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Pedo-Transfer Functions (PTFs) for Prediction of Water Release Curves in Clay Soils

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ABSTRACT

Soil hydraulic properties determine by either direct or indirect Approaches. However, direct method is a time consuming process and usually not possible for larger areas. Therefore, the most widely used method to obtain these properties is the application of Pedo-Transfer Functions (PTFS) as an indirect method. These are generally empirical relationships which allow the hydraulic properties of a given soil to be predicted from more widely available data, usually textural class alone or texture, bulk density and organic carbon content. The aim of this study was to determine the main hydraulic properties (water retention curve) of the clay soils by PTFS. 50 samples with clay texture were taken randomly from Kordestan, Kermanshah and Kerman regions. The particle size distributions, bulk densities and calcium carbonate percentage of the soil samples were determined by the Hydrometry, Core and Acid Neutralization methods, respectively. The retention curve was obtained using pressure plate apparatus. The easily obtainable variables were separated into two groups: i- particle-size distribution, bulk density and calcium carbonate percentage and ii- bulk density, geometric mean and geometric standard deviation of particle diameters and calcium carbonate percentage. Two point PTFs types and two parametric PTFs forms were developed to predict six points at the soil moisture characteristic and the parameters of Van Genuchten (1980). The results indicate that the variables of the first group have better estimation the Van Genuchten parameters and presser vation humidity in o, -33, -100, -300, -500 and -1500 kPa of metric potential. It was also noted that the amount of clay is not the only factor on which the hydraulic properties can be estimated in soil. More ever, the type of clay and its morphology and mineralogy properties can be affected the soil hydraulic properties.

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INTRODUCTION

Soil hydraulic properties in unsaturated zone are key aspects in determining soil quality and soil function. For example, the water retention curve, which defines the relationship between soil water content (θ) and soil water pressure head (h), is an important physical property of soil material. On a plot scale, soil hydraulic properties can be measured. But it is a time consuming and expensive process and not possible for larger areas. For the latter case, using method to determine the water retention curve indirectly from easily measured properties or properties available from routin soil survey data is usual. Boumaintroduced the term Pedo Transfer Function (PTF). These are generally empirical relationships which allow the hydraulic properties of a given soil to be predicted from more widely available, easily, routinely or cheaply measured data.

Some PTF_S have been developed to predict single values of a hydraulic property. For example, the saturated hydraulic conductivity, available water capacity or the water content at particular metric potentials. Others have been developed to predict the parameters of an equation which describes the whole of the water release and/or conductivity characteristic. The equation of Brooks and Corey and Van Genuchten are examples. PTF_S can be categorized into class and continuous PTF_S. Class PTF_S predict certain soil properties based on the class (textural, horizon, etc.) to which the soil sample belongs. Continues PTF_S predict certain soil properties as a

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continuous function of one or more measured variable. Although the advantages and limitation of PTF_S are well discussed by several authors [2], its applications to problematic soils such as clay soil is neither extended nor verified. Generally methods to the fit water- retention PTF_S are as following:

1- The most common method in point estimation PTF is to employ multiple linear regressions (MLR) for example:

$\theta_p = a$ sand + b silt + c clay + d organic matter + e bulk density

Where θ_p is the water content (m^3m^{-3}) at soil water pressure head P and a, b, c, d, and e are regression coefficients. Multiple linear regressions are also used in parametric PTF_S. Parameters of the hydraulic models are estimated by fitting the model to water-retention data with nonlinear regression and empirical relationship between basic soil properties and model parameters are then formed.

Scheinost *et al*., found difficulty in estimating the scaling and shape parameter *a* and *m* of the Van Genuchten equation using the regression approach. Realizing the over-parameterization of the Van Genuchten equation, they proposed the following approach (Multiple linear regressions, ENR)

I- Set-up the expected relationship between the parameters of the hydraulic model and soil properties.

II- Insert the relationship in to the model and estimate the parameters of the relationship simultaneously by fitting the extended model using nonlinear regression to all date.

A recent approach for fitting PTF_S is to use artificial neural network. The artificial neural network (ANN) is a network of many simple processors each possibly having a small amount of local memory. The mathematical model of an ANN comprises of simple functions linked together by weights. The network consist of a set of input units, a setup of out put units and a set of hidden unit, which link the inputs to out puts. The hidden units extract useful information from inputs and use them to predict the out put units.

Usually clay soils are characterized with high fertility potential owing to cation exchange capacity, but its hydraulic properties have been studied less frequently due to swelling, shrinkage, preferential flow and wetting front instability of these soils. Therefore, the main objective of this study was to derive PTF_S to predict the soil water retention curve of some clay soils.

MATERIALS AND METHODS

From the top 30 *cm* soil depth, 100 core and 100 disturbed samples were collected from Kordestan, Kerman and Kermanshah provinces, Iran. The samples first were air dried and sieved with a 2 mm sieve. The particle size distributions of the soil sample were obtained with hydrometer method. In order to derived the PTF_S in one soil texture class. 50 clay soil samples among others were selected. The soil bulk density was determined by the core method. The equivalent calcium carbonate that indicates the lime content was obtained with acid neutralization. The soil water retention curves were determined, using a pressure plate apparatus at 0, 33, 100, 300, 500, and 1500 kPa in three replicates. The measurement properties were used as the predicative variables to estimate the water retention curve and Van Genuchten parameters. These properties were the following:

1) Particle-size distribution
2) Bulk density (gr/cm^3)
3) Lime content (%)
4) Geometric mean particle-size diameter (d_g)
5) The geometric standard deviation (δ_g)

d_g and δ_g can be obtained according to Shirazi and Boersma (1984):

$$\begin{cases} d_g = \exp a \\ a = 0.01\sum_{i=1}^{3} F_i \, Ln M_i \end{cases} \tag{1}$$

$$\begin{cases} \sigma_g = \exp b \\ b^2 = 0.01\sum_{i=1}^{3} F_i \, Ln^2 M_i - a^2 \end{cases} \tag{2}$$

Where F_i are percent masses of Sand, Silt and Clay particles (%) and M_i is arithmetic mean particle size of the soil (*mm*). These values for the USDA system from *Shirazi* and *Boersma* is $M_d = 1.025$ *mm* for Sand, $M_t = 0.026$ *mm* for Silt, and $M_y = 0.001$ *mm* for Clay soils.

The normality of the data was tested, using the Mini Tab program (Ryan and Joiner, 1994). Those parameters that demonstrated abnormality were normalized with the following transformations:

sand = log sand*

d_g^* = log d_g

$TNV^{*}=\log TNV$

$\delta_g^{*}=\log \delta_g$

Where $sand^{*}$, TNV^{*}, d_g^{*} and δ_g^{*} are the normalized *sand*, *TNV*, d_g, and δ_g parameters, respectively. These normalized parameters are used in the all regression analyses.

The non linear least square optimization program, RETC was used to predict the parameters Θ_r, α and n from measured water - retention data. The best subset regression method was used to derive the pedotransfer functions. Only those variables that were significant at 1 % confidence level were used in the multiple regression analyses.

Table 1: The mean, maximum, minimum, and SD of soil properties.

Variable	BD (gr/cm$^{3)}$	Sand (%)	Silt (%)	Clay (%)	TNV (%)	d_g (mm)	δ_g (mm)
Mean	1.27	13.58	39.47	49.69	21.20	0.0104	10.69
Maximum	1.54	36.00	59.00	68.00	57.80	0.0307	21.52
Minimum	1.01	3.00	21.00	30.00	4.20	0.0037	6.25
SD	0.134	6.87	7.20	8.65	11.54	0.0050	2.76

To develop point and parametric $PTF_{S,}$ the independent variables were classified into two groups. The sand percent, silt percent, clay percent, bulk density and equivalent calcium carbonate (TNV) were used as independent variables of group (a). The group (b) was consisted to d_g, δ_g, BD and TNV. Thus four types of PTF_S were obtained as following:

Type 1: the point PTF_S based on group (a) variables.
Type 2: the point PTF_S based on group (b) variables.
Type 3: the parametric PTF_S based on group (a) variables.
Type 4: the parametric PTF_S based on group (b) variables.

RESULT AND DISCUSSION

For developing of Pedo_ Transfer Functions, Four PTF_S were presented in this study as following:

Type 1: the point PTF_S predict the water content at o,-33,-100,-300,-500 and -1500 kPa according to the sand, silt and clay percent, bulk density and TNV percentage. The derived PTF_S are given in table 2.

Table 2: the derived first type point $PTF_{S.}$

No	Derived Pedo Transfer Functions	R^2_{adj}
1	Θ_5 =0.2+0.315clay.83sand*-2.23TNV*+12.5BD	0.431
2	$\Theta_{33kpa\,=}$-8.3 +0.505clay-7.01 sand*-5.66 TNV* +29.9BD	0.531
3	$\Theta_{100kpa=}$1.3+ O.421clay- 5.67sand*-4.65 TNV*+3BD	0.507
4	$\Theta_{300kpa=}$0.893+0.00675clay-0.098sand* - 0.0744TNV* +0.313BD	0.503
5	$\Theta_{500kpa=}$-7.06+0.398clay-3.34sand* -2.72TNV* +15.0 BD	0.523
6	$\Theta_{1500kpa=}$ -9.49=0.392 CLAY -3.02 sand* -2.27 TNV* +15.9MD	0.531

The comparison of the measured and estimated water contents at the pressure heads equivalent to the filed capacity (33 kPa) and the permanent wilting point (1500 kPa), are show in Fig.1.

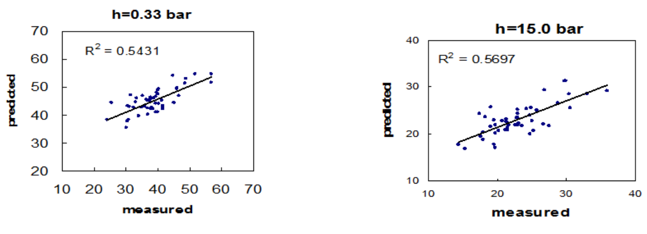

Fig. 1: The measured and predicted water contents, using type 1 point PTF_S at FC (a) and PWP (b).

The results indicated α significant correlation with p=0.001 between the measured and estimated values. The negative correlation between the sand and carbonate content indicated that by increasing sand and calcium carbonate, the surface area for water retention decreasing but water content was increased with increasing clay content. This can be related to the influence of clay on carbonate particles that appeared in clay size, could not act as clay particles specific particle surface and hence the water content. But calcium to retain the soil water. These results suggest lower adsorption energy by the soil calcium carbonate.

Type 2: These types of the point PTF_S were derived, using *dg*, δg BD and TNV as independent variables. The derived PTF_S for this group are given in table 3. The comparison of the measure and estimated water contents at the pressure heads equivalent FC and PWP are shown in Fig. 2. Comparison of the R^2_{adj} for the first and second type of point PTF_S indicated that there aren't significant differences between two groups of PTF_S. It was also noted that the amount of clay is not the only factor for better predict the water retention more ever the type of clay and its morphology and mineralogy properties can affect soil hydraulic properties.

Table 3: The derived second type of point PTF_S.

No	Derived Pedo Transfer Function	R^2_{adj}
1	$\Theta_{5=}$6.81-16.3dg*+11.6 BD	0.456
2	$\Theta_{33kpa=}$-70.0- 3.8dg*+12.9δg*-4.99TNV*+31.0BD	0.336
3	$\Theta_{100kpa=}$52.3-26.1 dg+12.0 δg*-4.15 TNV*+18.4 BD	0.517
4	$\Theta_{300kpa=}$-0.053-0.43dg*+0.218 δg*-0.0688 TNV*+ 0.34 BD	0.520
5	$\Theta_{500kpa=}$ -60.0-24.5 dg*+15.7 δg* -2.30TNV*+16.3BD	0.534
6	$\Theta_{1500kpa}$= -57.9-22.3 δg*-14.1 TNV*+16.7 BD	0.544

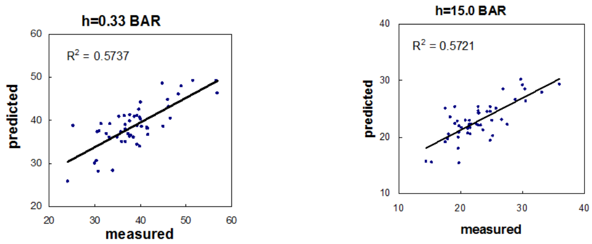

Fig. 2: The measured and predicted water contents, Using type 2 point PTF_S at FC (c) and pwp (d).

Type 3: These types of functions predict the Van Gnuchten (1980) parameters from the first set of variables. The obtained functions for this group are given in table 4. The results shown that clay content appeared to be the most important input to predict O_r parameter.

Table 4: The derived first type parametric PTF_S.

No	Derived Pedo Transfer Function	R^2_{adj}
1	O_r= 0.234+0.00329 clay+ 0.0316 TNV*	0.217
2	N=0.113+0.0523 TNV*+0.86 BD	0.128
3	α=0.715-0.029 clay-1.61 BD	0.164

Type 4: these functions predict the soil hydraulic parameters from the first and second group of variables. The results obtained are listed in table 5.

Table 5: The derived second type of parametric PTF_S.

No	Derived Pedo Transfer Function	R^2_{adj}
1	O_r= -0.296-0.119 dg*+ 0.154 BD+ 0.0434 TNV*	0.205
2	N=0.176-0.0296 dg* +0.197 BD + 0.0424 TNV*	0.116
3	α= 1.050+ 0.528 dg* -1.51 BD	0.167

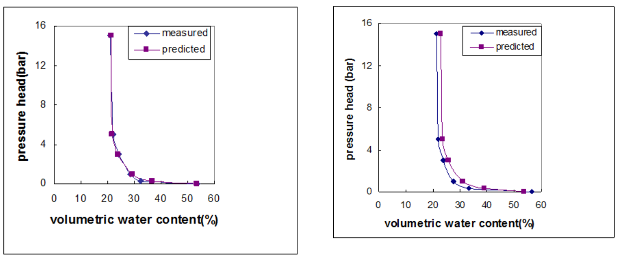

Fig. 3: The measured and estimated soil moisture characters.

Conclusions:

The results presented above indicated that the point PTF_S had better predication of water retention curve than parametric PTF_S in clay soils. On the other hand, parameters PTF_S can not accurately predict Van Genuchten parameters. One reason can be attributed to the fact that when hydraulic parameters are estimated by

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nonlinear regression. Some errors are already included in the model this may result in a large uncertainly when the parameters are correlated with the predictive variables.

The obtained soil moisture characteristics were compared with that derived with PTF_S. The results indicated a significant correlation (p=0.001) between the measured and estimated data. The comparison between the measured and estimated retention curves with PTF_S are depicted in Fig. 3.

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