now very few studies have dealt whit the model of Groenevelt and Grant (2004); therefore, we suggest to use this model and derive new PTFs for its parameters for a wider range of soil samples and soil texural data bases to complete the obtained results of this study.

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