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PHYSICAL QUALITY EVALUATION OF SOME AGRICULTURAL SOILS FROM BACĂU COUNTY

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Key words: soil physical quality, soil water retention curve, saturated hydraulic conductivity, penetration resistance, bulk density, total porosity.

Abstract. Estimation of the soil physical quality of four agricultural soils from Bacău county was done by investigating different soil physical properties (bulk density, penetration resistance, saturated hydraulic conductivity, total porosity, soil water retention, *S* index). Data analysis showed that high penetration resistance and bulk density lead to formation of a compacted layer just below the ploughing depth. On the other hand, the tilled layers of the soil profiles had better hydraulic conductivity and porosity as compared with the deeper soil horizons. Organic matter content, clay content and bulk density influences the soil physical quality as quantified by *S* index, whereas only organic matter content and bulk density influences the saturated water content. In addition, it was found that the soil physical quality index, *S*, may be predicted by using pedotransfer functions.

Introduction

The concept of soil quality conservation is a central link in the development of management strategies to promote sustainability in agriculture. In order to do this it is necessary to understand the principal factors that control soil quality. In general, soil quality is derived from certain soil attributes or characteristics of a physical, chemical and biological nature. Among the more important physical characteristics that are commonly used for evaluation of soil physical quality are included bulk density, penetration resistance, water holding capacity, infiltration rate, and hydraulic conductivity. It should also be noted that soil physical quality has big influences on chemical and biological processes that take place in the soil.

It is rather difficult to quantify soil physical quality by a single measure and up to now a combination of a range of properties has usually been used. However,

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a new index of soil physical quality (*S*) was proposed recently (Dexter, 2004a,b,c), which is intended to be easily and unambiguously measurable using standard laboratory equipment. According to this new theory, *S* is a measure of soil structure which controls many of the soil physical properties and it is hoped that will prove to be useful for the overall assessment of soil quality. Using the *S* index for physical quality characterization of the soils is useful due to the fact that it has the same meaning for different soil types and, moreover, different management practices can be compared. An arbitrary critical value of $S = 0.035$ was proposed such that values of *S* larger than this indicate soil of good physical quality and values of *S* smaller than this indicate poor soil physical quality.

Soil water retention and other soil physical properties are important for the physical quality of the soil and also are recognized as major constraints for crop production. Studies on soil water retention are needed in order to assess water availability to plants. The soil water retention characteristic, which relates soil water potential to soil water content, is a classical method that expresses water holding properties of the soil. Several empirical soil water retention curve models are available in the literature (Brooks and Corey, 1964; Campbell, 1974; van Genuchten, 1980) that describe soil water retention properties.

The soil water retention characteristic measurements are time consuming, tedious and expensive, and there is an increasing interest in the soil physics field for modelling of this property from simple soil properties (e.g. texture, bulk density, organic matter content). Among these techniques are pedotransfer functions (PTF) that relate soil water retention and hydraulic conductivity to basic soil parameters (Vaz *et al.*, 2005). Another approach is based on the similarity between the shape of the particle-size distribution and water retention curves and on basic physical relationships to derive water retention curves from particle-size distribution data (Vaz *et al.*, 2005), the Arya-Paris model (Arya and Paris, 1981) being the well-known approach. The physicoempirical Arya-Paris model contains an empirical scaling parameter, α, that is used to estimate pore radius (r_i) from particle radius (R_i) (Vaz *et al.*, 2005). The Arya-Paris model (1981) assumes that r_i is determined by scaling pore length, which is calculated from the packing of spherical particles of size R_i to natural pore length by using the scaling factor α (Vaz *et al.*, 2005).

The objectives of the work reported here were to evaluate the physical quality of some agricultural soils from Bacău county by investigating different soil physical properties and also to predict the soil physical quality (*S*) index by means of pedotransfer functions from readily-available soil properties.

1. Materials and methods

Soil Data Set. Particle size distribution, organic matter content, bulk density, soil penetration resistance, saturated hydraulic conductivity and total porosity data used in the present study were obtained by authors from the RISSA soil database. The selected soils for this study are located in the Bacău county, namely: profile P1 in Letea Veche location, profile P2 in Cleja location, profile P3 in Valea Seacă location and P4 in Caşin location. According to the SRTS (2003) soil classification (Florea and Munteanu, 2003), the soils used in this paper are: P1 - Eutric Aluviosol, P2 - Stagnic Luvosol, P3 - Tipic Eutricambosol and P4 - Albic-stagnic Luvosol. The basic physical characteristics of the soil profiles are presented in Table 1 and the figures show that the investigated soils are medium to fine textured soils.

Tab. 1 - Basic physical characteristics of the investigated soils

Location	**Profile No.**	**Depth**	**Particle size distribution**			**Soil texture class**	**Organic matter content**
			sand	**silt**	**clay**		
		(cm)	**(%g/g)**	**(%g/g)**	**(%g/g)**		**(%)**
Letea Veche	P1	5 - 20	27.7	36.8	35.5	TP	3.31
		30 - 40	21.2	40.4	38.4	TP	3.31
		45 - 55	32.7	33.5	33.8	TP	2.36
		70 - 80	62.6	17.1	20.3	SF	
		85 - 100	72.7	12.6	14.7	SF	
Cleja	P2	5 - 15	49.0	28.1	22.9	LL	1.51
		20 - 35	44.6	28.7	26.7	LL	1.20
		40 - 50	38.5	26.4	35.1	TT	0.84
		60 - 80	37.4	26.6	36.0	TT	
		90 - 110	45.8	24.0	30.2	LL	
Valea Seacă	P3	5 - 20	46.7	27.5	25.8	LL	1.98
		23 - 33	46.9	26.7	26.4	LL	1.51
		35 - 45	46.8	27.1	26.1	LL	1.58
		60 - 80	45.1	25.6	29.3	LL	0.68
		90 - 110	48.7	26.6	24.7	LL	
Caşin	P4	0 - 10	45.0	34.0	21.0	LP	4.56
		10 - 20	41.1	31.5	27.4	LL	2.05
		30 - 45	34.5	28.4	37.1	TT	1.55
		55 - 75	23.4	37.3	39.3	TP	0.48
		95 - 115	25.9	25.9	48.2	AL	

Arya-Paris model.This model (Arya and Paris, 1981) was used to estimate the van Genuchten (1980) parameters and is based on the analogy between the soil water retention curve and the cumulative curve of distribution by size of soil particles.

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:

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

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:

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

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:

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

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

2.Results and discussions

Soil physical properties. Soil penetration resistance and bulk density are often used in studies concerning soil degradation by compaction. In this study the values of penetration resistance and bulk density increased down the soil profile, the sub-soil layers showing a greater mechanical strength than the top-soil layers. Plots of penetration resistance and bulk density as functions of soil depth are presented in Fig. 1. The compacted layer is observed just below the ploughing depth, values of both bulk density and penetration resistance increasing sharply at this depth.

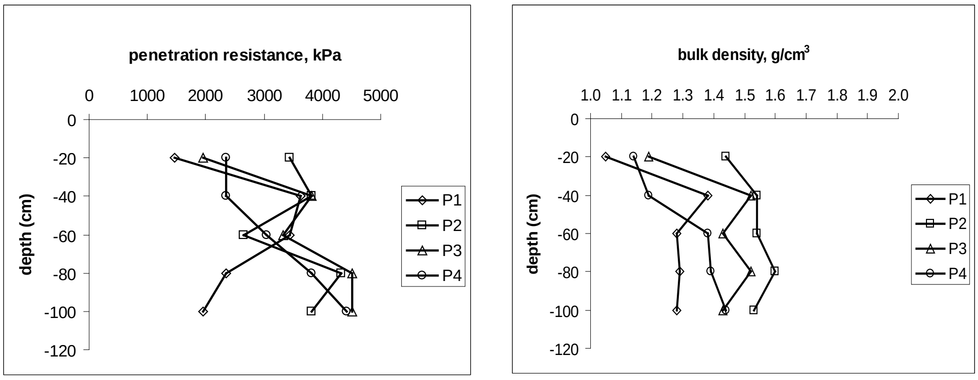

Fig. 1 - Plots of soil penetration resistance and bulk density as functions of depth

Penetration resistance is used to simulate the mechanical impedance encountered by growing roots (Whitebread *et al.*, 2000). Several authors (e.g. Ferreras *et al.*, 2000) suggested that the level of mechanical strength, as recorded by penetrometer, can severely restrict root growth, particularly in the plough pan. A value of penetration resistance of 2 – 2.5 MPa is quoted in the literature as a critical value above which root growth is reduced significantly (Busscher *et al.*, 1986).

Degradation of soils due to compaction is a worldwide problem, and the problems caused by this were intensively studied and reported in many articles (e.g. Defossez and Richard, 2002). Lipiec and Nosalewicz (2004) showed that a characteristic response of a root system to increasing soil compaction level is a decreased root length, retarded root penetration and shallower rooting depth. The authors in their work showed that irrespective of soil type and site the soil compaction resulted in greater concentration of roots in upper soil (0 – 10 cm) and reduced root growth in deeper soil, mostly due to excessive mechanical impedance such as hard pan.

Statistical analysis of data showed that increasing bulk density (*BD*) increases significantly the soil penetration resistance (*RP*) and the regression equation which describes this relationship is as follows:

$$RP = -3432.5 + 4850.1\,BD \qquad r^2 = 0.63; \quad p < 0.0001 \qquad (7)$$

$$(\pm 1220.9) \quad (\pm 880.9)$$

Soil structure represents one of the major attributes of soil quality (Dexter, 2004a). It affects the soil pore system and through it the water movement processes in soil. The highest values of saturated hydraulic conductivity (*Ksat*) were recorded in the first layer of the soil profile P1 where the total porosity was also the highest (Fig. 2). The generally greater hydraulic conductivity of the top-soil layers of all four soil profiles may be ascribed to a better porous system in which both micro- and macro-pores are present due to increased amount of finer particles.

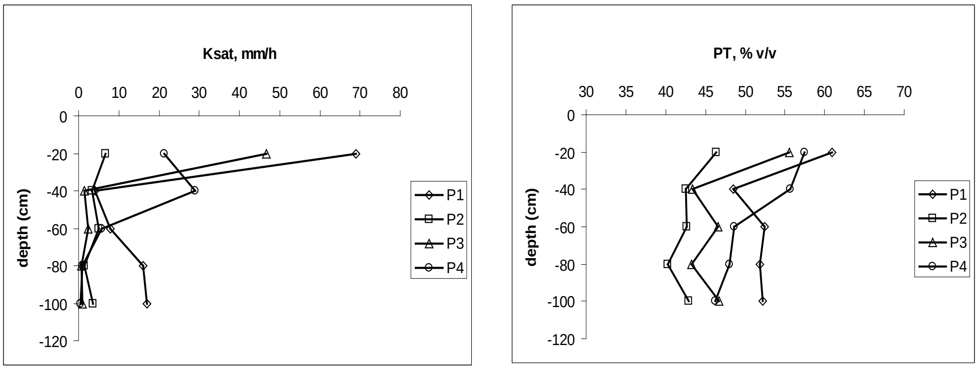

Fig. 2 - Plots of saturated hydraulic conductivity and total porosity as functions of depth.

Pagliai *et al.* (2004) stated the significant role played by soil porosity in evaluation of the impact of management practices on the quality of soil structure. They found that adopting alternative tillage systems, such as ripper subsoiling, on a cambisol the macro-porosity was generally higher and more-homogeneously distributed through the profile when compared with a conventional tillage system, and the resulting soil structure had a better quality, as confirmed by the higher hydraulic conductivity measured in the soil tilled by ripper subsoiling.

Fig. 3 shows the soil water retention curves of the four investigated soils. The soil water retention curves were obtained after using the Arya-Paris model for estimating the van Genuchten parameters (Eq. 5). The fitted parameters were then used to calculate *S* index using Eq. (6). The resulting values of *S* together with the fitting parameters are presented in Table 2. The range of values in Table 2 show that these soils have very different pore size distributions which is mainly due to differences in their micro-structure.

Determination of soil water retention curve is necessary for many applications. However, the measurement procedures are both time-consuming and tedious. 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.

Tab. 2 - Values of the parameters of van Genuchten equation obtained using Arya-Paris model and of the *S* index

Location	**Profile No.**	**Depth**	**van Genuchten parameters:**					***S***
			α	n	m	θ_{res}	θ_{sat}	
		(cm)	**(-)**	**(-)**	**(-)**	**(kg kg^{-1})**	**(kg kg^{-1})**	**(-)**
Letea Veche	P1	5 - 20	0.03	1.19	0.16	0.00	60.38	0.071
		30 - 40	0.01	1.19	0.16	0.00	48.34	0.058
		45 - 55	0.04	1.11	0.10	0.35	52.50	0.042
		70 - 80	0.06	1.22	0.18	0.21	53.27	0.072
		85 - 100	0.06	1.29	0.23	0.15	52.15	0.085
Cleja	P2	5 - 15	0.07	1.21	0.17	0.00	45.66	0.058
		20 - 35	0.04	1.20	0.17	0.00	41.89	0.052
		40 - 50	0.04	1.10	0.09	0.29	42.05	0.032
		60 - 80	0.05	1.10	0.09	0.29	39.68	0.028
		90 - 110	0.15	1.15	0.13	0.00	42.26	0.042
Valea Seacă	P3	5 - 20	0.04	1.19	0.16	0.28	55.41	0.066
		23 - 33	0.05	1.13	0.12	0.23	42.90	0.039
		35 - 45	0.05	1.14	0.13	0.24	46.63	0.045
		60 - 80	0.05	1.13	0.12	0.25	43.20	0.039
		90 - 110	0.06	1.17	0.14	0.23	46.94	0.051
Caşin	P4	0 - 10	0.04	1.17	0.14	0.24	56.98	0.062
		10 - 20	0.04	1.15	0.13	0.30	55.09	0.054
		30 - 45	0.04	1.11	0.10	0.36	47.92	0.037
		55 - 75	0.02	1.16	0.14	0.00	47.55	0.051
		95 - 115	0.03	1.13	0.12	0.00	45.66	0.041

As a general trend, the top-soil layers had greater values of water content at saturation when compared with sub-soil layers. This may be attributed to a decrease of organic matter content and an increase of bulk density values within the soil profiles. Statistical analysis showed that the organic matter content and bulk density affected significantly the water content at saturation (θ_{sat}). The regression equations together with the correlation coefficients that illustrate the effect of organic matter (*OM*) content and bulk density (*BD*) on the soil water content at saturation are as follows:

$$\theta_{sat} = \underset{(\pm 2.30)}{41.58} + \underset{(\pm 2.30)}{3.88}\ OM \qquad r^2 = 0.54;\ \ p = 0.003 \qquad (8)$$

$$\theta_{sat} = \underset{(\pm 1.03)}{100.70} - \underset{(\pm 0.74)}{38.01}\ BD \qquad r^2 = 0.99;\ \ p < 0.0001 \qquad (9)$$

The differences in shape of water retention curves between top-soil and sub-soil layers may be as a result of either externally-applied mechanical stresss by agricultural machinery which can lead to compaction of the layer below ploughing depth, or internally-applied mechanical stress due to drying of the soil which causes shrinkage due to the effective stresses generated by the pore water suction and the surface tension in the water menisci. It is known that both increasing bulk density and soil drying reduces the volume of the soil pores (Vizitiu *et al.*, 2010).

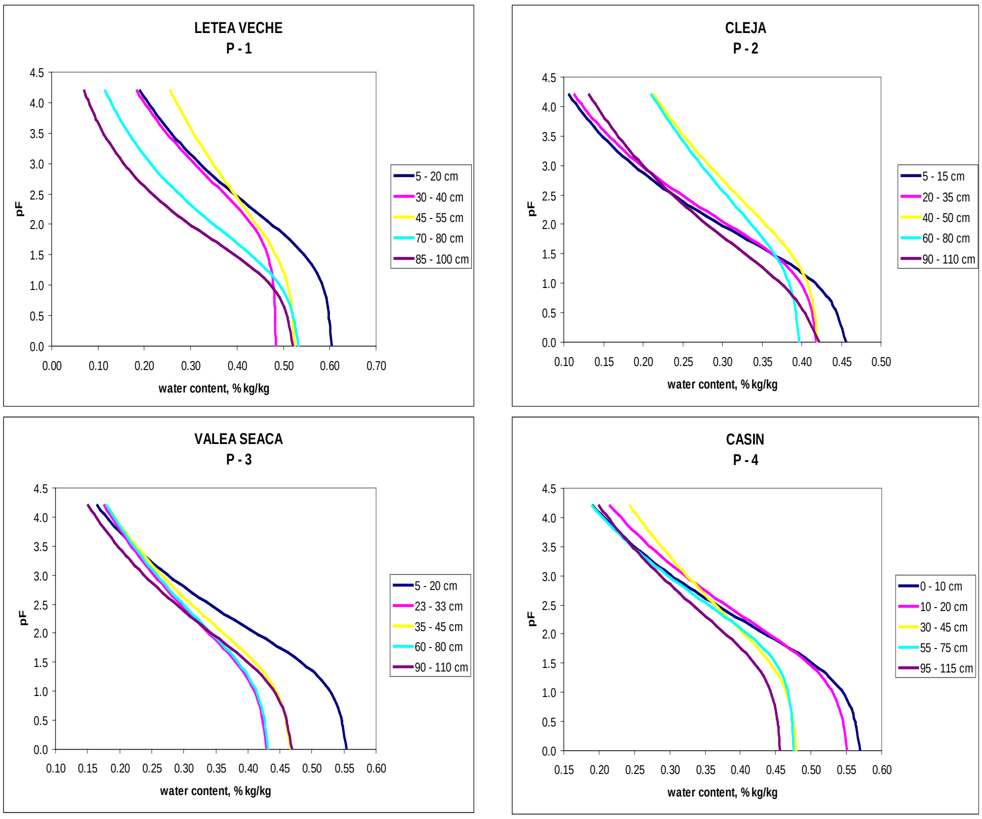

Fig. 3 - Soil water retention curves of the four investigated soils.

The van Genuchten parameters were used to calculate the values of *S* index by using the equation 6. The resulting values of *S* show that these soils have different pore size distributions along the soil profile which is mainly due to differences in their micro-structure. According to Dexter's theory (2004a,b,c) the values of *S* index were in the range of the *S* values defining a poor (S = 0.028 – 0.032) and good (S = 0.037 – 0.085) soil physical quality.

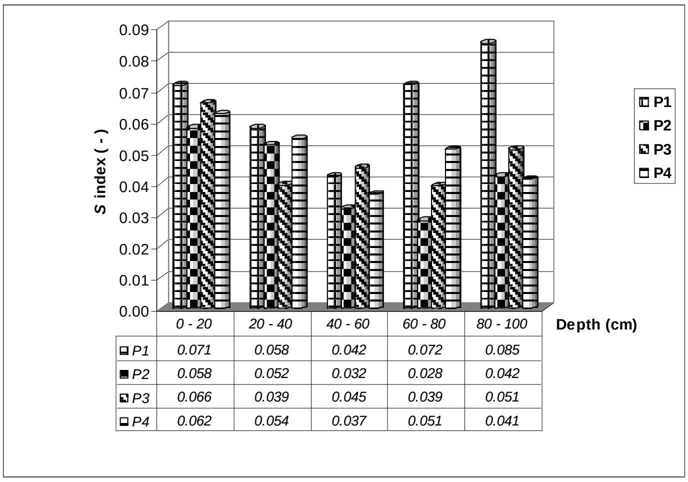

Fig. 4 - Variation of the soil physical quality index, *S*, with depth.

From the Fig. 4 it can be seen that the deeper layers of the soil profiles have lower values for *S* index. That means the soil physical quality as quantified by *S* is better in the top-soil horizons than in the sub-soil horizons, except for the profile P1 where the values of *S* index showed a decrease up to 40 - 60 cm and then increased with depth. This can be due to both higher contents in organic matter of the top-soils and lower values of bulk density. When statistical analysis was performed it was found that *S* index is positively correlated with organic matter (*OM*) content and negatively correlated with bulk density (*BD*) and clay content (*clay*), and the regression equations which describe these relationships are as follows:

$$S = \underset{(\pm 0.005)}{0.038} + \underset{(\pm 0.002)}{0.006}\,OM \qquad r^2 = 0.39; \quad p = 0.01 \qquad (10)$$

$$S = \underset{(\pm 0.02)}{0.15} - \underset{(\pm 0.02)}{0.07}\,BD \qquad r^2 = 0.51; \quad p = 0.0004 \qquad (11)$$

$$S = \underset{(\pm 0.011)}{0.083} - \underset{(\pm 0.0003)}{0.001}\,clay \qquad r^2 = 0.32; \quad p = 0.009 \qquad (12)$$

Prediction of S index using pedotransfer functions. 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. To produce a pedotransfer function for estimation of soil physical quality index, *S*, clay contents and bulk density values were taken as independent data variables. The resulting regression equation may be used as a pedotransfer function for prediction of the soil physical quality index, *S*, and is as follows:

$$\log (S_{predicted}) = -\,0.404 \;-\; 0.477 \log (clay) + 1.503 \log (1/\rho) \qquad (13)$$
$$(\pm 0.199) \quad (\pm 0.140) \qquad\qquad (\pm 0.337)$$
$$r^2 = 0.70; \quad p < 0.0001$$

This equation is for clay contents between 14.7 and 48.2 %, and for bulk densities between 1.05 and 1.60 g/cm^3. As can be seen the regression equation is statistically significant. A similar pedotransfer function was found also and reported by Vizitiu *et al.* (2010) for Polish arable soils.

Figure 5 illustrates the agreement between the calculated *S* values with Arya-Paris model and van Genuchten equation and the predicted *S* values using Eq. (13) from above. The correlation between predicted and calculated values of *S* was found to be also statistically significant. The equation which describes this relation is:

$$\log (S_{predicted}) = -\,0.386 \;+\; 0.705 \log (S_{calculated}) \qquad (14)$$
$$(\pm 0.141) \quad (\pm 0.107)$$
$$r^2 = 0.70; \quad p < 0.0001$$

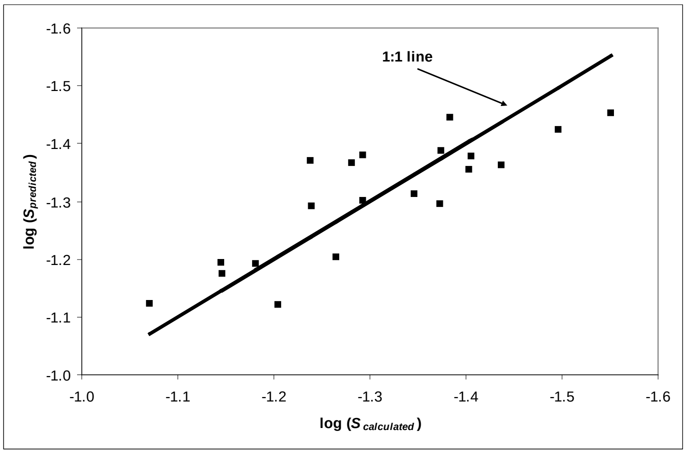

Fig. 5 - Plots of predicted versus calculated log (*S*) values. The black squares represent the predicted log (*S*) values with the PTF function from above (eq. 13). The 1:1 black line represents the calculated log (*S*) values with Arya-Paris model and van Genuchten equation.

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, 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 considered when evaluating soils.

Conclusions

High values of penetration resistance and bulk density in the ploughing pan led to forming of a compacted layer just below the ploughing depth.

The tilled layers from the surface of the investigated soils showed higher values of both saturated hydraulic conductivity and total porosity, which is attributed to a better porous system.

Increased organic matter and lower bulk density values resulted in an increase of soil water content at saturation in the top-layers of the soils.

The soil physical quality of the investigated soils, as quantified by *S* index, is generally better in the top-soil horizons than in the sub-soil horizons due to higher contents of organic matter and lower bulk density values.

Also the soil physical quality index, *S*, may be predicted by using readily-available soil properties (e.g. clay content, bulk density) and a pedotransfer function was produced for the four investigated soils.

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