# Estimative Calculation of Hydrophysical Parameters from Simply Measurable Soil Properties

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## Introduction

It has been known since the paper of BROOKS and COREY /1964/ that the shape of water retention characteristic curves is similar to that of particle size distribution functions. Numerous analytical models were developed /HAVERKAMP and PARLANGE, 1986/, but their applicability was generally limited to ideal cases, e.g. uniform particle size distribution, homogeneously packed particles without organic matter, etc.

Others used a statistical approach to find the above correlations /e.g. BLOEMEN, 1980; GUPTA and LARSON, 1979; RAJKAI et al., 1981; SCHUCH and BAUDER, 1986/. The results of these studies are not comparable with each other because of the significant differences in the sample materials used.

Some of the statistical approaches of water retention data are not directly correlated with the measured soil properties, but these are substituted by the parameter values of a fitted empirical function /e.g. MADAN-KUMAR, 1985/.

The theoretical and practical importance attached to a knowledge of the relation between water retention, texture and other soil features gives significance to studies making this knowledge more general, e.g. categorization and mapping of hydrophysical properties and moisture regime of soils /VÁRALLYAY, 1989/, etc. This is why a former study /RAJKAI et al., 1981/ has been extended using a larger data base, including salt affected soils, and empirical functions have been applied to substitute parameter values for the measured data.

## Materials and methods

The data base used involves 275 soil samples without salinity-alkalinity taken from about 60 soil profiles in the Great Hungarian Plain and 48 samples with a non-negligible salinity taken from 14 salt affected soil profiles.

Samples containing more than 5% organic matter were excluded from the statistical analysis.

pF values were measured according to the Hungarian standard at 10 suction values. At pF values of 0 to 2.7 100 cc water-saturated soil core samples were exposed to suction in boxes containing sand and kaolin plates. pF 3.4 and pF 4.2 values were determined on resaturated soil pastes in pressure membrane apparatus with cellophane membranes. The pF 6.2 values were calculated from hygroscopic measurements applying a relative humidity of 34% above the samples /with the use of $CaCl_2 \cdot 6H_2O$ as humidity regulator/. Dry bulk density was used and was assumed to be constant within the whole suction range.

Particle size fraction percentages were measured by the conventional sedimentation method. Particle size classes are identical with the US standard. Sodium pyrophosphate was used as suspending solution. Other soil feature determinations followed standard methods.

The main physical and chemical characteristics of salt affected soil samples can be found in the paper of RAJKAI /1987-1988/.

In order to describe the measured pF and particle size fraction values, the following three parameter functions were fitted to them /VÁRALLYAY et al., 1979/:

$$\Theta/\Theta_o = 1/[1 + (X/X_o)^b] \qquad /1a/$$

where: $\Theta_o$, $X_o$ and b are experimental constants;
$\Theta$ = soil moisture content, vol. %;
X = soil moisture suction, water column cm.

$$P/P_o = 1/[1 + (d/d_o)^c] \qquad /1b/$$

where: $P_o$, $d_o$ and c are experimental constants;
P = cumulated particle size percentage, %;
d = particle size boundary value, μm.

Functions 1a and 1b were fitted to the 10 pF points and 7 cumulated particle size fraction values by a non-linear iteration procedure.

By widening the spectrum of independent soil variables some additional variables were generated as silt fraction /I/; the sum of four silt fractions, as fine fraction; the sum of clay plus two finer silt fractions and as sand/ /silt ratio.

For the selection of the soil variables best correlated to pF values, stepwise regression analysis was used. After determining the independent variables best correlated to pF values the following regression function was fitted by multiple linear regression /PACHEPSKIJ et al., 1982/:

$$pF_H = b_o + b_1 X_1 + b_2 X_2 + b_3 X_1 X_2 + b_4 X_1^2 + b_5 X_2^2 \qquad /2/$$

where: $b_o - b_5$ are regression coefficients;
$X_1$ = explanatory variable at the first place;
$X_2$ = explanatory variable at the second place.

In the case of salt affected soil samples the chemical characteristics /pH, total salt content, soluble + exchangeable sodium, CEC and $CaCO_3$ content/ were also included in the analysis.

The analyses were repeated using the parameter values of Function 1a as dependent variables and those of Function 1b as independent ones instead of the measured values.

## Results and discussion

The distribution of samples according to the textural classification of soils is given in Fig. 1. The deviation of the current data from normality and from those found in earlier experiments /RAJKAI et al., 1981/ can be clearly seen. The results of stepwise regression and of the applied multiple linear regression of equation /2/ can be found in the paper of RAJKAI /1987-1938/.

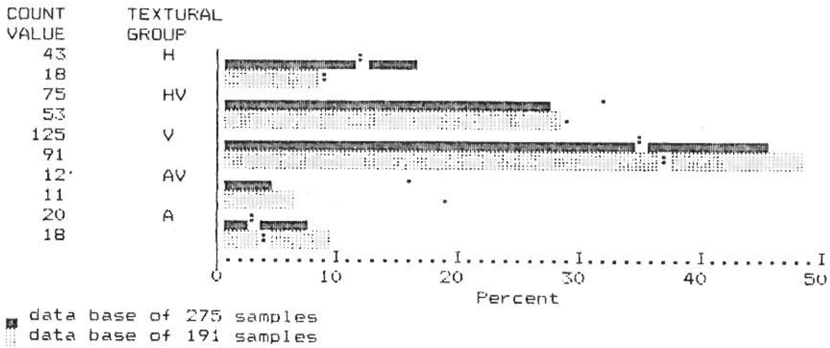


*Fig. 1*
Frequency distribution of the sample material. Textural groups: H: sand; HV: sandy loam; V: loam; AV: clayey loam; A: clay

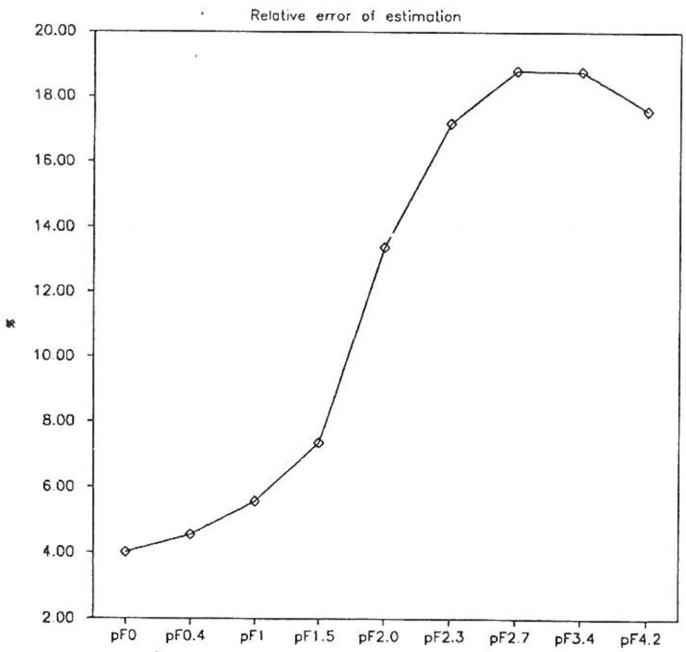


*Fig. 2*
Relative error of estimation

It can be seen that in the low suction range /< pF 2/ the bulk density is the determining soil variable, while in the high suction range /> pF 2.3/ the fine fraction quantity is decisive, as is the organic colloid quantity expressed as organic matter /carbon/ content.

From the standard error values it can be observed that the field capacity /pF 2.3/ with the highest absolute error is 5.86 % of moisture content. The relative error increases continuously and reaches 17 % at pF 4.2 /Fig. 2/.

The observed phenomenon, i.e. the drop in the information content of explanatory variables at increasing suction values, may reflect at least two different effects. One of these may result from the higher variance /uncertainty/ of the moisture content values measured in the higher suction /i.e. the lower moisture content/ range where the risk of the occurrence of different types of errors may be higher and may result physical consequences, as e.g. decreasing moisture content causes a sharp drop in water conductivity, which results in a reduction in the effective conductive contact surface between soil and membrane; a change in the pore volume due to a shrinkage of the soil solid matrix, etc.

The other group of errors may arise due to the neglect of important soil properties as explanatory variables. Unfortunately very little can be done about this, because there is a fixed technology for the measurement procedure, and it is impossible to extend the properties determined on the soil samples afterwards.

However, the $R^2$ values of the correlations may provide certain information on these effects. The $R^2$ value shows what proportion /percentage/ of the total variance of the pF values measured at a given suction can be "explained" by the explanatory soil variables applied. The share of the "unexplained" part is the highest at moisture values close to field saturation; or in other words, the uncertainty of the regression estimation is the highest in this moisture range. In this case, further soil variable/s/ must be included in the correlation analysis. Suitable variables are likely to be those which describe soil structure or clay mineral properties.

The physical interpretation of the parameters of the empirical Functions 1a and 1b are available in the paper of RAJKAI /1987-1988/. This is why the correlation analyses described above were carried out using the parameters of Functions 1a /for pF data/ and 1b /for particle size distribution/ substituting these for the measured data. The results obtained when substituting pF data by the parameter values of Function 1a, and those obtained when particle size fraction values are substituted by the parameter values of Function 1b can be found in the paper of RAJKAI /1987-1988/. The $R^2$ and the standard error values suggest that the applied functions are suitable for the description of the pF-curves and the cumulated particle size distribution curves of soils, and that their parameter values can be successfully used instead of the measured data in further analyses.

One of the main conclusions which can be drawn from the above is that a unique function can be found to describe and substitute two different soil features such as pF and particle size distribution. The high correlation found between the parameters CPF and CMECH, which reflect the general slope of the functions, confirms in similarity the shape of pF and cumulated particle size distribution functions recognised by BROOKS and COREY /1964/.

The calculation of pF values by estimating the parameter values of Function 1a is also possible using the regression functions summarized in the paper of RAJKAI /1987-1988/.

The significance of this latter method of predicting pF values is more theoretical than practical.

The correlation study between dependent /pF/ and explanatory /other/ soil variables can be made more specific by dividing the soil samples into textural classes as is given by RAJKAI /1987-1988/. These textural classes can also be well distinguished in the form of pF-curve "bands" as demonstrated in the paper of RAJKAI /1987/1988/. The group mean values of BPF and BMECH, from Functions 1a and 1b, would appear to be the most distinctive parameters. It can be concluded that these parameters sensitively express the textural differences in spite of the fact that they have no direct physical meaning.

When correlating the parameter values of Function 1a, as dependent variables, with that of Function 1b, and with the bulk density and organic matter content of the soil, as independent variables, a close correlation can be found with regard to APF and CPF, but there is no acceptable correlation /estimation/ with the parameter BPF /see Table 1/. BPF seems to be an intrinsic parameter of the pF function.

*Table 1*

Results of regression analyses for the parameters of Functions 1a, 1b and soil bulk density

| Parameters of Function 1a | $X_1$ | $X_2$ | $R^2$ | Standard error |
|---|---|---|---|---|
| APF | TFS | CMECH | 0.7054 | 4.369 |
| BPF | BMECH | TFS | 0.1396 | 11021.804 |
| CPF | CMECH | TFS | 0.7364 | 0.135 |

It should be noted that regression functions can be determined for each textural class, but their applicability is limited by the small number of subsamples constituting textural classes /see Figure 1/.

In the case of soil samples containing salts the chemical properties have a determining influence on the pF values. The results of regression analysis can also be found in the paper of RAJKAI /1987-1988/. It can be seen that the most determinant soil property in the low suction range /=<pF 2.7/

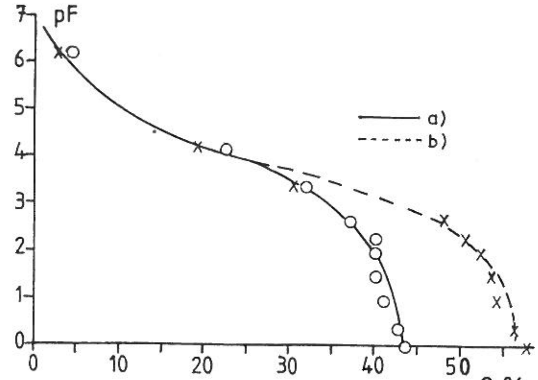


*Fig. 3*

Measured and estimated /neglecting the influence of salinity-alkalinity/ pF-curves for a salt affected silty-laom soil at Kelemenszék /Hungarian Plain/ a/ Estimated; b/ Measured. Bd: 1.56 g/cm$^3$; Clay %: 39.3; $CaCO_3$ %: 25; $Na_{exch}$: 20.3 meq/100 g soil; Salt %: 2.5

is the exchangeable sodium quantity and in the high suction range /$\geq$pF 2.7/ the clay content. The bulk density, total salt and carbonate content of the soil play a secondary role. As a practical consequence of the above analysis, the salinizing or desalinizing effect on water retention of a given soil texture can be estimated. The example given in Figure 3 illustrates this possibility.

## Conclusions

Physical models describing the relations existing between particle size and pore size distribution are limited to well-defined circumstances, such as ideally distributed, uniformly packed solids without organic matter, etc. Consequently, the statistical evaluation of the data base presented here could be of significance in either interpreting or applying the results in the context of the theory. Regression functions determined statistically using pF values make it possible to estimate moisture content percentages as a function of soil texture, bulk density and organic matter content.

The same analysis has been carried out on salt affected soil samples. In this case the chemical soil characteristics /as exchangeable sodium percentage, ESP; pH; salt content and ion composition of water soluble salts/ proved to have a determining effect on the pF curve of the soil.

With the help of the two sets of regression equations the effect of salinity-alkalinity on different soil texture or the effect of texture on different salinity-alkalinity parameters can be estimated.

The three-parameter empirical functions used to describe pF curves and cumulated particle size distribution proved suitable for the substitution of the measured data. It has particular significance if a large number of data on soil moisture characteristics is required, e.g. for the mapping and monitoring of hydrophysical properties and moisture regime of soils and in their control.

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