A PEDO-TRANSFER FUNCTION FOR PREDICTING THE PHYSICAL QUALITY OF AGRICULTURAL SOILS

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Abstract

Pedo-transfer functions are mathematical equations that use basic features describing the soil (e.g. particle size distribution, bulk density, organic matter content) in order to predict other properties the values of which are not otherwise available. To predict the physical quality of agricultural soils a pedo-transfer function that uses basic soil properties (e.g. particle size distribution, dry bulk density, organic matter content) was produced. Evaluation of the soil physical quality was done by using the S index values. S is a measure of soil structure which controls many of the physical properties of soils. S index was calculated after using the Arya-Paris model in order to obtain the parameters from van Genuchten equation that describe the water retention properties of soils. Data analysis from 1923 soil horizons showed that the S index can be predicted by a single equation from basic soil features, such as clay contents and dry bulk density values that were taken as independent data variables. A statistically significant multiple linear regression equation was found and proposed as pedo-transfer function for prediction of the soil physical quality index, S ($r^2 = 0.41$; $p < 0.0001$). Pedo-transfer functions are useful solutions for investigation of different aspects of the physical quality of agricultural soils that do not have readily-available measured data.

Key words: (pedo-transfer function, S index, soil water retention curve)

A pedo-transfer function (PTF) is a function that uses basic features describing the soil (e.g. particle size distribution, bulk density and water content) in order to predict other properties the values of which are not otherwise available. Pedo-transfer functions were defined by Grunwald et al. (2001) as mathematical equations that describe the relationship between the input and the output of a system in terms of the transfer characteristics.

Pedo-transfer functions are widely used for estimating soil hydraulic properties (Hodnett and Tomasella, 2002; Minasny et al., 1999; Minasny and McBratney, 2000; Rajkai et al., 1996; Wagner et al., 2001; Wösten et al., 1995, 1999). The paper by Wagner et al. (2001) reviews eight well-known pedo-transfer functions used for evaluation of soil hydraulic conductivity (saturated and unsaturated) from routinely available soil data. The statistical analysis of the pedo-transfer functions used in the above review recommended that the model of Wösten (1997) as the best for prediction of the unsaturated hydraulic conductivity because it requires an input of measured saturated hydraulic conductivity.

Although the water retention characteristic is of great importance in present-day agricultural, ecological, and environmental soil research, it is not a readily-available soil property (Cornelis et al., 2001). The main reason is that its measurement is time consuming and therefore rather costly, so there is a continued interest in the establishment of pedo-transfer functions. Therefore, models have been developed to predict the water retention characteristics from more easily measurable and more readily-available soil properties, such as particle size distribution, organic matter content and dry bulk density (Arya and Paris, 1981; Cornelis et al., 2001).

In the literature various scientists (e.g. Minasny et al., 1999) presented a comparison between different approaches to the development of PTFs for soil water retention properties. For instance, Minasny et al. (1999) divided the PTFs into three groups: i) point estimation – certain points from the soil water retention curve can be estimated (e.g. field capacity, permanent wilting point); ii) parametric estimation – the relationship between volumetric soil water content θ and pressure head h is described by closed-form equation; and iii) physico-empirical models – soil water retention curve is derived from physical attributes. Also, Minasny et al. (1999) stated that three different methods were used to fit the PTFs for soil water retention curve, namely: multiple linear regression, extended nonlinear regression and artificial neural network.

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On the other hand, the concept of soil physical quality is not a new concept. Early scientific interest has pointed out the importance of soil physical environment for plant growth and for chemical and biological soil conditions.

It was introduced recently an index for the overall soil physical quality evaluation (Dexter, 2004), S, which was obtained from the soil water retention curve measurements and is defined as the slope of the water retention curve at its inflection point. S can be determined either directly from the soil water retention curve or indirectly can be fitted into a mathematical function and the slope at the inflection point can be calculated from the estimates of the parameters of the used function. In the present study the parameters of the van Genuchten (1980) equation were used.

The main goal of the work presented in this paper was to produce a pedo-transfer function for predicting the physical quality of romanian agricultural soils as quantified by the S index.

MATERIALS AND METHODS

Particle size distribution, organic matter content, dry bulk density data used in the present study were obtained by authors from the ICPA soil database (Monitoring the Quality Status of Romanian Soils). Data from 22 out of 41 counties were used, which means that 1923 soil horizons were analyzed in the present study. Because of the very large number of the primary results for soil properties we shall not present them in the present paper.

The soil physical quality index, S, is a measure of soil structure which controls many of the physical properties of soils, and it was calculated using the Arya-Paris (1981) model that estimates the parameters from van Genuchten (1980) equation. This model is based on the analogy between the soil water retention curve and the cumulative curve of distribution by size of soil particles, and it was applied to evaluate pairs of θ (soil water content) - ψ (matric potential). The methodology by which the Arya-Paris model was applied in order to obtain the estimated parameters from van Genuchten equation in briefly is presented in the following paragraphs.

Arya-Paris model divides the cumulative distribution curve by size of soil particles in *n* fractions as defined by the average particle radius. Capillaries volume and their associated radius is calculated for each fraction using the equation:

$$V_i = (W_i / \rho_p) \cdot e \qquad i = 1 \dots n \qquad (1)$$

where *Vi* is the volume of capillaries (per unit mass of sample) associated to the particles from class *i*, *Wi* is the mass of particles from class *i* relative to the total mass of the sample, ρ_p the particle density and *e* is the pore index.

Volumetric water content is obtained by progressive accumulation of the volume of capillaries and their division to soil bulk density (assumed equal for all fractions):

$$\theta_i = \sum_{j=1}^{j=i} \frac{V_j}{V_b} \qquad i = 1, 2, \dots, n \qquad (2)$$

where θ_i is the water content (as volume base) represented by the volume of capillaries for which the upper limit of capillary radius corresponds to the upper limit associated to the *i* class of pores, V_b is the volume of soil sample ($=1/\rho b$, where ρb is the bulk density of the undisturbed soil sample).

Assuming that the solid mass of soil from domain of *i* particles is composed from spherical particles of the same size, the relationship between the radius of capillaries associated with this class of particles and the particle size is:

$$r_i = R_i \sqrt{\frac{4 e n_i^{1-\alpha}}{6}} \qquad (3)$$

where r_i is the radius of capillaries, and R_i is the mean size of particles.

The radius of capillaries is converted to matric potential by using the Jurin law:

$$\psi_i = \frac{2\sigma}{\rho_w g r_i} \qquad (4)$$

where ψ_i is the capillary water pressure, σ is the superficial tension, ρ_w is the water density and *g* is gravitational acceleration.

The α parameter introduced by Arya and Paris is an effective way to assess the length of capillaries in natural soils using as a measure spherical particles associated with the class in which was divided the solid fraction of soil. In the original version of the model the α parameter value was 1.38 for all soils tested.

In a further approach, Tyler and Wheatcraft (1989, 1990, 1992) associated the α parameter with the fractal dimension of pore space, based on observation that the capillary length increases with decreasing of the size of associated solid soil particles. It was considered that the α parameter is influenced by fractal like mechanisms associated to the water retention in soil at low levels of water content.

In this way it can be considered as the value of fractal dimension of soil the α parameter value calculated by equalizing the water content determined by the Arya-Paris model corresponding to 15 bar matric potential with the experimentally measured value (Mitscherlich hygroscopicity coefficient).

Arya-Paris model with the α values calculated by the previous method was applied to evaluate pairs of θ (soil water content) - ψ (matric potential).

It was then used the van Genuchten equation for estimation of the soil water retention curve in the analyzed soils:

$$\theta = (\theta_{sat} - \theta_{res}) \cdot \left[1 + (\alpha h)^n\right]^{-m} + \theta_{res} \qquad (5)$$

with the Mualem (1976) restriction, $m = 1 - 1/n$, and where the variables have their usual meanings (θ is the water content at the suction h, θ_{sat} is the water content at saturation, θ_{res} is the residual water content, α is adjustable scaling factor, n, m are adjustable shape factors).

The van Genuchten equation was later used to assess the index S for soil physical quality (Dexter, 2004):

$$S = -n(\theta_{sat} - \theta_{res}) \cdot \left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]} \qquad (6)$$

where the various terms are as defined in equation (5).

RESULTS AND DISCUSSIONS

Pedo-transfer functions are mathematical equations that use basic features describing the soil (e.g. particle size distribution, bulk density, organic matter content) in order to predict other properties the values of which are not otherwise available.

Pedo-transfer functions are useful solutions when scientists investigate different aspects of the physical quality of soils and do not have readily-available measured data. Having this aspect in mind, we attempted to find a direct relationship between the S index and some basic physical characteristics which are usually measured in most soil physics laboratories.

Study of soil physical quality, like *S* index, play an important role in the overall assessment of agricultural soils. However, its measurement may be for some laboratories difficult and expensive. Pedotransfer functions provide an easy alternative by estimating this parameter from more readily-available soil data.

Therefore, the use of Arya-Paris model, based on particle size distribution data, for estimation of soil water retention curve represents a better alternative. Particle size distribution data characterizes reasonably well the spatial variability of the soil water retention curve. In addition, calculations of particle size distribution measurements are much easier and their determination is less time-consuming as compared with soil water retention measurements.

The van Genuchten parameters obtained after the Arya-Paris model was applied, were used to calculate the values of S index by using the equation (6). After this operation was completed, the next step of our investigations was to produce a pedo-transfer function for estimation of soil physical quality index, S. For this clay contents and dry bulk density values were taken as independent data variables. Also the random numbers method was chosen to divide the measured data into two sets. One set of data was used to produce the PTF multiple linear regression equation, the second set of data was used to test and evaluate the PTF equation. In this way, an independent data set for testing the PTF equation was used. This was possible because we analyzed 1923 soil horizons, which gave us enough S values that were later divided into two data sets. A set of 500 values randomly selected for S were used to produce the PTF, while the remaining set of 1423 values was later used to evaluate the PTF.

The multiple linear regression equation found and proposed that it can be used as a pedo-transfer function for prediction of the soil physical quality, S, is as follows:

$$\log(S_{predict.}) = -0.634 - 0.339\log(clay) + 0.962\log(1/\rho)$$
$$(\pm 0.022)\ (\pm 0.013)\qquad (\pm 0.041)$$
$$r^2 = 0.41; \quad p < 0.0001$$

Although the correlation coefficient is not high (r^2=0.41), the regression equation proposed as pedo-transfer function is statistically significant (p<0.0001). Moreover, this equation indirectly includes the effect of organic matter content on the soil bulk density values. It is known that increasing organic matter content in soils lead to a decrease of soil bulk density values. A similar pedotransfer function was found also and reported by Vizitiu *et al.* (2010) for Polish arable soils.

Figure 1 illustrates the agreement between the calculated S values using Arya-Paris model and the predicted S values using the equation from above proposed as PTF. The correlation between predicted and calculated values of *S* was found to be also statistically significant (r^2=0.45; p<0.0001). The equation which describes this relation is:

$$\log(S_{predicted}) = -0.756 + 0.409\log(S_{calculated})$$
$$(\pm 0.015)\ (\pm 0.012)$$
$$r^2 = 0.45; \quad p < 0.0001$$

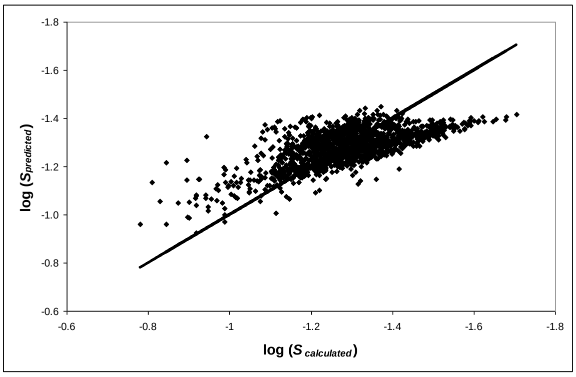

Figure 1 **Plots of predicted versus calculated log (*S*) values. The black squares represent the predicted log (*S*) values with the PTF function from above equation. The 1:1 black line represents the calculated log (*S*) values with Arya-Paris model and van Genuchten equation.**

Since the soil physical quality index, S, is a measure that enables different soils and the effects of different management practices to be compared directly (Dexter, 2004, Vizitiu et al., 2010), prediction of S using pedotransfer functions is an important aspect studied in this investigation. Nevertheless, it must be emphasized that S is only one method of quantifying soil physical quality, and is only one of the several factors that need to be addressed when evaluating agricultural soils.

CONCLUSIONS

Soil physical quality index, S, may be easily predicted from basic soil properties, such as clay contents and dry bulk denstity values. It was found that there is a significant correlation between these properties and S index.

A pedo-transfer function was developed for prediction of the soil physical quality index, S. Pedo-transfer functions are useful solutions for investigation of different aspects of the physical quality of agricultural soils that do not have readily-available measured data.

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