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ESTIMATING VAN GENUCHTEN SOIL WATER RETENTION CURVE FROM SOME SOIL PHYSICAL PROPERTIES

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ABSTRACT

The modeling of water movement through soils typically requires the functional representation of soil hydraulic properties, such as the water retention curve. Among different water retention models, van Genuchten (VG) model is an appropriate one. The objectives of this study were to quantify relationships between the VG model parameters and soil physical properties and to select equations that are useful for prediction of VG model for soil water retention curve. Fifty four soil samples were used for soil water characteristics determination by ceramic plate extractor, soil particle size determination by hydrometer method, soil bulk density and soil organic matter. Multiple regression was used to determine the relationships between m and h_p (soil water suction at reflection point of the soil water retention curve) and the aforementioned soil physical properties. The results indicated that multiple regression models may be used to estimate, with acceptable accuracy, the water retention curve of VG type from soil sand content, bulk density and organic matter percent. The proposed regression models were used for prediction of soil water retention curve for three different soils with an acceptable accuracy.

Key words: Pedo-transfer function, van Genuchten, Water retention curve.

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تخمین منحنی مشخصه آب خاک وان گنوختن بوسیله ویژگی های فیزیکی خاک

علیرضا سپاسخواه و حسین بندار

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چکیده

برای مدل کردن حرکت آب در خاک، توابع هیدرولیکی مانند منحنی مشخصه آب خاک لازم است. در بین مدل های مختلف برای منحنی مشخصه آب خاک، مدل وان گنوختن یکی از مناسب ترین آن ها است. هدف این پژوهش ارائه روابطی بین عوامل مدل وان گنوختن و ویژگی های فیزیکی خاک بوده تا از روی آن ها بتوان منحنی مشخصه آب خاک را تخمین زد. منحنی مشخصه آب خاک برای ۵۴ نمونه خاک در دستگاه سلول فشاری به همراه تجزیه مکانیکی به روش هیدرومتری، چگالی ظاهری خاک و درصد ماده آلی خاک تعیین شد. روابط بین عوامل وان گنوختن، m و h_p (مکش آب خاک در نقطه عطف منحنی مشخصه آب خاک) و ویژگی های فیزیکی خاک به وسیله رگرسیون چندگانه به دست آمد. نتایج نشان داد که این روابط رگرسیون چندگانه ممکن است با دقت قابل قبولی، برای تخمین منحنی مشخصه آب خاک از روی درصد شن، چگالی ظاهری و

درصد ماده آلی خاک به کار برده شوند. روابط رگرسیون ارائه شده منحنی مشخصه آب خاک را برای سه خاک دیگر با دقت قابل قبولی تخمین زد.

INTRODUCTION

The modeling of water movement through soils typically requires the functional representation of soil hydraulic properties, such as the water retention curve (soil water characteristic) and the hydraulic conductivity. The unsaturated soil hydraulic properties are commonly represented by empirical models which describe the relationships between soil water content, and matric potential (soil water suction). The problem of estimating soil hydraulic properties then reduces to estimating parameters of the appropriate model. Two such models that are widely used are those suggested by Brooks and Corey (2) and van Genuchten (18). In the Brooks and Corey (BC) model, the soil water retention function,(h) is represented by:

$S_e=(h_d\ h^{-1})^{\lambda}$, $h>h_d$ [1a]

$S_e=1$, $h<=h_d$ [1b]

while for the van Genuchten (VG) model, the functional form is:

$S_e=[1+(\alpha h)^n]^{-m}$ $h>0$ [2a]

$S_e=1$, $h<=0$ [2b]

where $S_e=(\theta-\theta_r)/\ (\theta_s-\theta_r)$ is effective saturation, h is soil water matric potential (suction, cm), θ is volumetric soil water content ($cm^3\ cm^{-3}$), (r is the residual soil water content (cm3 cm-3), (s is the saturated water content, hd and λ are BC model parameters and α and n are the VG model parameters, and m=1-1/n.

Several methods have been described in literature for estimating parameters in models for soil hydraulic properties. The most straightforward approach is to fit an appropriate soil water retention model to h-Θ measurements. Methods to obtain h-ɵ data are: (i) laboratory pressure plate extraction (8) where water is removed or added to a soil sample in stepped pressure applications, and (ii) the use of in-situ paired neutron probe measurements and tentiometer readings (3). Both laboratory and field methods are time-consuming, and the equipments for performing routine measurements are not widely available.

Because of frequent need for water retention estimates in agricultural applications, many attempts have been made to derive water retention values from soil survey data, or from more simply obtained soil physical and structural properties (12). Clapp and Hornberger (4) and Rawls et al. (11) classified parameters for the BC parameters according to textural classes. Gupta and Larson (7), De Jong (5), and Puckett et al. (10) used regression analysis, relating soil moisture data to texture, organic matter, and bulk density data. Generally, variability for estimates using textural data has been high (4), and some of the regression equations obtained from the locally measured textural data are site specific.

Stankovich and Lockington (13) concluded that the VG model fits better to the experimental data than the BC model. Therefore, many researchers use VG model for their experimental data and flow of water in soil (13).

An estimation method that describes the soil water retention relationship based on other soil characteristics is referred to as pedo-transfer function (PTF). The PTF were evaluated by comparing estimated with measured water retention values using test data sets with a broad range of soils (14, 15, 16). The parameters in the van Genuchten model were estimated using the regression equations developed and reported by Vereecken et al. (17). The particle-size distribution, the organic carbon, and the saturated hydraulic conductivity of the soil were used in these regression equations.

Tietje and Tapkenhinrichs (14) claimed that the most practical method was to predict retention function parameters (e.g., the parameters of the van Genuchten equation) but, the prediction of van Genuchten retention function parameters, and using a PTF was found to be inaccurate (14).

The objectives of this study were to quantify relationships between the VG model parameters and soil physical properties and to select equations that are useful for prediction of the VG model for soil water retention curve.

Theory

van Genuchten (18) proposed the following equation to describe the complete soil water retention curve (modified form of Eq. [2a]):

$\theta=(\theta_r + \theta_s-\theta_r)/[1+(\alpha h)n]m$ [2a]

From the measured data of θ and h, the h-θ curve is drawn and then reflection point at (θ_p) and its corresponding hp are determined as follows:

$$\theta_p=\frac{(\theta_s + \theta_r)}{2} \quad [3]$$

At the reflection point of the h-θ curve, the slope of curve is determined as follows:

$Sp=[d\theta / d\log h](1/(\theta_s-\theta_r)]$ [4]

According to van Genuchten (18), the value of m in Eq. [2a] is determined as follows:

$m=1-Exp(-0.8Sp)$, $Sp<1$ [5a]

$m=1-(0.5755/Sp)+(0.1/Sp^2)+(0.025/Sp^3)$, $Sp>1$ [5b]

Then, the value of α in Eq. [2a] is determined as follows:

$\alpha= 1/h_p\,(2^{1/m}-1)^{1-m}$ [6]

and $n=1/(1-m)$

MATERIALS AND METHODS

Fifty four undisturbed soil samples from different soils were used from Fars (Kushkak area, clay loam and silty clay soils) and Khorasan provinces (sandy loam, loam, silt loam, clay loam and sandy clay soils) of I.R. of Iran. These samples were taken by a drop-hammer type core sampler (d=50 mm and h=30 mm). Bulk samples collected from each site were air dried, passed through a 2-mm sieve, and were used to determine particle size distribution by the hydrometer method (6).

The 50-mm high core samples were used to determine bulk density by using oven dry soil mass and volume of the core samples (1). The soil water retention curves were obtained at soil water pressure head values of 0, 30, 50, 100, 200, 400, 600, 800, 1000, 1200, and 1500 kPa. A 100 kPa ceramic plate extractor was used for applied air pressure range of 0-100 kPa and a 1500 kPa ceramic plate extractor was used for applied air pressure range of 100-1500 kPa.

The bulk samples from the same sites were used for organic matter determination by a method proposed by Nelson and Sommers (9).

Curves were fitted through analytical procedure proposed by van Genuchten (18) and the hp and m values were determined for calculation of α and n in the VG model. Then, multiple regression analysis was used to obtain the relationship between these parameters and soil particle size separates, organic matter and bulk density. Furthermore, the proposed regression model was used to predict the) θ-h curve for three soils to be compared with their measured)(h) data for validation.

RESULTS AND DISCUSSION

The range of physical properties of 54 soil samples are shown in Table 1, indicating that the soil samples were widely different and cover a wide range of soil textures.

Table 1. Range of physical properties for 54 soil samples.

Range	Silt (%)	Sand (%)	Clay (%)	OM (%)	Bulk density (g cm-3)
Minimum	20.5	10.12	10.6	0.0	2.22
Maximum	54.0	56.3	43.88	2.22	1.57

According to van Genuchten (18) the values of m and α are estimated for soil water characteristics in Eq.[2a]. For calculation of α, the value of hp is required according to Eq.[6]. Therefore, the soil particle size separates, organic matter and bulk density were used in multiple regression analysis to determine these parameters. However, the regression analysis did not allow the clay and silt contents to be entered in the model. The multiple regression equations for m and hp are as follows:

m=0.4+0.0099((p)+0.03556(OM)-0.1874(Bd)+0.1566log(Sand) [7]

R2=0.823

$hp=-2835.6-89.3(OM)+2919.1\ (Bd)+242.7\ \log(Sand)-7270.7\log\ (Bd)$ [8]

$R^2=0.714$

in which θ_p is soil water content at reflection point, $cm^3\ cm^{-3}$, h_p is the soil water suction at reflection point, cm, Bd is the bulk density , g cm^{-3}, and OM is the soil organic matter, % by mass.

From the aforementioned physical properties of a soil the m and h_p values may be predicted. Then, the values of n and α can be calculated from Eq. [6].

To predict the VG model for the soil water retention curve, θ_s and θ_r should also be predicted. θ_s may be calculated from soil bulk density and soil particle density. A multiple regression for estimation of θ_r has been obtained as follows:

$\theta_r=0.263\ (Silt)+0.374\ (Clay)+2.583(OM)-11.18(Bd)$, $R^2=0.83$ [9]

Model Validation

The measured soil water contents were compared with those obtained by the van Genuchten model and the proposed regression equations in Figs. 1 and 2. In general, the VG model and the proposed regression equations under-estimated water contents especially at the low water contents (about 0.2 $cm^3\ cm^{-3}$). Furthermore, the water contents obtained by the VG model were compared with those obtained by the proposed regression equations in Fig. 3.

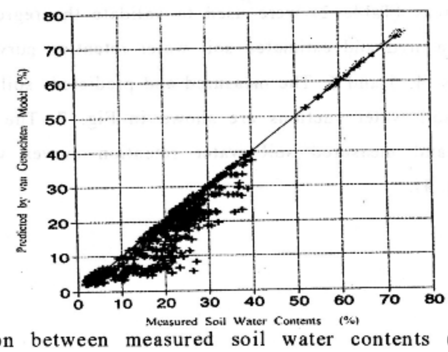

Fig 1. Comparison between measured soil water contents (%) and those predicted by van Genuchten model.

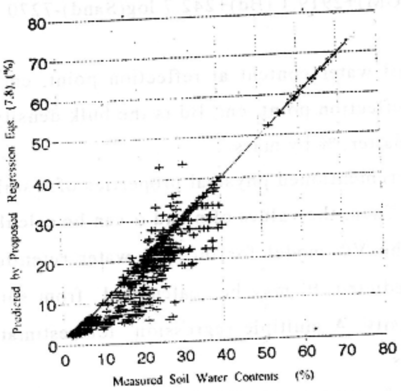

Fig. 2. Comparison between measured soil water contents (%) and those predicted by regression Eqs.[(7, 8].

The results indicated that the water contents obtained by the regression equations closely followed those obtained by the VG model.

The physical properties of three soil samples not included in the regression analysis from Bajgah clay loam (fine mixed, mesic, Typic Calcixerepts) and Kushkak clay and clay loam, (fine cabonatic, mesic, Aquic Calcixerepts) areas (Table 2) were used to validate the regression models [Eqs. 7, 8]. The measured and estimated soil water retention curve (VG model) are shown in Figs. 4, 5 and 6. The measured and predicted soil water contents at corresponding soil water suctions are shown in Fig. 7. The agreement between the estimated and measured soil water retention curves was very good for Bajgah soil (Fig. 4).

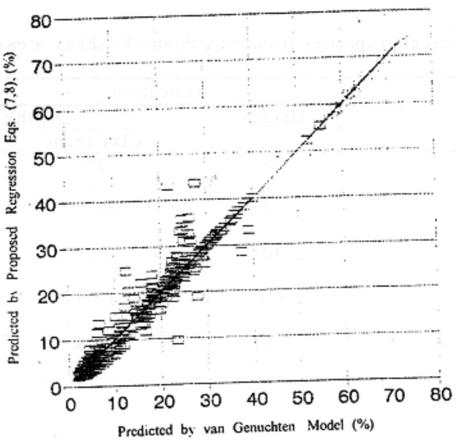

Fig. 3. Comparison between predicted soil water contents by van Genuchten model and those by regression Eqs. [7, 8].

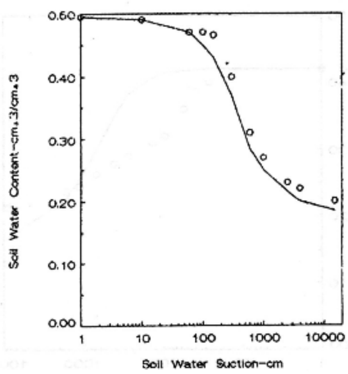

Fig. 4. Predicted soil water retention curve and the measured data (o) for Bajgah soil (clay loam, θ_r=0.17, θ_s=0.49, h_p=406 cm).

Table 2. Soil physical properties from Bajgah and Kushkak areas.

Properties	Location		
	Bajgah	Kushkak	
		Clay loam	Clay
Sand (%)	35	28	19
Silt (%)	35	40	36
Clay (%)	30	32	45
OM (%)	2.0	1.96	1.83
Bulk density (g cm^{-3})	1.43	1.08	1.13

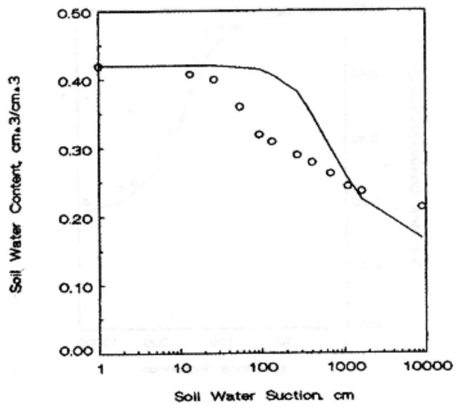

Fig. 5. Predicted soil water retention curve and the measured data (o) for Kushkak soil (clay loam, (θ_r=0.16, θ_s=0.42, h_p=250 cm).

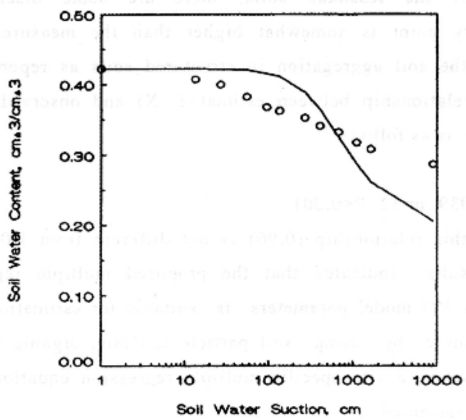

Fig. 6. Predicted soil water retention curve and the measured data (o) for Kushkak soil (clay, (r=0.18, (s=0.42, hp=224 cm).

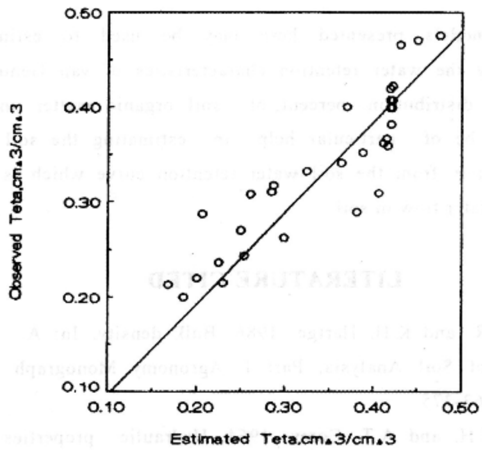

Fig. 7. The relationship between measured and predicted soil volumetric water contents at corresponding soil water suctions in Kushkak and Bajgah areas.

However, for the Kushkak soils, there are some discrepancies, i.e., predicted air entry point is somewhat higher than the measured values. This might be due to the soil aggregation in structured soils as reported by Wagner et al. (19). The relationship between estimated (X) and observed (Y) values of soil water contents is as follows:

$$Y=0.96\,X \quad [10]$$

$R^2=0.980$, $SE=0.0039$, $n=32$, $P<0.001$

The slope of this relationship (0.96) is not different from 1.0 of a 1:1 line. Therefore, the results indicated that the proposed multiple regression model for prediction of VG model parameters is suitable for estimation of VG soil water retention curve by using soil particle analysis, organic matter and soil bulk density. However, a site specific multiple regression equation based on the local data may be warranted.

CONCLUSION

Regression models presented here may be used to estimate with acceptable accuracy the water retention characteristics of van Genuchten type from particle size distribution, percent of soil organic matter and soil bulk density. This will be of particular help in estimating the soil unsaturated hydraulic conductiviy from the soil water retention curve which is required in modeling salt and water flow in soil.

LITERATURE CITED

1. Blake, G.R. and K.H. Hartge. 1986. Bulk density. In: A. Klute (ed.), Methods of Soil Analysis, Part I. Agronomy Monograph No. 9 (2nd edition). 363-375.
2. Brooks, R.H. and A.T. Corey. 1964. Hydraulic properties of porous media. Hydrology Paper No. 3. Colorado State University, Fort Collins, CO, U.S.A.

15. Tomasella, J. and M.G. Hodnett. 1998. Estimating soil water retention characteristics from limited data in Brazilian Amazonia. Soil Sci. 163:190-202.

16. van den Berg, M., E. Klamt, L.P. van Reeuwijk and W.G. Sombroek. 1997. Pedotransfer functions for estimating moisture retention characteristics of ferralsols and related soils. Geoderma, 78:161-180.

17. Vereecken, H., J. Dielst, J. van Orshoven, J. Feyen and J. Bouma. 1992. Functional evaluation of pedotransfer functions for the estimation of soil hydraulic properties. Soil Sci. Soc. Amer. J. 56:1371-1378.

18. van Genuchten, M.Th. 1980. A closed-form equation for predicting hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Amer. J. 44:892-897.

19. Wagner, B.V., R. Tarmawski, G. Wessolek and R. Plagge. 1996. Estimation of hydraulic properties of aggregated soils using a two-domain approach. Can. Agric. Eng. 38:241-247.