Research Journal of Agricultural Science, 43 (3), 2011

SOIL PHYSICAL QUALITY AS QUANTIFIED BY *S* INDEX AND HIDROPHYSICAL INDICES OF SOME SOILS FROM ARGEŞ HYDROGRAPHIC BASIN

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Abstract: *This paper presents the soil water retention curves determined on two soil types from hydrographic basin of Arges River: P1 - Eutricambisol tipic, P2 - Vertisol stagni-pellic. Undisturbed soil cylinders were sampled on the genetic horizon depths characteristic for each soil type. The soil water retention curves were measured in the laboratory using standard equipment for retention measurements supplied by the Dutch Eijkelkamp company. The principle of the method is based on the determination of the soil water content corresponding to a certain level of water suction applied. By applying the Solver Microsoft Office Excel program the measured values of the water content from soil water retention curves were used to estimate the parameters of the van Genuchten equation which were later used to estimate the soil water retention curves and the main hidrophysical indices: field capacity (FC), wilting point (WP) and plant available water (PAW). The obtained results have illustrated the evident similitude between the estimated soil water retention curves from the van Genuchten equation and the measured soil water retention curves in the laboratory. Then the S index for agricultural soil physical quality was estimated using also the parameters of the van Genuchten equation. The S index is defined, in terms of the van Genuchten parameters, as the slope of the water retention curve in its inflection point. The estimated values of S have showed that the soil with more equilibrate medium texture (soil profile P1) has higher values of the S index for estimation of the soil physical quality as compared with the clayey heavy textured soil (soil profile P2). Consequently, the soil Eutricambisol tipic (P1) has a higher soil physical quality then the soil Vertisol stagni-pellic (P2). The good physical condition of the medium textured soil (soil profile P1) as quantified by S index is associated with an increase of the water storage capacity of the investigated soils. Moreover, the shape of the soil water retention curves of the soil Vertisol stagni-pellic (P2) illustrates that this soil presents the degradation processes of its physical condition.*

Key words: *soil water retention curve, soil physical quality, S index, van Genuchten equation, hidrophysical indices*

INTRODUCTION

Soil water retention and movement is determined by the action of various common forces, but they cannot be summed. To quantify these forces a generalized energetic index was established, named as soil *water potential*, and it represents the energy which water has it into the soil. The soil water potential is differentiated according to the nature of the forces acting upon the water: gravitational, matriceal, osmotic, hydrostatic.

In unsaturated soils, the water movement is determined by the matric potential, namely by the pressure applied on the particle surfaces and into the capillary pores. The force with which the water is retained by the soil particles represents the *suction force* or just *suction*.

The relationship between the water content corresponding to a certain water matric potential or suction (pF) is important in studies concerning the hidrophysical properties of a soil. In the literature this relationship is defined as soil *water retention curve*, *water characteristic* etc. and estimates the storage capacity of the soil for water at different values of matric potential or different levels of soil suction.

The role and importance of soil physical quality for sustainable agricultural development under environmental protection conditions is receiving increasing attention from both scientists and farmers. In order to have soil with a high physical quality it is necessary to have two main structural features: firstly, the soil must be stable in water and secondly, the soil must have a suitable pore size distribution that will enable the soil to absorb, store and release water for plant use. Such soils will have also a good aeration status and will be more easily penetrable by plant roots. An important part of the pore network in heavy-textured soils is micro-cracks that make the soil friable and easy to till over a wide range of water contents.

It is 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, an 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 micro-structure which controls many of the soil physical properties and it is hoped that it may prove useful for the overall assessment of soil quality. 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.

The objectives of the work presented in this paper were determination of the soil water retention curves on two soil types from the hydrographic basin of Argeş river and then estimation of the soil physical quality index, *S*, by using the parameters of van Genuchten equation, and also estimation of the soil hidrophysical indices (e.g. filed capacity – *FC*, wilting point – *WP*, plant available water – *PAW*) from the water retention curves.

MATHERIALS AND METHODS

Undisturbed soil samples (cylinders of 100 cm^3 volume) were sampled from profiles digged in Agreş county in two locations around the Argeş hydrographic basin river, namely: profile P1 in Leordeni location and profile P2 in Suseni location. Undisturbed soil cylinders were sampled on the genetic horizon depths characteristic for each soil type. Soil sampling was done in the autumn of the year 2008 after the harvesting of wheat and maize crops. According to the SRTS (2003) soil classification, the soils used in this paper are: P1 – Eutricambosol tipic and P2 – Vertisol stagni-pellic. The basic physical characteristics of the soil profiles investigated are presented in *Table 1*.

Table 1

Physical characterization of the investigated soils

Location	Profil No.	Depth	sand (>20µm)	silt (20-2µm)	clay (<2µm)	Soil texture class	Organic matter	Bulk density
		(cm)	($g\ g^{-1}$)	($g\ g^{-1}$)	($g\ g^{-1}$)		(%)	($g\ cm^{-3}$)
Leordeni	P1	0-15	45.8	22.5	31.7	LL	2.3	1.28
		15-30	46.2	22.5	31.3	LL	2.2	1.42
		30-46	48.0	21.1	30.9	LL	1.7	1.59
		46-62	50.3	21.0	28.7	LL	0.9	1.61
Suseni	P2	0-20	29.6	29.2	41.2	TT	2.7	1.61
		20-39	33.2	24.7	42.1	TT	2.1	1.46
		39-57	21.1	23.5	55.4	AL	1.3	1.48
		57-74	20.9	22.8	56.3	AL	1.0	1.47

Determination of the soil water retention curve: Undisturbed soil samples were saturated with water by capillarity for 24 - 72 hours and then dried to 12 different levels of suction. Soil water retention characteristics were measured using sand and kaolin boxes (Eijkelkamp) for the low levels of suction (1, 2.5, 10, 31.6, 63.1 and 100 hPa) and membrane pressure plates (Eijkelkamp) for the high levels of suction (500, 1000, 2500, 4000, 8000 and 15500 hPa). The mean values of the water content corresponding to each level of suction were then fitted to the VAN GENUCHTEN (1980) equation:

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

with the MUALEM (1976) restriction: $m = 1 - 1/n$.

where: θ water content at the suction h (kg kg^{-1});
θ_{sat} water content at saturation (kg kg^{-1});
θ_{res} residual water content (kg kg^{-1});
α adjustable scaling factor (hPa^{-1});
h water suction (equal to the modulus of the matric potential (hPa));
m, n adjustable shape factors.

Four replicates where used for each of the 12 levels of suction, making a total of 48 independent samples for each soil water retention curve obtained. In total 8 soil water retention curves were obtained.

Soil physical quality index, S, or the slope of the water retention curve in its inflection point (DEXTER, 2004a) was calculated by the following equation:

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

where the terms have the same meaning as in Equation (1).

RESULTS AND DISCUSSIONS

The mean values of the parameters of Equation (1) together with the calculated values of *S* index and the water contents corresponding to field capacity (*FC*), wilting point (*WP*) and plant available water (*PAW*) are presented in *Table 2* for the two soil profiles that were investigated.

Table 2

Mean values of the parameters of van Genuchten equation and of the *S* index, field capacity (*FC)*, wilting point (*WP*) and plant available water (*PAW*)

Location	**Depth (cm)**	θ_s **(kg kg^{-1})**	θ_r **(kg kg^{-1})**	α **(h Pa^{-1})**	***n*** **(-)**	***S*** **(-)**	***FC*** **(kg kg^{-1})**	***WP*** **(kg kg^{-1})**	***PAW*** **(kg kg^{-1})**
Leordeni P1	0-15	0.4807	0	0.0562	1.2082	**0.0613**	**0.2780**	**0.1169**	**0.1611**
	15-30	0.4503	0	0.0347	1.1908	**0.0539**	**0.2971**	**0.1351**	**0.1620**
	30-46	0.4100	0	0.0130	1.1578	**0.0426**	**0.3318**	**0.1768**	**0.1550**
	46-62	0.4410	0	0.0038	1.1686	**0.0482**	**0.4020**	**0.2206**	**0.1814**
Suseni P2	0-20	0.4295	0	1	1.0613	**0.0210**	**0.3071**	**0.2376**	**0.0695**
	20-39	0.5904	0.4163	1	1.3952	**0.0349**	**0.4363**	**0.4201**	**0.0162**
	39-57	0.6212	0.4031	1	1.3873	**0.0432**	**0.4292**	**0.4082**	**0.0210**
	57-74	0.5559	0	0.1798	1.0440	**0.0205**	**0.4708**	**0.3919**	**0.0789**

In the case of soil profile no. 1 (Eutricambosol), the topsoil layers had higher values of the saturated water content than the subsoil layers. This can be attributed to the fact that the organic matter content decreases with depth and the bulk density values increases with depth within the soil profile no. 1. On the other hand, in the case of soil profile no. 2 (Vertisol) the higher clay contents of subsoils resulted in higher values of saturated water contents at these depths. Statistical analysis showed that the clay content had a significantly greater effect than bulk density and organic matter content on the water contents at: saturation (θ_s), field capacity (*FC*), wilting point (*WP*) and plant available water (*PAW*). For quantification of the clay content effect on the water contents mentioned above the following regression equations were obtained:

$$\theta_s = 0.270 + 0.0057 \cdot clay \qquad r^2 = 0.63;\ p = 0.019 \qquad (3)$$
(±0.074) (±0.0018)

$$FC = 0.185 + 0.0046 \cdot clay \qquad r^2 = 0.48;\ p = 0.05 \qquad (4)$$
(±0.080) (±0.0019)

$$WP = -0.115 + 0.0095 \cdot clay \qquad r^2 = 0.71;\ p = 0.008 \qquad (5)$$
(±0.101) (±0.0025)

$$PAW = 0.300 - 0.0049 \cdot clay \qquad r^2 = 0.65;\ p = 0.015 \qquad (6)$$
(±0.059) (±0.0014)

From *Table 2* it can also be seen that decreasing organic matter content and increasing bulk density within the soil profile resulted in differences in plant available water (*PAW*), field capacity (*FC*) and wilting point (*WP*) between topsoil layers and subsoils, greater values being observed for soil profile with loamy texture from Leordeni (P1) when compared with soil profile with clayey texture from Suseni (P2). WALCZAK *ET AL.* (2002) and VIZITIU *ET AL.* (2010) also reported that the water content at field capacity was influenced by the particle size distribution and organic matter content. The effects of organic matter content and bulk density on the hidrophysical indices were quantified because these parameters (e.g. *FC*, *PAW*) are indicators of the physical quality of a soil and are correlated with *S* index.

Soil structure is an important factor in determining the amount of water present at field capacity because it controls the pore size distribution and therefore retention of water against gravity at high potentials (GARDNER *ET AL.*, 1999). DEXTER (2002) affirmed that if the soil surface has a good, stable structure then infiltration will be fast, and evaporation will be slow. This combination is most efficient for water storage in soils. On the other hand, if the structure of the soil surface is degraded, then infiltration will be slower and evaporation will be faster, and the consequence will be a reduction in water storage. *Figure 1* shows how the water content that is available for plants (*PAW*) is correlated with the soil physical quality index, *S*. Here *PAW* is defined by:

$$PAW = \theta_{FC} - \theta_{WP}\text{, kg kg}^{-1} \qquad (7)$$

where θ_{FC} and θ_{WP}, are the water contents at field capacity and at the wilting point of plants here assumed to be at h = 300 hPa and h = 15000 hPa.

There is a statistically-significant correlation between PAW and S as shown in *Figure 1*, and the regression line is given by:

$$PAW = -0.006 + 2.749 \cdot S \qquad r^2 = 0.36;\ p = 0.1177 \qquad (8)$$
(±0.065) (±1.505)

Similar relations as presented in Equation (8) were found by GAȚE *ET AL.* (2006) for Polish soils and by ASGARZADEH *ET AL.* (2010) for Iranian soils.

The use of different management practices which result in an increase of the total pore volume with diameter smaller than about 30 µm, without destroying finer pores, will result in an increase of the water content at field capacity and, therefore, an increase of plant available water (GARDNER *ET AL.*, 1999). For example, MCHUGH *ET AL.* (2003) in a study on a vertosol from Australia reported that replacement of conventional tillage systems with controlled traffic-zero till farming systems lead to amelioration of the soil after 3 years, which was demonstrated by increases of both hydraulic conductivity by 65% and plant available water by

34%. The authors attributed this improvement of the soil condition to an increased pore interconnectivity and pore size distribution. Under the controlled traffic-zero till farming system, the soil profile had changed from having a predominance of micro-pores (<30 µm equivalent pore diameter) to having a range of larger transmission pores (up to 350 µm equivalent pore diameter).

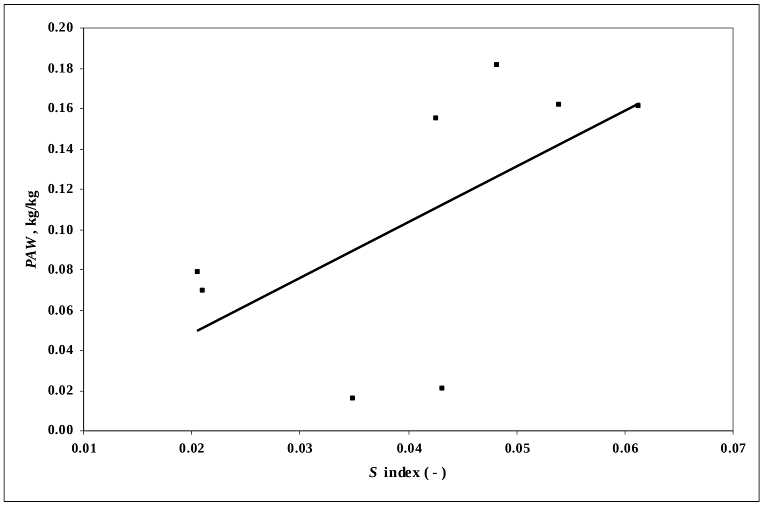

Figure 1. Plant available water (*PAW*) in relation to the soil physical quality index, *S*.

The mean values of *S* index for soil physical quality are also presented in *Table 2*. In the case of loamy textured soil from Leordeni greater values of *S* index were obtained when was compared with the clayey textured soil from Suseni. The soil from Leordeni location had higher values of *S* index both for topsoil and subsoil layers. On the basis of practical experience, Dexter (2004a) suggested that the boundary between soils with good and poor physical quality occurs at approximately $S = 0.035$. He also associated values of $S < 0.020$ with very poor physical condition. According to this classification, the soils used in these investigations were ranged between good physical quality class (P1) and poor physical quality class (P2).

In *Figures 2* and *3* the soil water retention curves of the investigated soils are presented. It was demonstrated in the graphs that the measured values at the 12 different levels of suction for determination of the soil water retention curves are well described by the van Genuchten equation. As a general trend, the topsoil layers had greater water contents at saturation when compared with subsoil layers for the loamy textured soil (P1), whereas in the case of clayey textured soil (P2) the water content at saturation was higher for subsoils then for topsoil layers. Usually, the topsoil layers and subsoils exhibit differences in water retention curves at water contents greater than 0.40 – 0.50 kg kg^{-1}. The lower value of this interval is observed in the case of soil profiles having loamy texture (*Figure 2*), whereas the upper value can be observed for soil profiles having clayey texture (*Figure 3*).

These differences in the shape of water retention curves between topsoil layers and subsoils may be as a result of either externally-applied mechanical stress 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 (TOWNER AND CHILDS, 1972). It is known that both increasing bulk density and soil drying reduces the volume of pores.

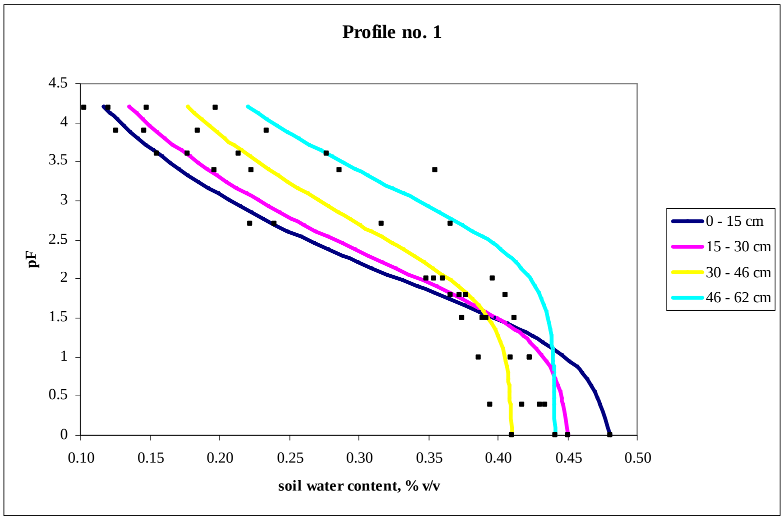

Figure 2. Soil water retention curves of the loamy soil from Leordeni (P2). Closed squares represent laboratory measurements

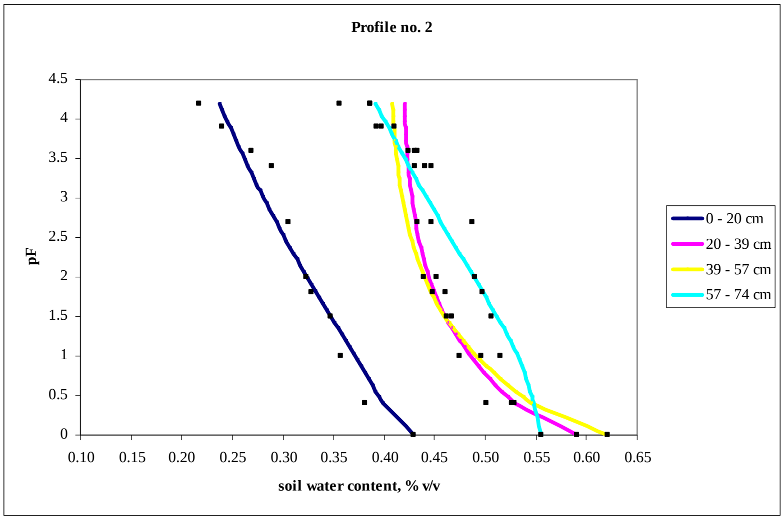

Figure 3. Soil water retention curves of the clayey soil from Suseni (P3). Closed squares represent laboratory measurements

Soil degradation, by compaction for example, is a process through which pore space is decreased; it alters the structure of cultivated soils, i.e., the spatial arrangement, size and shape of clods and aggregates and consequently the pore spaces inside and between these units

(DEFOSSEZ AND RICHARD, 2002). This change in pore size distribution changes the water retention characteristics and is easily observed by reduction of the slope of water retention curves (DEXTER, 2004a). In *Figure 4* it can be seen the differences in the shape of the water retention curves due to soil degradation for the topsoil layers of the two investigated soil profiles (P1 – Eutricambosol and P2 – Vertisol).

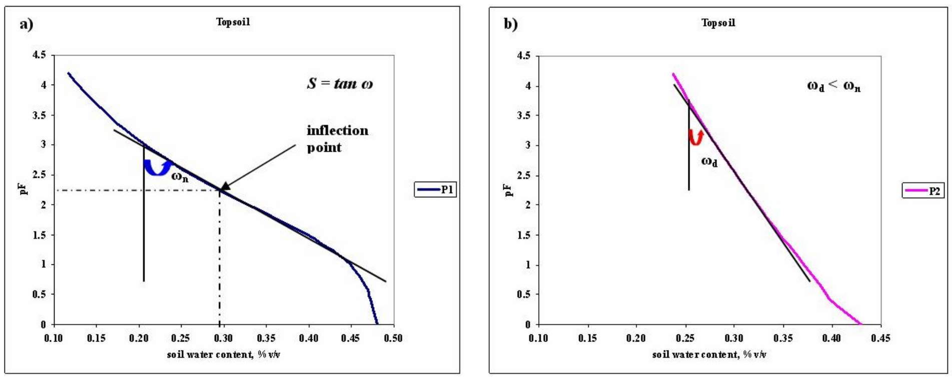

Figure 4. Soil water retention curves showing: **a)** the inflection point and the slope, tan ω, of the tangent to the curve at the inflection point in the case of non-degraded topsoil of profile no. 1; and **b)** the influence of soil degradation (i.e. soil compaction) on the shape of water retention curve in the case of degraded topsoil of profile no. 2.

Compaction is a process of degradation of soil structure which is a reduction of the pore volume of a soil mass, and usually is quantified through measurements of dry bulk density. When a soil is compacted, firstly the largest pores (i.e. structural pores) are lost, and this has the effect of changing the pore size distribution. This change can be easily observed by the reduction of the slope of water retention curves (DEXTER, 2004a).

CONCLUSIONS

Good soil physical quality of the profile with medium texture (P1), as quantified by *S* index, is associated with an increase of the water storage capacity of the analyzed soils from hydrographic basin of Arges river. A significant relationship between *S* and *PAW* has been found.

The medium textured soil (P1) presents higher values of *S* index for estimation of the physical quality as compared with the heavy, clayey textured soil (P2).

It has been demonstrated that the van Genuchten equation can be used for estimation of the soil water retention characteristics, and also the van Genuchten parameters can be used for calculation of the soil hidrophysical indices.

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