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USE OF TENSION INFILTROMETER AND WATER RETENTION CHARACTERISTICS IN THE ASSESSMENT OF SOIL STRUCTURE

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A b s t r a c t. For evaluating the functional consequences of soils having different structural status, soil profiles representing 3 sites and two cultivation variants were studied by conventional and new techniques, such as tension infiltrometer method and parametrization of the water retention characteristic (WRC) curves.

The soil types chosen represent heavy texture alluvial and salt affected soils of the Great Hungarian Plain. The salt affected soil represents structural degradation due to salinity/alkalinity as well.

The differences between cultivated and uncultivated soil variants proved to be insignificant. The conventional methods were not distinctive enough, with the exception of bulk density, which showed good agreement with the tillage practice. On the contrary, the applied measurement and interpretation techniques reflect the expected major differences. These preliminary results of the Hungarian case study show the indirect methods somewhat more effective than the direct ones in studying soil structure. The applied new techniques might enrich the tools for studying the structural status of soils.

K e y w o r d s: tension infiltrometer, water retention characteristics, soil structure

INTRODUCTION

For the assessment of the impacts of soil structure differences on the hydrophysical properties a test area including different soil types and cultivation variants was selected in the Middle Tisza Region in Hungary.

Heavy texture alluvial and salt affected soils were chosen for the experiments in Karcag.

The confined infiltration rate and the dynamic characteristics of different soil structural status were planned to be measured by tension infiltrometer technique in the different soil variants. The more static water retention characteristic curves were used for estimating the pore space of soils having different structural characteristics, such as soil aggregation, bulk density or cultivation variants. The soil structural status is a complex phenomenon having many different aspects of judgements. In the present study we have concentrated our interest to the above mentioned two main aspects in the characterization of the structural status of soils.

MATERIAL AND METHODS

Description of the investigated area

Location: The investigated soil profiles are located in the middle region of the Great Hungarian Plain, East of the River Tisza (Fig. 1).

Geomorphology: The investigated area is in the largest lowland in the Carpatian basin. On the geological map of Sümeghy it is clearly indicated that the Quaternary (Pleistocene) geological formations are on or near to the surface only in small parts of the area, which is mostly covered by later (younger) Holocene sediments. Among these there are only few aeolian sediments (sand, loess), they are mostly heavy textured (heavy clay, clay, clay-loam) alluvial materials of the river Tisza and its tributaries, and loess and loess-like deposits which were deposited - in most of the cases - into

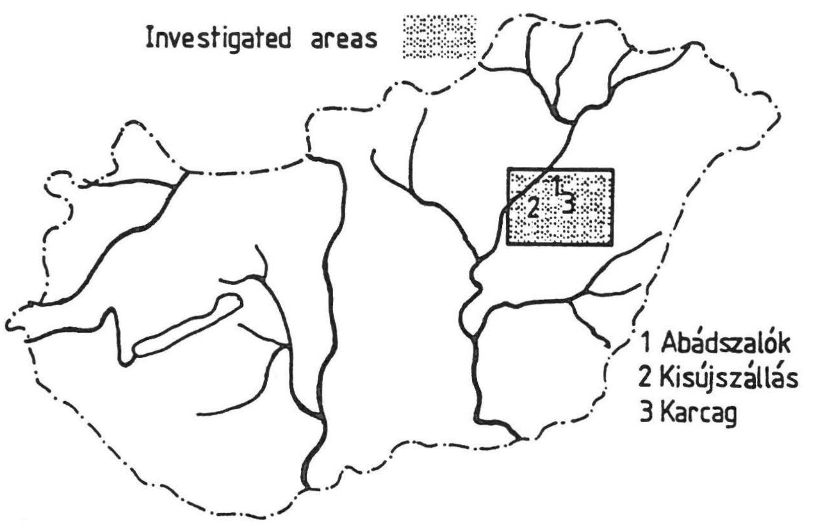

Fig. 1. The investigated areas in Hungary.

water or water-logged areas, and later re-deposited many times by lateral erosion and mixed with colluvial and alluvial materials. Consequently, this loess ('lowland loess') has completely different character than the aeolian loess, it is compact with high bulk density and low porosity and shows hydromorphic features, such as iron-manganese mottlings, gley spots and includes spheroid iron-manganese-organic matter concretions and lime concretions with irregular shape. On these highly mixed parent materials - common in high clay and swelling clay content - soil formation processes began after the prevention of periodical flooding and repeated silt depositions.

Soil formation processes are closely connected in the region to the surface and subsurface hydrological conditions. Considerable parts of the Hungarian Plain before the regulation of the Tisza River at the end of 19th century was permanently or temporarily inundated, and there were many small rivers which brought fine sediments into the area. After the completion of the water regulation of the River Tisza and tributaries waist areas were protected from inundation and water logging. As a consequence the ground water table sinked, but the effect of groundwater fluctuation can still be observed in many of the soil profiles. The groundwater fluctuates between 0.75 to 1.80 m under soils of the Karcag area and within 0.6 to 2.0 m under the soil profiles of the Kisújszállás and Abádszalók area. The groundwater chemistry in the area can be characterized by greatly variable salt content and alkalinity, and Na(Mg)-SO_4,Cl,HCO_3 type salt composition.

Climate

The investigated sites are situated within the Nagykunság (Great Cumania) geographical region, which is one of the warmest, the most extreme and the most continental part of the Hungarian Plain with high seasonal (or even daily) temperature fluctuations.

The average yearly precipitation amounts to 520-560 mm, most of which is in June. The winter is dry and cold. The mean maximum temperature is up to 20.8 °C in June-August, whereas the average monthly minimum temperature may be as low as -2.9 °C, which is usually recorded in January. The yearly mean values of potential evapotranspiration are 680-700 mm.

Soils

The formation of different soil types is in close correlation with the geological, hydrological as well as climatic conditions of the region.

The soil cover of Great Cumania can be properly characterized by a well-developed 'toposequence' ('catena') from the relatively higher territories in the direction to lower ones: chernozem - meadow chernozem - hydromorhic meadow soils - peaty meadow soils - peat bogs. This toposequence is combined in many cases with salinity/alkalinity influences with various degrees.

Salt affected soils cover extensive areas in the low-lying territories of the Great Cumania. They can be characterized by the following salinity/alkalinity sequence: shallow meadow solonetz - deep meadow solonetz - solonetzic meadow soil in which the degree of salinity/alkalinity is decreasing in '-' direction.

In the framework of this project 3 characteristic soil types of these sequences were investigated: alluvial meadow soil developed on River-Tisza alluvium; and meadow soil, as well as, meadow solonetz were developed on infusion lowland loess parent material.

Each soil type is represented by two cultivation or land use varieties:

Abádszalók: Alluvial meadow soil

a) cultivated/deep loosened (80 cm depth) in every 4th year, and ploughed yearly (25-30 cm depth),
b) uncultivated (a control area, without any profile modification during the last 10 years).

Both areas are drained by tube drainage system of 90 cm depth and 25 m spacing.

Kisújszállás: Meadow soil

a) deep loosened (80 cm depth) in every 4th year, and ploughed yearly (25-30 cm depth),
b) without loosening (normal ploughing 25-30 cm depth)

Karcagpuszta: Salt affected meadow solonetz

a) ameliorated and cultivated: (drainage system: 100 cm depth, 25 m spacing) and gypsum application (according to the exchangeable Na^+-content of the 0-25 cm top layer; deep loosening in every 4th year; in the meantime chiselling or disc-operation in 15-20 cm depth, yearly.
b) uncultivated: soil without any profile modification under natural grass vegetation.

Detailed soil profile descriptions of the measurement site in Karcagpuszta:

Soil type and cultivation: salt affected shallow meadow solonetz, uncultivated
Depth of the profile: 120 cm
Effervescence: from 32 cm
Thickness of humus layer: 60 cm
Alkalinity against phenolphtalein: 40 cm
Ground water table: 180 cm

Soil profile description:

A 0-3 cm

Pale grey, moist, weak, many fine roots, solodized loam. Abrupt boundary.

B_1 3-20 cm

Grey, dry, extremely hard, distinctly columnar structure, clay loam. Roots relatively plentiful. Tops of columns, and at some places the sides are discoloured. Abrupt boundary.

B_2 20-60 cm

Grey, somewhat darker, dry, hard, prismatic structure, gradual boundary.

BC 60-78 cm

Brownish grey, somewhat lighter in colour, dry, fine prismatic structure clay loam. Few roots. Iron mottles and iron concretions growing more frequent with depth. White lime spots fine lime concretions. Abrupt boundary in colour.

C 70-

Greyish yellow, moist, moderate hard, loess-like clay loam; white lime mottles and lime concretions.

Ameliorated and cultivated meadow solonetz soil:

Depth of the profile: 150 cm
Effervescence with dilute acid: 40 cm
Thickness of humus layer: 60 cm

Alkalinity against phenolphtalein: 45 cm
Ground water table: 185 cm

Soil profile description:

A-B_1 0-20 cm

The original A and B_1 horizons are mixed by tillage operations. Grey, dry, hard, coarse subangular blocky structure. Abrupt boundary.

B_2 20-60 cm

Grey, darker, hard prismatic structure. Gradual boundary.

BC 60-78 cm

Brownish grey, medium subangular blocky structure. Iron mottles and iron concretions, white lime spots, lime concretions. Abrupt boundary.

C 78-

Greyish yellow, moist moderate hard loess like clay loam. White lime mottle and lime concretions.

Analyses

Soil reaction was determined in 1:2.5 soil-water suspension reaching an equilibrium after 24 h.

Hydrolytic acidity was determined in 1:2.5 soil-Ca-acetate solution (pH 8.2 and concentration of 0.5M) by titration [10].

Calcium carbonate was determined by Scheibler's method.

Cation exchange capacity, exchangeable cations and organic matter content were determined by the standard methods [15,20].

Humus quality was determined after Hargitai [6] using the ratio of extinction of NaF and NaOH extract.

The humus stability coefficient (K_H) was calculated from the following relationship:

$$K_H = \frac{E_{\mathrm{NaF}}}{E_{\mathrm{NaOH}}\ H\,\%} \quad (1)$$

where E_{NaF} - average extinction value of NaF extract, E_{NaOH} - average extinction value of NaOH extract, H % - organic matter content.

Soluble salt content was estimated by measuring the electrical conductivity in saturation soil paste.

Particle size distribution was made by the pipette method.

Analysis of soil micro-aggregate status is based on Katchinsky [11] method. The index of structure (micro-aggregate stability) was calculated according to equation of Katchinsky:

$$IS = \frac{b-a}{b} \cdot 100 \quad (2)$$

where IS - index of structure, b clay content (%) determined by particle size analysis (with complete desintegration of all soil aggregates), a clay-sized particles (%) determined in water suspension without any other pretreatment and dispersion.

For assessing the linear swelling of soil the results of measurements were expressed in % of the original height of the soil column.

The linear shrinkage of soil was determined by Vageler and Alten [21] method. Linear shrinkage was expressed in percent of the length of the moist soil paste. The swelling rate and swelling percentage as well as the shrinkage was measured only from the surface horizon samples.

The tension infiltrometer method

For measuring unsaturated water conductivity of soils with different structural status a relatively new, in situ, field method called tension infiltrometer technique was used. The unconfined infiltration measuring technique comes from Australia [16] and was developed in the U.S.A. as well [2].

The main technical advantage of the method is its usability under field conditions. Another advantage is the easy reproducibility which makes it possible to study areal distribution of soil water conductivity and even to follow the seasonal variability of selected sites. The time of one measurement takes minimum 20 min and maximum a few hours at one tension level. It should be noted that at least three tension levels are required for one complete measurement. This comes from the formula describing the flux - water conductivity relation for unconfined infiltration situation into soil from a circular source of radius r by Wooding (1968):

$$Q = \pi r^2 K\,(1 + 4/(\pi r \alpha)) \quad (3)$$

where α is an instrument constant, r is the radius of cylindrical infiltration surface, K is the water conductivity at a given tension, Q is the steady-state unconfined infiltration rate.

The relationship between K and K_s is:

$$K(\Psi) = K_s \, exp(\alpha \ \Psi) \qquad (4)$$

where Ψ is the tension of infiltration applied, K_s is the saturated water conductivity (cm/min).

In the above equation there are two unknown constants (α and K_s), that is why two or a pair of equations are necessary to determine them [2]. If the infiltrometer parameter is determined, one can estimate K_s from Eq. (4) describing the relation between unsaturated water conductivity (K) and saturated conductivity (K_s).

The practical advantage of the method is its automated use. During the measurement infiltration data and base tension values can be collected automatically by the help of a data logger. During the experiment we have bought a Soil Measurement System (SMS) type tension infiltrometer and equipped it with a data collecting system. For this purpose we used an OMNIDATA 516C Polycorder. The data logger program was written for the Polycorder to collect infiltration and base tension data from the infiltrometer by using the outputs of the pressure transducers. A computer program was also developed for evaluating the logged infiltrometer data. However here we should note that our measurements can be evaluated only as an early morning, preliminar.

Water retention characteristic (WCR)

Water retention values were measured in laboratory using 100 cm^3 volume soil cores at 9 different suction and pressure values. pF=0 is the water saturated moisture condition, at pF=0.4 2.5 cm of water suction was applied, and in pF=1 to pF=2.7 range sand and kaolin boxes with hanging water columns were used [22]. In the high suction range - the pF=3.4 and pF=4.2 values - pressure membrane apparatus were applied.

Mathematical description of the WCR-curve

Several empirical functions are available for describing the WCR-curve of soils [1, 4, 5, 12, 19, 22, 24]. Once a function is fitted to the measured water retention values, the parameters of the given model can be related to selected soil components and properties. For example McCuen et al. [14] related the parameters of the Brooks and Corey function to different textural classes, whereas Madankumar [13] correlated the parameters of a fitted exponential function [6] to soil bulk density and the sand, silt and clay fractions. Vereecken et al. [25] similarly analyzed the correlations of fitted model parameters with soil properties using the function of van Genuchten [22].

In a different approach, distribution models were used by Arya and Paris [3] to predict the soil water retention curve from the particle-size distribution, dry bulk density and particle density. Their model was later modified by Haverkamp and Parlange [8] who applied the concept of shape similarity between the retention curve and the cumulated particle size distribution for sandy soils without organic matter. One way to implement the indirect estimation of the retention function is to use parametrization methods for estimating the unknown parameters in a certain mathematical expression describing the water retention characteristic.

For the measured WRC data of soil profiles studied in the present program we fitted a simple 3 parameter model called the Brutsaert function [5]:

$$\Theta = \Theta_s / (1 + (\Psi/\Psi_o)^n) \qquad (5)$$

where Θ is the measured soil moisture content in % of (cm^3/cm^3), Θ_s, Ψ_o and n are the model parameters, Ψ is the water tension (in cm of water).

The fitted model parameters carry information of the water retention function. The parameter Ψ_o reflects the most frequent (modal) water potential of the soil and n gives the average slope of the retention function [18]. The Ψ_o parameter values characterize the texture and water holding capacity of the soil matrix, while the n values show the graduation of the water release of the soil. These parameters might be sensitive enough for structural differences of soils, as well.

RESULTS AND DISCUSSION

Chemical and mineralogical properties of the studied soils

The soil chemical and mineralogical properties are of great importance both as factors affecting the soil physical and hydrophysical properties and as factors in aggregates formation.

Soil reaction

The results on the range of soil reaction (pH) and hydrolytic acidity (y_1) are summarized in Table 1.

The soil reaction of the investigated soils is slightly acidic to neutral in the surface horizons. The lowest pH values were measured in the A horizon of the alluvial meadow soil. The pH values of the studied profiles generally increase with depth. In case of salt affected profiles the pH-values of deeper layers reach or exceed the critical 8.5 pH, which is in good accordance with the presence of Na_2CO_3 salts (Table 2). The hydrolytic acidity values (y_1) of meadow soils are relatively high, which indicates that the CEC in the top layer is relatively unsaturated.

The soils in this study are free of $CaCO_3$, except the C horizon of the meadow soil in Kisújszállás (Table 2).

Cation exchange capacity (CEC) and exchangeable cations

The CEC is in the rage of 24-39 meq/100g soil (Table 3). The higher values are associated with samples of the A and B horizons. In case of alluvial meadow and meadow soils the Ca^{2+} an Mg^{2+} cations are dominant in the cation exchange complex and rich about 80-90 % of the total exchangeable cations. Ca^{2+} content is the highest (74-78 %), while Mg^{2+} content is in the range of 9-18 %.

The exchangeable Na^+-content of alluvial meadow soil is low, except the BC, and C horizons.

The Kisújszállás meadow soil has some solonetzic character, because the exchangeable sodium content is higher than the lower critical limit (ESP 5 %) of solonetzic soils in the deeper layers.

The cation composition of the salt affected soil is quite different from the above mentioned non salt affected soils: the Na^+ is the dominant cation of the exchange complex. Besides this,

Table 1. Results of chemical analysis of soils (I)

Depth (cm)	Horizon	pH (H_2O)	pH (KCl)	pH ($CaCl_2$)	y_1
Abádszalók, alluvial meadow soil uncultivated					
0 - 20	A	5.86	4.81	5.53	14.5
21 - 60	B	6.29	5.09	5.97	8.4
61 - 80	BC	6.67	5.41	6.27	4.1
81 - 120	C	7.20	6.12	6.89	1.9
Abádszalók, alluvial meadow soil cultivated					
0 - 20	A	6.18	5.21	5.82	11.2
21 - 60	B	6.44	5.25	6.09	6.8
61 - 80	BC	6.72	5.48	6.36	4.3
81 - 100	C	6.87	5.96	6.67	2.8
Kisújszállás, solonetzic meadow soil not loosened					
0 - 30	A	6.42	5.77	6.13	9.7
31 - 50	B	7.51	6.73	7.31	1
51 - 80	BC	7.67	7.09	7.43	0
81 - 130	C	6.72	5.69	6.49	3.1
Kisújszállás, solonetzic meadow soil deep loosening					
0 - 30	A	6.42	5.81	6.06	10.2
31 - 50	B	6.65	5.77	6.24	6.6
51 - 90	BC	7.31	6.32	6.82	2.2
91 - 110	C	7.74	7.03	7.29	0
Karcagpuszta, meadow solonetz soil uncultivated					
0 - 20	B_1	7.36	6.88	7.03	2.4
21 - 40	B_2	8.98	7.39	8.11	0
41 - 70	BC	8.06	6.87	7.34	0
71 - 85	C	8.97	7.76	8.50	0
Karcagpuszta, meadow solonetz soil uncultivated					
0 - 20	AB_1	7.81	6.86	7.30	0
21 - 50	B_2	8.42	7.08	7.91	0
51 - 70	BC	8.69	7.48	8.27	0
71 - 95	C	9.04	7.96	8.42	0

Table 2. Results of chemical analysis of soils (II)

Depth (cm)	Horizon	$CaCO_3$	Na_2CO_3	K_A	Total salt	OM
		(%)				
Abádszalók, alluvial meadow soil uncultivated						
0 - 20	A	0	0	61	0.09	3.35
21 - 60	B	0	0	62	0.1	1.65
61 - 80	BC	0	0	67	0.11	0.85
81 - 120	C	0	0	57	0.16	-
Abádszalók, alluvial meadow soil cultivated						
0 - 20	A	0	0	63	0.08	2.54
21 - 60	B	0	0	72	0.11	1.29
61 - 80	BC	0	0	71	0.13	1.03
81 - 100	C	0	0	59	0.18	-
Kisújszállás, solonetzic meadow soil not loosened						
0 - 30	A	0	0	60	0.08	3.17
31 - 50	B	0	0	66	0.15	0.34
51 - 80	BC	4.9	0	62	0.13	0.48
81 - 130	C	0	0	69	0.17	-
Kisújszállás, solonetzic meadow soil deep loosening						
0 - 30	A	0	0	59	0.07	3.17
31 - 50	B	0	0	64	0.08	1.88
51 - 90	BC	0	0	68	0.1	0.75
91 - 110	C	4.2	0	67	0.1	-
Karcagpuszta, meadow solonetz soil uncultivated						
0 - 20	B_1	0	0	67	0.39	1.55
21 - 40	B_2	0	0.151	66	0.32	0.6
41 - 70	BC	0	0	75	0.43	1.17
71 - 85	C	0	0.197	87	0.24	-
Karcagpuszta, meadow solonetz soil uncultivated						
0 - 20	AB_1	0	0	66	0.36	1.37
21 - 50	B_2	0	0.199	86	0.54	0.50
51 - 70	BC	0	0.153	100	0.4	0.36
71 - 95	C	0	0.225	81	0.41	-

Table 3. Results of chemical analysis of soils (III)

Depth (cm)	Horizon	Ca	Mg	K	Na	CEC
		(me/100 g)				
Abádszalók, alluvial meadow soil uncultivated						
0 - 20	A	25.5	5.0	0.9	1.19	31.00
21 - 60	B	27.9	6.0	0.8	1.44	41.60
61 - 80	BC	22.6	4.0	0.7	1.82	36.60
81 - 120	C	21.9	4.0	0.5	2.73	24.80
Abádszalók, alluvial meadow soil cultivated						
0 - 20	A	25.4	5.0	1.2	1.40	34.30
21 - 60	B	30.9	7.0	1.0	1.82	40.10
61 - 80	BC	25.5	6.0	0.6	2.20	33.60
81 - 100	C	20.7	4.0	0.6	2.73	31.50
Kisújszállás, solonetzic meadow soil not loosened						
0 - 30	A	25.9	3.0	2.5	1.19	39.40
31 - 50	B	20.8	5.0	0.9	3.09	40.10
51 - 80	BC	25.0	5.0	0.8	2.91	33.60
81 - 130	C	27.3	6.0	0.6	2.73	31.50
Kisújszállás, solonetzic meadow soil deep loosening						
0 - 30	A	25.3	3.0	2.3	1.61	38.70
31 - 50	B	28.9	5.0	1.6	1.40	36.40
51 - 90	BC	24.7	5.0	1.3	2.29	37.40
91 - 110	C	22.3	4.0	0.8	2.69	27.60
Karcagpuszta, meadow solonetz soil uncultivated						
0 - 20	B_1	14.7	8.0	0.9	15.07	35.60
21 - 40	B_2	14.9	9.0	0.9	19.28	34.10
41 - 70	BC	13.3	8.0	0.8	17.15	32.90
71 - 85	C	12.3	7.0	0.7	17.97	27.60
Karcagpuszta, meadow solonetz soil ameliorated and cultivated						
0 - 20	AB_1	17.9	7.0	1.0	13.77	31.60
21 - 50	B_2	13.6	7.0	0.8	20.81	35.10
51 - 70	BC	13.1	9.0	0.9	24.19	31.30
71 - 95	C	9.2	4.0	0.5	21.69	24.00

the exchangeable Mg^{2+} content is much higher, than in case of meadow soils.

The exchangeable K^+ is relatively low compared to the other cations. But according to the fertilizer experiments carried out on these fields, the amount of different K-forms is big enough to supply the plants for a long (more than 10 years) period.

Organic matter content and humus quality

The organic matter (OM) content shown in Table 2 varies within a wide range. The lowest OM content values can be found in the upper layers of the salt affected soils.

The humus stability coefficient, which is proportional with the amount of Ca-saturated humus, shows the lowest values in case of alluvial meadow soil and salt affected soil. In the case of the alluvial meadow soil the low value might be due to the acidic character of the soil and in case of salt affected soil the low Ca-ratio is because of the exchangeable complex (Fig. 2).

Salinity/alkalinity

The salt content estimated by measuring the electrical conductivity is moderate in the surface layers of Abádszalók and Kisújszállás soils. In the deeper horizons it is higher than the critical 0.1 % value. This indicates that there is a potential hazard of secondary salinization alkalization from the deeper layers.

The total salt content of the solonetz soil is relatively high (Table 2).

Soil texture

The particle size distribution of the studied soils are given in Table 4. According to these data the BC and C horizons can be classified in two groups: The alluvial meadow soil in Abádszalók contains more fine sand fraction in the C horizon than the other two soil types. The A and B horizons are relatively similar for all soils. Generally the studied soils can be classified into the silty-clay texture class.

Table 4. Particle size distribution of the soils

Depth (cm)	Horizon	Sand			Silt			Clay	Texture
		>0.25 mm	0.25-0.05mm	0.05-0.02mm	0.02-0.01mm	0.01-0.005mm	0.005-0.002mm	0.002> mm	
Abádszalók, alluvial meadow soil uncultivated									
0 - 20	A	0.1	4.3	11.2	11.4	11.8	13.4	47.8	SC
21 - 60	B	0.1	4.7	9.2	8.8	11.8	11.6	53.8	SC
61 - 80	BC	0.1	7.7	9.8	9.6	11.2	9.0	52.6	C
81 - 120	C	0.2	23.2	20.2	10.4	7.4	6.8	31.8	CL
Abádszalók, alluvial meadow soil cultivated									
0 - 20	A	0.1	2.5	11.2	10.2	11.0	12.6	52.4	SC
21 - 60	B	0.1	3.3	8.4	9.2	9.8	12.6	56.6	SC
61 - 80	BC	0.1	10.9	8.2	8.0	10.0	10.2	52.6	C
81 - 100	C	0.2	28.1	13.8	7.0	7.8	8.8	34.4	CL
Kisújszállás, solonetzic meadow soil not loosened									
0 - 30	A	0.1	2.5	17.6	9.6	12.8	12.8	44.6	SC
31 - 50	B	0.1	3.3	8.8	15.4	15.6	11.8	45.0	SC
51 - 80	BC	0.1	2.5	8.0	15.2	19.2	13.2	41.8	SC
81 - 130	C	0.2	14.1	14.0	7.2	9.8	8.8	46.0	C
Kisújszállás, solonetzic meadow soil deep loosening									
0 - 30	A	0.1	1.7	16.8	11.0	12.6	11.8	46.0	SC
31 - 50	B	0.1	2.7	13.0	11.6	10.6	10.4	51.6	SC
51 - 90	BC	0.1	0.9	12.2	8.0	12.0	10.8	56.0	SC
91 - 110	C	0.3	1.9	9.0	13.2	16.8	15.4	43.4	SC
Karcagpuszta, meadow solonetz soil uncultivated									
0 - 20	B_1	0.2	6.8	17.2	14.0	10.4	9.6	41.8	SC
21 - 40	B_2	0.1	0.7	12.6	11.8	13.8	9.6	51.4	SC
41 - 70	BC	0.2	3.4	12.4	12.8	10.8	8.6	51.8	SC
71 - 85	C	0.1	3.9	1.4	16.2	20.2	16.0	42.2	SC
Karcagpuszta, meadow solonetz soil ameliorated and cultivated									
0 - 20	AB_1	0.1	3.9	16.8	13.8	9.0	11.2	45.2	SC
21 - 50	B_2	0.2	1.6	12.2	10.0	10.4	8.8	56.8	SC
51 - 70	BC	0.2	0.0	12.2	12.0	11.2	10.0	54.4	SC
71 - 95	C	0.1	0.1	11.2	14.8	19.0	15.4	39.4	SCL

L - Loam, S - Silt, C - Clay.

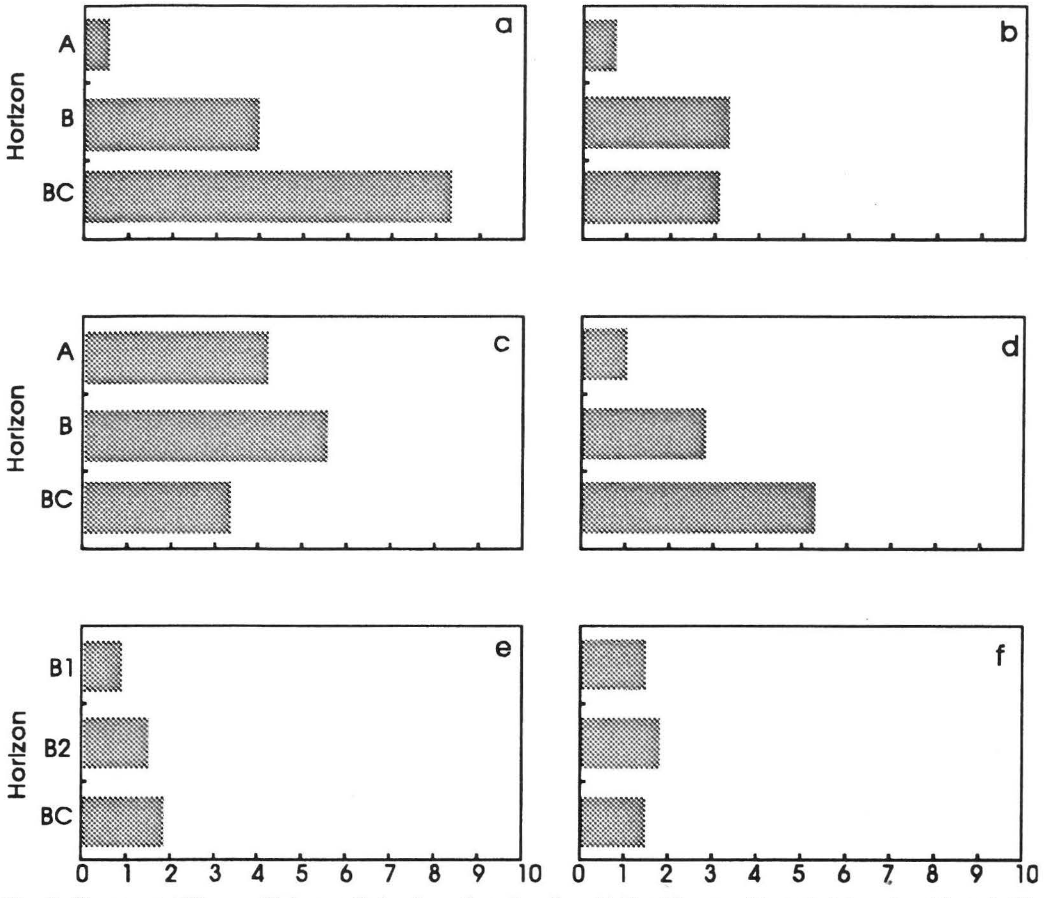

Fig. 2. Humus stability coefficients of the investigated soils: Abádszalók, uncultivated (a) and cultivated (b); Kisújszállás, not loosened (c) and deep loosening (d); Karcagpuszta, uncultivated (e) and cultivated (f).

Bulk density

The measured bulk density values for the studied soil profiles are shown in Fig. 3. The bulk density values of Abádszalók soils are lower compared to the Kisújszállás and Karcagpuszta soils.

The general expectation is to have lower bulk density values in the surface horizons of the cultivated soil variants.

Regarding the Kisújszállás soil, there are not considerable differences between the bulk density values of the two cultivation variants. This fact is in agreement with our previous experimental results and experiences in the region, that the favourable 'bulk-density reducing' effect of deep-loosening is not longer than 3-4 years under the given conditions. Soil sampling for the present study was carried out in the 3rd year after deep-loosening.

The ameliorated and cultivated variants of the salt affected soil show only somewhat lower bulk density values than the uncultivated one.

Stability of soil micro-aggregates

Data about the index of soil structure (IS) are shown in Fig. 4. The investigated soils have IS values that range between 20-98. A specific behavior can be observed from the IS data; the highest 'stability values' were obtained for salt affected soil with high exchangeable sodium content. The stability

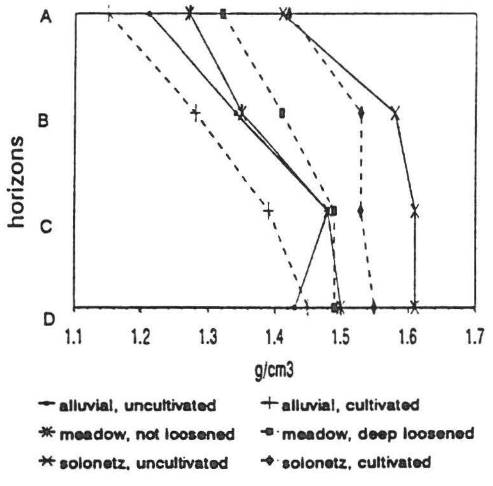

Fig. 3. Bulk density of the investigated soils.

index of meadow soil in Kisújszállás increased with depth even though the chemical composition of deeper layers is becoming more and more salty with increasing exchangeable sodium content. The conclusion which can be drawn from these data is that this method is not applicable for the characterization of the structural status of heavy-textured, highly sodium-saturated soils, because the high IS values in such cases are not the indicators of high structure-stability of these soils, but simply the consequences of their compactness and 'slow-wetting' character. Similar conclusions were drawn by numerous authors several years ago on the limited applicabilities of wet-sieving procedures for the determination of 'aggregate stability' in such soils.

Swelling and shrinking characteristics

The swelling process (Fig. 5) within a short time period (250 min) shows only slight differences among the investigated soils. The meadow soil in Kisújszállás can be characterized with a slower swelling rate in the beginning phase. There are not considerable differences between the swelling rate of alluvial meadow soil and salt affected soil in the beginning swelling phase.

Taking into account a longer time period (24 h) the highest swelling percentage could be measured in the A horizon of the slightly acidic alluvial meadow soil, the lowest one in the surface horizon of the salt affected soil. The shrinkage percentages do not coincide with the order of swelling.

The highest rate of shrinkage could be measured in the soil samples of salt affected soil. Between the Kisújszállás meadow and Abádszalók alluvial meadow soils, there are not any differences in the extent of shrinkage.

Evaluation of the infiltrometer measurements

The unsaturated water conductivity values in the suction range close to water saturation show characteristic differences for the three different soil varieties. The extrapolated saturated water conductivity, together with the unconfined water conductivity measured at 3 cm tension reflect reliable magnitude and differences of the heavy textured soils and cu ltivation treatments, as its is seen in Fig. 6. The uncultivated alluvial soil in Kisújszállás has the same saturated conductivity as the cultivated soils in Karcagpuszta and Abádszalók. The infiltration rate at 3 cm tension is somewhat smaller for the uncultivated alluvial soil than for the cultivated solonetz soil. The infiltration rates at 6 cm tension are almost the same for all three soils. The verification of these results needs further field check in space and time.

Evaluation of WCR-models

The parameter values of the fitted Brutsaert function are used for characterizing the WRC-curves of the study soils (Fig. 7). From Fig. 7 it can be read that Ψ_o parameter describing the most frequent water potential of the soil matrix [17] is consequently smaller for the cultivated variants than for the uncultivated ones and indicates a higher amount of available moisture in these soils. The expected difference in the model parameter n of the cultivated and uncultivated

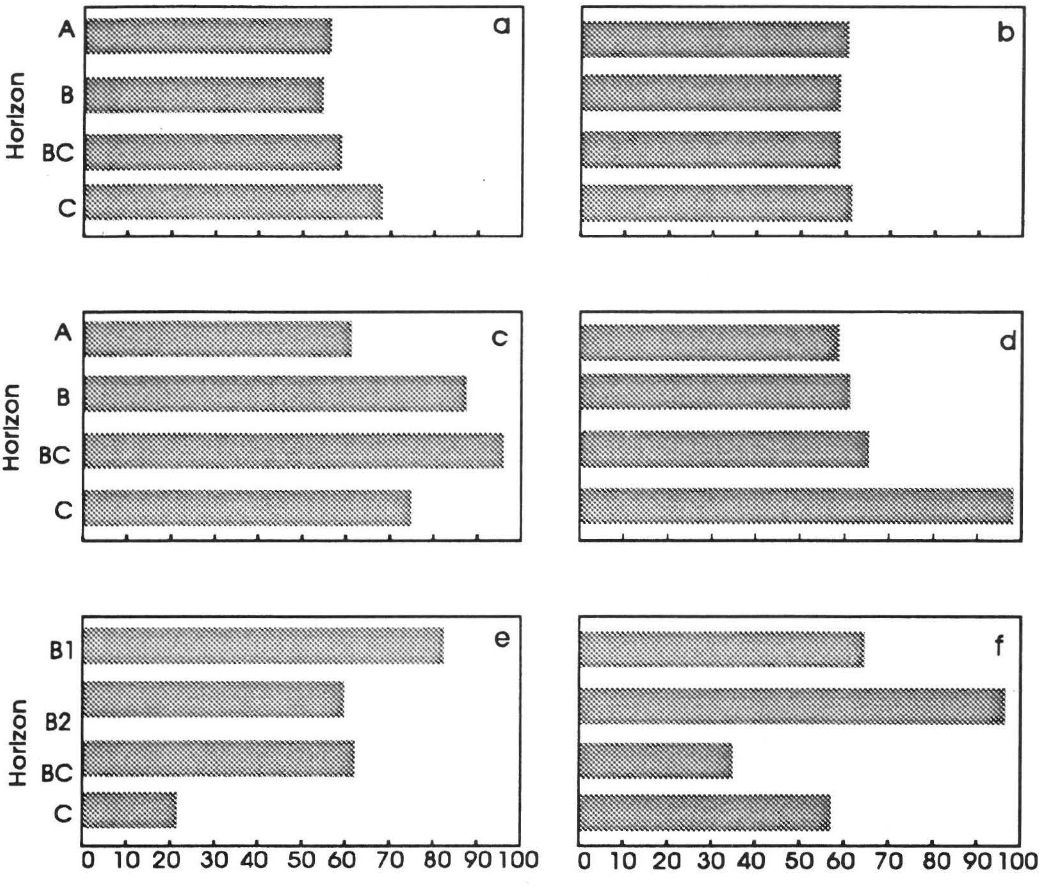

Fig. 4. Micro aggregate stability of the investigated soils: Abádszalók, uncultivated (a) and cultivated (b); Kisújszállás, not loosened (c) and deep loosening (d); Karcagpuszta, uncultivated (e) and cultivated (f).

soil variants is shown only by the Abádszalók soil's case. The expectation is a smaller *n* value of the cultivated variant compared to the uncultivated soil. This indicates a lower moisture potential change in case of unit moisture content difference. This derived soil property is the reciprocal of the soil parameter known as differencial moisture capacity [9].

The use of WRC-model parameters for the indication of differences in structural state of soils is not yet fully known. This idea is worth to study in the future.

SUMMARY

The assessment of the functional relations of soil structure is a very actual research direction within soil science. The morphological aspects of the soil structural elements have been applied in soil survey and soil micromorphology. However the functional consequences of the changes in soil structural status are not yet adequately known. The understanding, description, quantification, modeling, monitoring and prediction of these functional consequences are important either from agricultural or environmental point of view. Intensive agricultural cultivation practices heavily damage the 'original' soil structure, the soil aggregates, which may lead to unfavourable consequences in soil water management or aeration. For sustainable agricultural development and soil management, ensuring

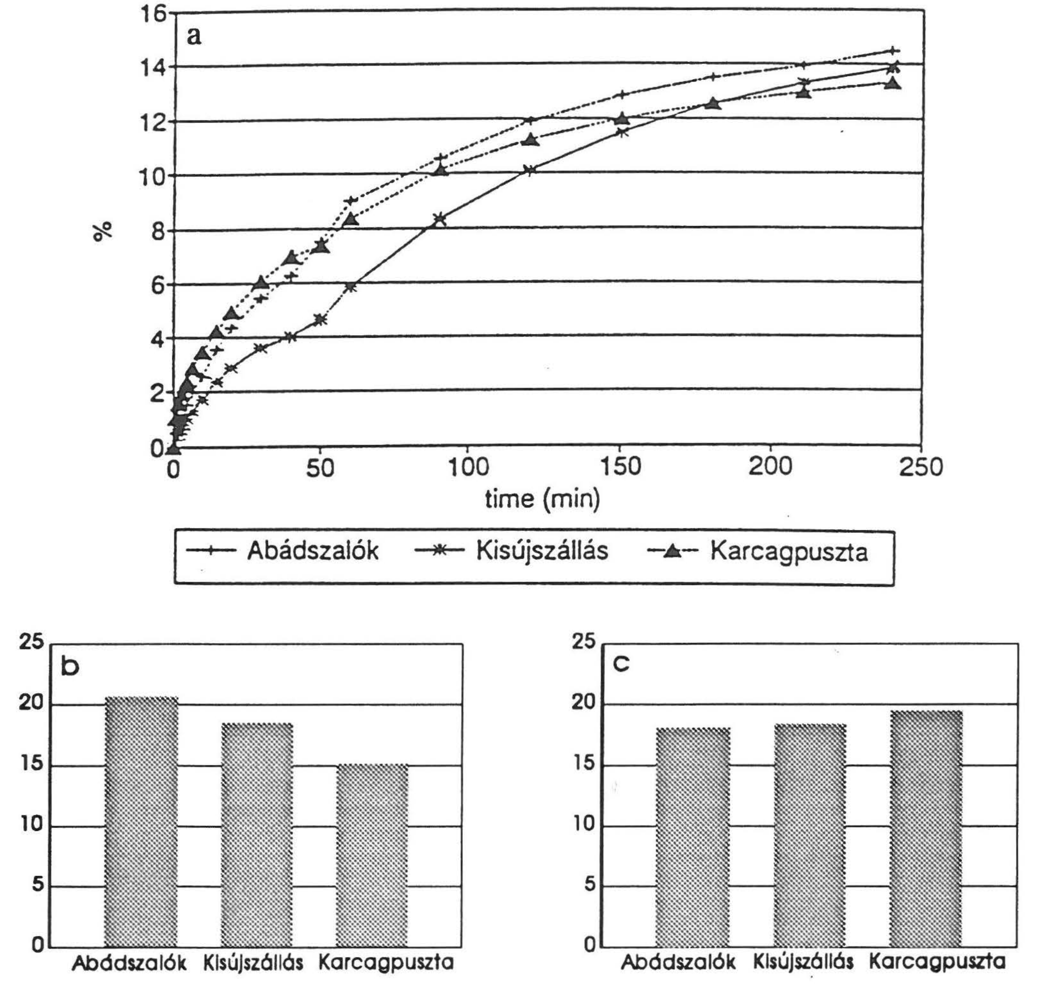

Fig. 5. Swelling: a (0-250 min), b (24 h) and shrinkage (c) of the investigated soils.

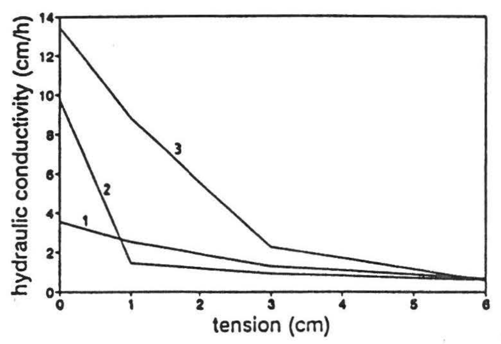

Fig. 6. Near saturated water conductivity values of the investigated soil measured by tension infiltrometer. 1 - solonetz, cultivated; 2 - alluvial, uncultivated; 3 - meadow, cultivated.

normal soil functions a better knowledge on the functional relations of soil structure are required. Finding the appropriate methods in studying the consequences of the changes of soil structure is a task itself.

This study presents two new techniques for studying the functional consequence of the structural status of soils. The tension infiltrometer allows to measure the unconfined infiltration rate of the soil *in situ*. This technique makes it possible to gather infiltration data both in space and time for studying the consequence of the cultivation practice and changes in structural status on near saturated water conductivity of soils.

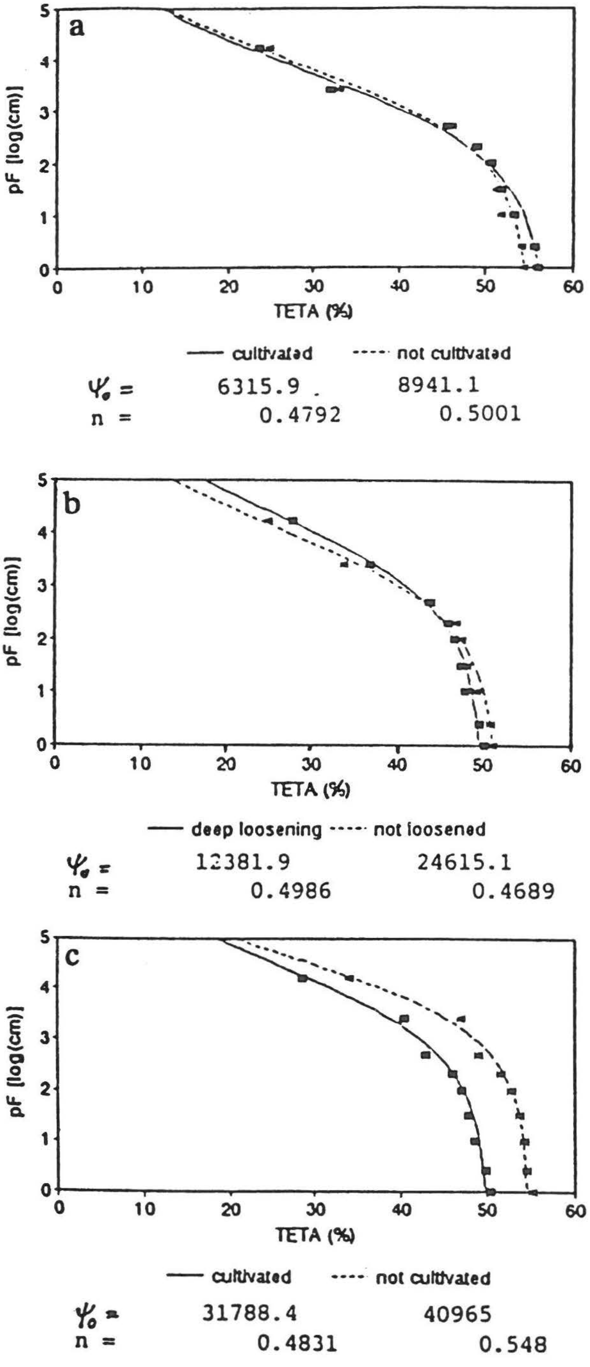

Fig. 7. Measured water retention data and fitted water retention characteristic curves with the parameter values of the fitted function of the investigated soils: Abádszalók, 20-25 cm (a); Kisújszállás, 30-35 cm (b) and Karcag-puszta, 20-25 cm (c).

The other applied technique aims to express the consequences of soil aggregation on the water retention characteristic (WRC) of the soil. Instead of studying the conventional point of the WRC we proposed to analyse the parameter values of the fitted empirical function to the measured WRC data. The physical indicator value of the fitted model parameters was looked for in this study.

Since the research task has a very complex nature, our present work can be evaluated as a preliminary study for a more detailed experimental program.

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