Int. Agrophysics, 2002, 16, 79-82

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Comparison of correlation models for the estimation of the water retention characteristics of soil

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Received September 11, 2001; accepted October 24, 2001

A b s t r a c t. This paper presents a comparison of three models for the estimation of soil water retention characteristics. They are based on the correlation between soil water content values at chosen values of soil water potential and the solid phase parameters of the soil, i.e., particle size distribution, content of organic C, specific surface area and bulk density.

K e y w o r d s: soil water retention, correlation models

INTRODUCTION

Water retention is a basic hydrophysical characteristic of soil, described as the dependence between soil water content and soil water potential. A knowledge of soil water potential - soil water content characteristics is necessary for studying water availability for plants, plant water stress, infiltration, drainage, water conductivity, melioration and the movement of solutes in the soil. The spatial distribution of water characteristics in the soil is also an important factor in investigations of the consequences of climate change.

The determination of soil water potential - soil water content characteristics is both time and labour consuming and also requires the use of expensive special equipment. This is the reason that intensive work has been done for over twenty years on the formulation of algorithms - models, which enable soil water retention curves to be determined on the base of other soil physical properties routinely measured in laboratories (Rajkai and Varallyay, 1989; Williams *et al*., 1992). The following soil properties are most frequently taken into consideration for the estimation of soil water retention curves: particle size distribution or the percentage contribution of particular granulometric fractions, organic matter content and bulk density (Gupta and Larson, 1979; Rawls and Brakiensiek, 1982; Rajkai and Varallyay *et al*., 1989). In some instances granulometric distribution is considered as the only parameter (e.g., Ahuja *et al*., 1985; Haverkamp and Parlange, 1986; Husz, 1967). Additionally, soil particle density (Arya and Paris, 1981), soil structure and the mineralogical composition of clays are used (Williams *et al*., 1992). For estimation of the water retention curve the particular measured values of water characteristics are sometimes used, i.e., water content under complete saturation, water content at chosen soil water potential values and the amount of water available for plants (Carsel and Parrish, 1988; Rawls and Brakensiek, 1982). More and more frequently fractals and artificial neural nets are used in modelling. The comparison of the agreement of water retention curve courses obtained in the laboratory and predicted from different models has been presented in papers.

The aim of this study is the comparison of the results of water content evaluation for chosen soil water potential values with the use of commonly used models, based on linear multiple correlation proposed by Gupta and Larson (1979) and Rawls and Brakensiek (1982), and the model proposed by Walczak (1984).

MATERIALS AND METHODS

The determination of an impact of soil solid phase parameters on soil water potential - soil water content characteristics was performed on soil samples taken from arable layers of 10 soil profiles. These were: Eutric Cambisols, Eutric Fluvisols, Mollic Gleysols, Orthic Luvisol and Haplic Phaeozem, which are characterised by various physical properties, i.e., sand content from 10 to 88%, silt content: 6-66%, clay content: 6-45%, $C_{org.}$ content: 0.66-2.64%, specific surface area: 16-70 $m^2 g^{-1}$ and bulk density: 1.26-1.75 Mg m^{-3} (Table 1).

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T a b l e 1. The basic properties of investigated soils

Soil	Particle size distribution (%) (ϕ in mm)			C org. content (%)	Specific surface area (H_2O vapour) (m^2 g^{-1})	Bulk density (Mg m^{-3})
	1-0.1	0.1-0.02	<0.02			
Eutric Cambisol	28	52	20	0.66	30	1.66
Eutric Cambisol	88	6	6	0.86	16	1.75
Eutric Cambisol	57	15	28	1.18	20	1.71
Eutric Cambisol	30	44	26	1.19	28	1.37
Eutric Fluvisol	10	45	45	1.27	70	1.67
Eutric Fluvisol	33	24	43	1.31	63	1.57
Mollic Gleysol	44	37	19	1.74	37	1.72
Mollic Gleysol	21	42	37	2.64	67	1.26
Orthic Luvisol	50	32	18	0.76	21	1.71
Haplic Phaeozem	16	66	18	1.62	37	1.28

The soil samples were placed, with their original structure, into cylinders of 100 cm^3 volume (the height of 5 cm). The soil water potential - moisture characteristics were determined by drainage for 11 points in the range of soil water potential from 98.1 to $1.5 \cdot 10^6$ J m^{-3}, using low and high pressure chambers produced by the SoilMoisture Equipment Corp. USA.

RESULTS AND DISCUSSION

Models investigated

For each of the three water retention models, a statistical analysis was performed based on the multiple correlation between soil moisture for soil water potential values chosen and the parameters of the soil solid phase. The structure of the models analysed is similar and Gupta and Larson and Rawls and Brakiensiek models are commonly used for to estimate the water retention curve on the basis of the knowledge of the solid phase parameters of the soil.

The water retention model of Gupta and Larson is based on the following multiple regression equation:

$$\theta_p = a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_4 + a_5 X_5, \quad (1)$$

where: θ_p (m^3m^{-3}) is the predicted water content, X_1 - the percentage content of sand fraction, X_2 - the percentage content of silt fraction, X_3 - the percentage content of clay fraction, X_4 - the percentage content of organic C, X_5 - the bulk density (Mg m^{-3}), while parameters a_1, a_2, a_3, a_4 and a_5 are the regression coefficients.

In the water retention model of Rawls and Brakensiek, which is a modification of the Gupta and Larson model, the following equation of multiple regression is used:

$$\theta_p = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_4 + a_5 X_5, \quad (2)$$

where: θ_p (m^3m^{-3}) is the predicted water content, X_1 - the percentage content of sand fraction, X_2 - the percentage content of silt fraction, X_3 - the percentage content of clay fraction, X_4 - the percentage content of organic C, X_5 - the bulk density (Mg m^{-3}), while parameters a_0, a_1, a_2, a_3, a_4 and a_5 are the regression coefficients.

The water retention model of Walczak is based on the following equation of multiple regression:

$$\theta_p = b_0 + b_1 Y_1 + b_2 Y_2 + b_3 Y_3, \quad (3)$$

for water potential values in the range from 98.1 to $49 \cdot 10^3$ J m^{-3} and

$$\theta_p = b_0 + b_1 Y_1 \quad (4)$$

for water potential values higher then $49 \cdot 10^3$ J m^{-3}, where: θ_p (m^3m^{-3}) is the predicted water content, Y_1 - the specific surface area (m^2g^{-1}), Y_2 - the mean weight diameter of particles (mm), Y_3 - the bulk density (Mg m^{-3}) and the parameters b_0, b_1, b_2, b_3 are the regression coefficients.

The mean weight diameter of particles (D), which is present in the above equation as Y_2:

$$D = \frac{\sum_{i=1}^{n} \left(\frac{D_{i_{\max}} + D_{i_{\min}}}{2} \right) \cdot P_i}{100\%} \quad (5)$$

where: n - a number of fractions, $D_{i_{\max}}$ and $D_{i_{\min}}$ - the maximum and minimum diameters of i-th fraction (mm), respectively, P_i - the percentage content of i-th fraction.

Statistical analysis

The water content values for the soils investigated, predicted using the models presented have been compared with the water content values measured. The comparison was done by an analysis of the correlation parameters between measured - θ_m and predicted - θ_p soil water content values using each of the models. Figure 1 presents the measured

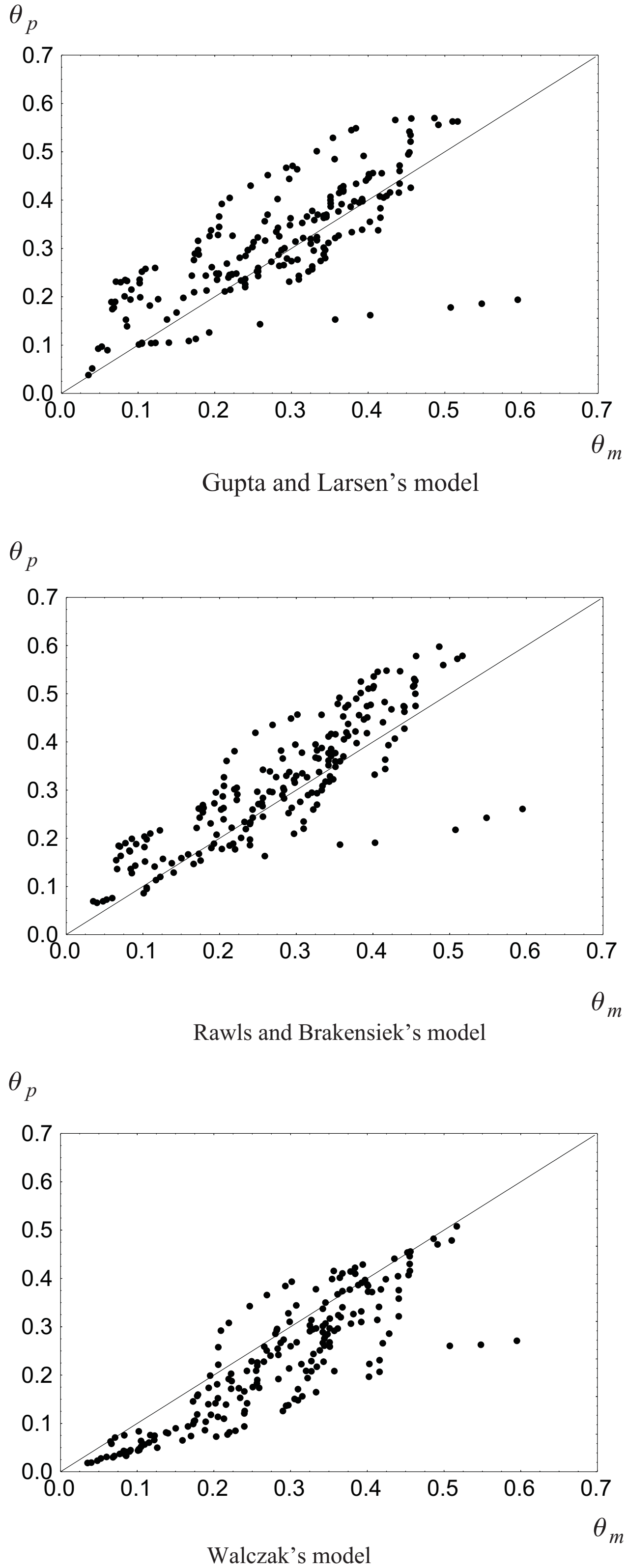

Fig. 1. Predicted water content (θ_p) versus measured water content (θ_m) values according to three models.

values of the soil water content versus the predicted soil water content using the analysed models.

For each model, the regression equation was determined between the water content values predicted using the models analysed and measured water content values:

$$\theta_{Gupta} = 0.11160 + 0.72197 \cdot \theta_{measured} \tag{6}$$

$$\theta_{Rawls} = 0.06762 + 0.88028 \cdot \theta_{measured} \tag{7}$$

$$\theta_{Walczak} = -0.0289 + 0.91 \cdot \theta_{measured} \tag{8}$$

The results of performed analysis are presented in Table 2.

The models of Gupta and Larson and Rawls and Brakensiek have a very similar structure. They differ only by a free factor in the equation of multiple regression. As independent variables, a percentage content of sand, silt and clay, a percentage content of organic C and bulk density are used in these models. The use of the percentage content of sand, silt and clay in the regression equation seems to be incorrect from the statistical point of view, because these quantities are linearly dependent and their sum equals 100%. In Walczak's model, particle size distribution has been replaced with one parameter - the mean weight diameter of particles, the content of organic C is neglected, specific surface area and bulk density are used, whose statistical significance is evident in the potential range from 98.1 to $49 \cdot 10^3$ J m^{-3} (pF 2.7). Above the potential equal $49 \cdot 10^3$ J m^{-3} in this model, the specific surface area plays a significant role and the bulk density can be neglected.

The statistical analysis performed (Table 2) leads to the conclusion that from the analysed models based on the linear multiple correlation between the soil water content and the chosen parameters of soil solid phase at chosen soil water potential, Walczak's model describes the course of the actual retention curve with the smallest estimation error. This is confirmed by the highest value of correlation coefficient (R = -0.8658), the smallest standard error of estimation (SEE = -0.0633) and the highest value of Snedecor (F = 593) and (t = 24.35) coefficient which speak for the best correlation between soil water content values predicted from the model and measured water content values.

T a b l e 2. Correlation coefficients (R), standard errors of estimation (SEE), Snedecor coefficients (F) and (t) coefficients for the analysed models

Model	R	SEE	F	t
Gupta & Larson	0.7352	0.0795	232	15.26
Rawls & Brakensiek	0.8239	0.0723	418	20.46
Walczak	0.8658	0.0633	593	24.35

CONCLUSIONS

On the basis of the laboratory investigations performed and soil water retention characteristics calculated using chosen models (acc. to Gupta and Larson, Rawls and Brakensiek, and Walczak) as well as statistical analysis, it was stated that Walczak's model, including the mean weight diameter of soil particles, specific surface area and bulk density, is the best of the models studied for describing the real courses of soil water retention curves. It was confirmed by the highest value of correlation coefficient, the smallest standard error of estimation and the highest values of Snedecor and t coefficients. This data assures us of the best correlation between soil water content predicted from this model and measured water content values.

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