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The importance of volume changes in the determination of soil water retention curves on the East Slovakian Lowland

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Abstract

Estimation and application of water retention curves in heavy soils have own specifics. The reason for these specific properties is the composition of the high clay texture. This is manifested by volume changes of soil depending on moisture. Up to 40% change in the volume compared to the saturated state was recorded in the conditions of the East Slovakian Lowland. The results described in this work are based on research work carried out in the East Slovakian Lowland and represent an analysis of selected 42 samples out of a total of 250 samples in which laboratory measurements of soil water retention curves and volume changes were performed. Selected samples represent the localities Senné and Poľany. Volumetric changes were measured in a laboratory by measuring the dimensions of soil samples. Appropriate changes in the volume of soil samples should be measured when determining moisture retention curves. Neglecting this physical effect leads to a distorted determination of the water retention curves in heavy soils. In the laboratory measurement of water retention curves points, changes in the volume of the sample were measured in the range of 0.24–43.67% depending on the soil moisture potential during drainage. In the case of neglecting the effect of shrinkage during the drainage of samples, a certain error is occurring in the calculation of the volumetric moisture. The range of this error was 1–13% of volumetric moisture.

Key words: *heavy soils, soil shrinkage, soil texture, soil volumetric moisture, soil water retention characteristics*

INTRODUCTION

Soil water retention curves (SWRC) are an important hydrophysical characteristic of soils. The course of SWRC is obtained by laboratory measurements of its points in intact soil samples. During measurements, the moistures are expressed in dependence on moisture potential. The parameters for analytic representations of a course of SWRC are searched on the basis of measured points. Therefore, a dependency $-h(w) = f(\theta)$ is searched where $-h(w)$ is soil moisture potential (cm of water (w) column) and θ is volumetric soil moisture ($cm^3 \cdot cm^{-3}$). It is widespread to make an analytic representation of SWRC by the means of calculation method developed by MAULEM [1976] and improved by VAN GENUCHTEN [1980]. Measurement of water retention curves is time-consuming, especially in heavy soils. High clay content in heavy soils causes volumetric changes [BRONSWIJK 1991; JAMEI *et al.* 2007], which in field conditions are manifested by the formation of a two-domain soil structure [NOVÁK 1999; NOVÁK *et al.* 2000; ŠOLTÉSZ *et. al.* 2016; TALL 2007; TALL 2008; VITKOVÁ *et al.* 2017]. This is formed by a network of cracks and soil matrix. In addition, the volume changes are also reflected in the vertical movement of the soil. These specific properties of heavy soils affect the dynamics of water regime and water retention. In numerical simulations on mathematical models describing the water regime of soils, water retention curves are a key input parameter [BETHUME, TURRAL 2001; KATEB *et al.* 2019; MAJERČÁK, NOVÁK 1994; OOSTINDIE, BRONSWIJK 1992; ŠIMUNEK *et al.* 2013; TALL, GOMBOŠ 2005; VAN GENUCHTEN *et al.* 2000]. The reliability of model outputs is closely related to the accuracy of water retention curves estimation. In heavy and extremely heavy soils, this can imply the need to measure volume changes in soil samples. Soil volume changes can change the shape of the water retention curves. These differences can also be observed in soils with high organic matter content such as peat soils. The comparison of the laboratory and field measured moisture retention characteristics with respect to volume changes was presented by OLESZCZUK *et al*. [2000].

The goal of this article is to compare the courses of water retention curves in selected soils of East Slovakian Lowland (ESL) when neglecting the volume changes during the measurement and taking them into account. Further quantify the differences in the retention properties of the investigated soils resulting from the comparison of their courses. Next aim is to characterize the investigated soils according to the content of clay particles and shrinkage characteristics and formulate dependencies between the content of clay particles in the soil and the error size resulting from neglecting the volume changes.

MATERIALS AND METHODS

SELECTION OF SAMPLING LOCALITIES

The results described in this work are based on research work carried out in the ESL and represent an analysis of selected 42 soil samples (S1–S42) out of a total of 250 samples in which laboratory measurements of SWRC were performed. The selection was limited only to samples with high clay content and assumption of volume changes during drainage of soil samples. The selected samples represent two localities Senné (S1–S24) and Pol'any (S25–S42). The situation of investigated localities within ESL is shown in Figure 1.

Fig. 1. The situation of the selected localities; source: own elaboration

The experimental locality Senné (48°39'54"N latitude and 22°02'51.5"E longitude) is situated in the central part of ESL in the Senian depression area with an altitude of 100 m. The area is characterized by wetlands, which caused the genesis of local heavy soils. Soils in Senné are typical representatives of extremely heavy soils with a dominant clay component (particles <0.002 mm). The presence of clays causes volume changes in the soil, which are manifested by the opening and closing of cracks, respectively vertical movement of the soil surface. The soil profile in Senné is in basal part formed by clay loam, which in the direction of the surface passes through clays to silty clay loam. The surface is covered with permanent grassland. On the locality of Pol'any (48°28'5.6" N latitude and 21°58'52.7" E longitude) are mostly occurring the gleyic fluvisols, which were created by the floods of rivers (Latorica), streams and marshes, due to hydromorphic conditions and as a consequence of the declining area. The degree of soil hydromorphicity is also due to the high proportion of clay particles that are sedimented mainly in depressions. The soil profile in Pol'any is formed in the lower layers by clay, which in the direction of the surface pass through the silty clay loam to the silty loam. The texture of the analysed soil profiles was measured by the Cassagrande density measurement method (Fig. 2).

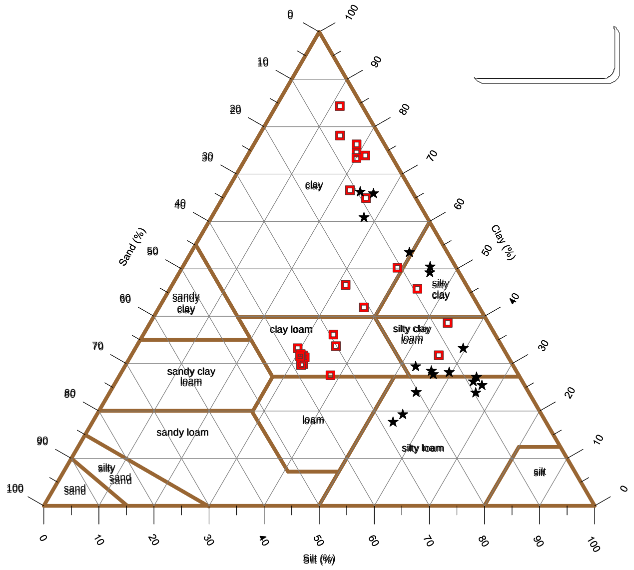

Fig. 2. Soil texture of the selected localities according to the USDA soil classification triangle; source: own results

A soil sampling to the Kopecky cylinders (100 cm^3) was realized from every 0.1 m to a depth of 2.5 m in the vertical direction. Some interlayers could not be included in the 42 analysed samples. Afterwards in the laboratory, these samples were fully saturated with water. After replenishment, the samples were transferred to the pressure plate extractor (Photo 1).

Photo 1. The pressure plate extractor apparatus (phot. *B. Kandra*)

LABORATORY MEASUREMENT OF WATER RETENTION CURVE POINTS

The measurement methodology was based on the ISO standard [ISO 11274: 1998] and rules of international ring test laboratories [COOLS, DE VOS 2009] aimed at evaluating this hydrophysical characteristic. During the measurement, the soil moisture potential values were used according to the FSCC (0, –10, –51, –102, –336, –1019, –2548, –5097 cm). At the beginning the soil sample is fully saturated with water. Subsequently, draining starts under the influence of the exact pressure. From the soil sample flows out the water bounded with force (pressure potential), which has been overcome by set pressure. Drainage was terminated after a certain period of time when it reached a steady state between the exerted pressure and pressure potential of soil water in soil sample. Functional relationship between pressure and soil moisture express the points on the SWRC. To determine the correct volumetric moisture in the samples of heavy and extremely heavy soils, it is necessary to take into account the volume changes. During drainage this is the rate of gradual shrinkage of the soil column. Therefore, during every weighting of samples was measured twice in various directions (preferably at 90° angle from each other) the height (h_1, h_2) and diameter of soil column (the diameters d_1–d_4 were measured at both ends (ø1, ø2) of the column) by means of a digital Vernier calliper (Fig. 3).

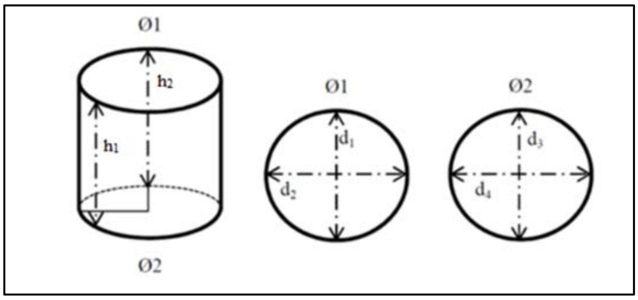

Fig. 3. Measurement of volume changes of soil samples; h_1, h_2 = the height, d_1–d_4 = diameter of soil column, ø1, ø2 = ends of the column; source: own elaboration

Then, were calculated the volumes of soil columns based on the average measurements which were subsequently used for the calculation of volumetric moisture. The calculation of volumetric moisture was based on the equation:

$$\theta_{-h(w)} = \frac{M_{-h(w)} - M_{\mathrm{dry}}}{V.\rho_w} \qquad (1)$$

Where: $\theta_{-h(w)}$ = sample volumetric moisture ($\mathrm{cm^3 \cdot cm^{-3}}$) at moisture potential $-h(w)$, $M_{-h(w)}$ = sample weight (g) at moisture potential $-h(w)$, M_{dry} = weight of the dried sample (g) at 105°C, V = soil sample volume ($\mathrm{cm^3}$), ρ_w = water density ($\mathrm{g \cdot cm^{-3}}$).

While measuring the drainage branch of SWRC in the samples of selected localities, a gradual shrinkage of soil columns occurred. At the end of the measurement, the samples were dried and their final shrinkage was measured. The resulting sample volumes were used to calculate the volume change potential expressed by the coefficient of linear extensibility (COLE) [GROSSMAN *et al.* 1968; PARKER *et al.* 1977; PENG *et al.* 2007; SCHAFER, SINGER 1976]. The COLE calculation was based on the range of volume changes corresponding to soil moisture in the saturated state to the dried state in a laboratory oven at 105°C.

Data analysis consisted of mutual comparison of measured points of SWRC courses. Changes in soil samples volume depending on soil moisture potential and clay content were quantified. Shrinkage of the samples during drainage had affected the results of measuring points of SWRC. These results were compared with the results where the volume changes were disregarded. Statistical methods of correlation and simple regression analysis were used for this purpose.

RESULTS AND DISCUSSION

QUANTIFICATION OF VOLUME CHANGES

Dependences between the fraction of clay, silt and sand against COLE are determined (Fig. 4). The highest tightness to the COLE coefficient was demonstrated for the clay fraction (R^2 = 0.92; Fig. 4A), the lower for the silt fraction (R^2 = 0.64; Fig. 5B) and the lowest for the sand fraction (R^2 = 0.22; Fig. 5C).

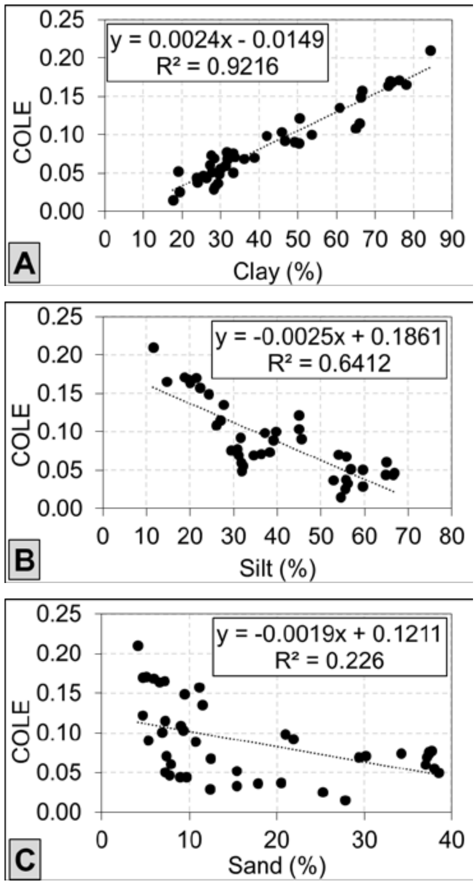

Fig. 4. Linear dependence between the coefficient of linear extensibility (COLE) and investigated fractions: A) clay, B) silt, C) sand; R^2 = determination coefficient; source: own study

During the drainage of the samples, the volume changes began to be measurable only at the moisture potential values of –336 cm and in the whole set of samples it was only at the moisture potential of –1019 cm. Figure 5 shows a linear trend between clay content in samples and % shrinkage (ΔV) against samples volume in saturation state (100 cm^3) at measured potentials.

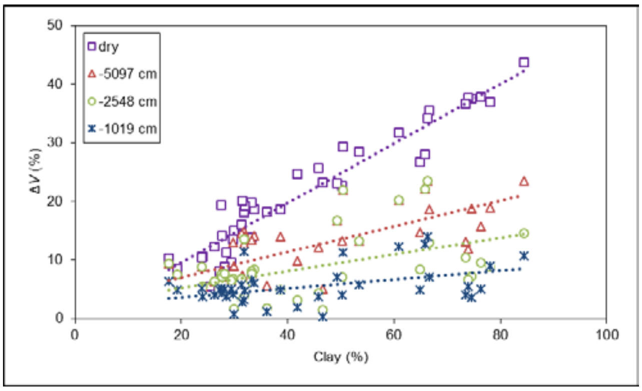

Fig. 5. Linear trends of percent of shrinkage (ΔV) with clay fraction at moisture potential –*h*(*w*); source: own study

In all cases, the trend of values is increasing, which means that the rate of shrinkage of soil samples increases with increasing clay content. Under natural conditions, GOMBOŠ *et al*. [2009] recorded a soil shrinkage (ΔV) up to 40% and soil movement in the vertical direction up to 0.13 m in the East Slovakian Lowland. Correlation coefficients between content of clay (%) and ΔV increase with increasing potential and indicate an increasing dependence between the investigated indicators (Tab. 1). The steepness of the linear trends means that as the moisture potential increases, the shrinkage of the soil samples increases at a given clay content. As with clay, correlation was also performed for the silt and sand fractions. The coefficient values are negative, which means that the magnitude of the volume changes increases with decreasing content of these fractions. From the comparison, the most significant influence of the clay fraction on changes in the volume of soil samples can be unambiguously confirmed. Higher correlation values for silt than sand indicate that clay and silt fractions predominated in the samples and sand content was minor.

Table 1. Linear correlation between evaluated parameters at moisture potential

Moisture potential *h*(*w*)	Clay		Silt		Sand	
	ΔV	$\Delta\theta$	ΔV	$\Delta\theta$	ΔV	$\Delta\theta$
–1 019 cm	0.43	0.58	–0.38	–0.46	–0.18	–0.32
–2 548 cm	0.48	0.60	–0.32	–0.38	–0.34	–0.44
–5 097 cm	0.73	0.84	–0.67	–0.69	–0.27	–0.43
Dry	0.96	–	–0.84	–	–0.41	–

Explanations: ΔV = samples shrinkage, $\Delta\theta$ = deviation of samples volumetric moisture.
Source: own study.

Based on the COLE values, the percentage shrinkage was expressed separately for each locality depending on the moisture potential (Fig. 6). Samples with the highest and lowest COLE values were analysed, along with the mean expression of the change in volume of all samples at the investigated localities. The maximum and minimum values of COLE correspond to the maximum and minimum values of the clay content in the samples. The clay content in the Senné locality ranged between 27% and 84% and in the Poľany locality between 17% and 66%. The largest shrinkage after drying was seen in samples from Senné ΔV_{max} = 43.67%, ΔV_{avg} = 25.14% and ΔV_{min} = 13.55% (Fig. 6A). The values from the Poľany locality were slightly smaller ΔV_{max} = 34.16%, ΔV_{avg} = 16.54% and ΔV_{min} = 10.27% (Fig. 6B).

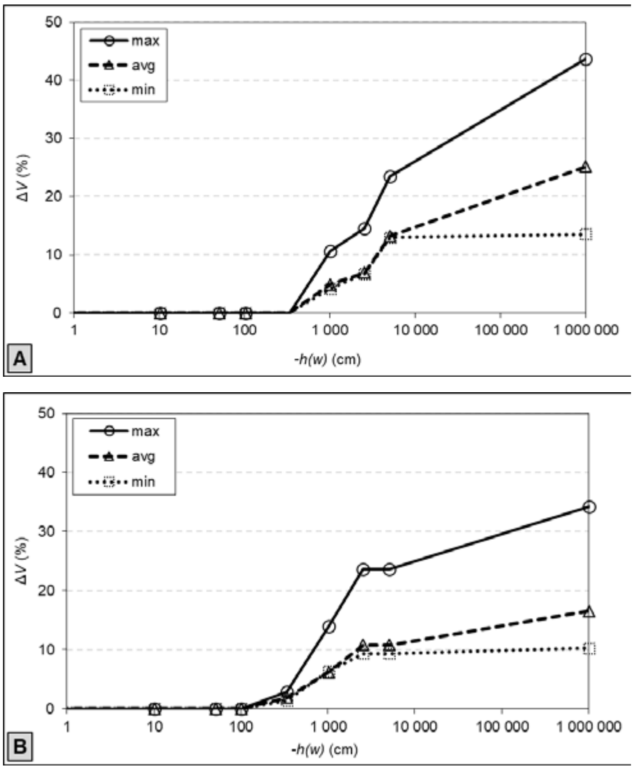

Fig. 6. Shrinkage of soil samples ΔV at moisture potential –*h*(*w*): A) Senné, B) Poľany; source: own study

ANALYSIS OF SOIL WATER RETENTION CURVES

The obtained shrinkage volumes were further used to correct the calculated soil volumetric moisture. When analysing heavy soils from the evaluated localities, the deviations in volumetric moisture after taking into account volume changes and their neglecting are significant. The measured points of the soil water retention curves (SWRC) with hydrolimites field water capacity (FWC), threshold point (TP) and witling point (WP) are shown in Figure 7. For comparison, two courses of theta (θ) and theta reduced (θ_r) are plotted for each locality. Theta is the real soil volumetric moisture based on real sample volume. It counts with sample shrinking. Theta reduced is the soil volumetric moisture calculated on the volume of the sampling Kopecky cylinder (100 cm^3). The locality Senné is represented by samples S1–S24 (Fig. 7A). The clay content in layers to a depth of 0.8 m varies in the range of 30–50%. These are samples S1–S8, where the deviations between

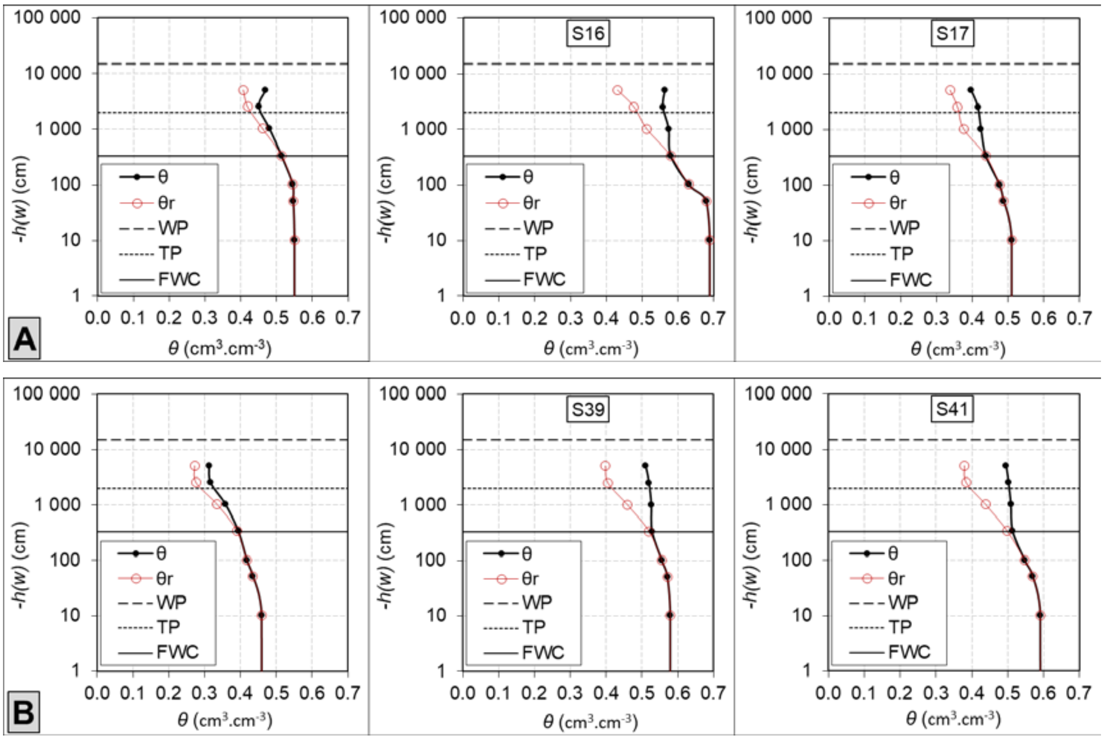

Fig. 7. Measured points of soil water retention curves (SWRC) in two investigated localities: A) Senné, B) Poľany; $-h(w)$ = moisture potential, θ = volumetric moisture, *FWC* = field water capacity, *TP* = threshold point, *WP* = wilting point; source: own study

θ and θ_r are smaller. From this layer, a sample of S8 with a clay content of 50.24% (COLE = 0.0894) was selected for the demonstration. The highest representation of clay is in samples S9–S16 (65–84%) in the soil profile depth 0.9–1.6 m. The deviations in the courses of the measured points of the SWRC are significant. This layer is demonstrated by the sample S16 with a clay content of 84.35% (COLE = 0.2108). At a soil depth of 1.7–2.5 m a decrease in clay content of 27–33% was again observed. This layer is characterized by samples S17–S24. In Figure 7A, sample S17 with a clay content of 31.74% (COLE = 0.0694) was selected for preview from this part of the soil horizon. Deviations in the courses of SWRC points are similar as in the first layer. The soil from Poľany was divided into two material layers. The first layer is defined to a depth of 1.6 m with a clay content of 17–33% (S25–S36). From this layer was selected representative sample S32 with a clay content of 27.14% (COLE = 0.6090). The second layer at a depth of 1.7–2.5 m with a clay content of 49–66% (S37–S42) is represented by two samples, S39 with 65.88% of clay (COLE = 0.1155) and the sample S41 with 66.24% of clay (COLE = 0.1495). Again, considerable deviations between the measured points can be seen, and it is clear that with increasing potential the deviations between θ and θ_r also increase.

The deviations between the real and reduced volumetric moisture values $\Delta\theta$ ($\Delta\theta = \theta - \theta_r$) is shown in Figure 8 for sites of Senné (S1–S24) and Poľany (S25–S42). The

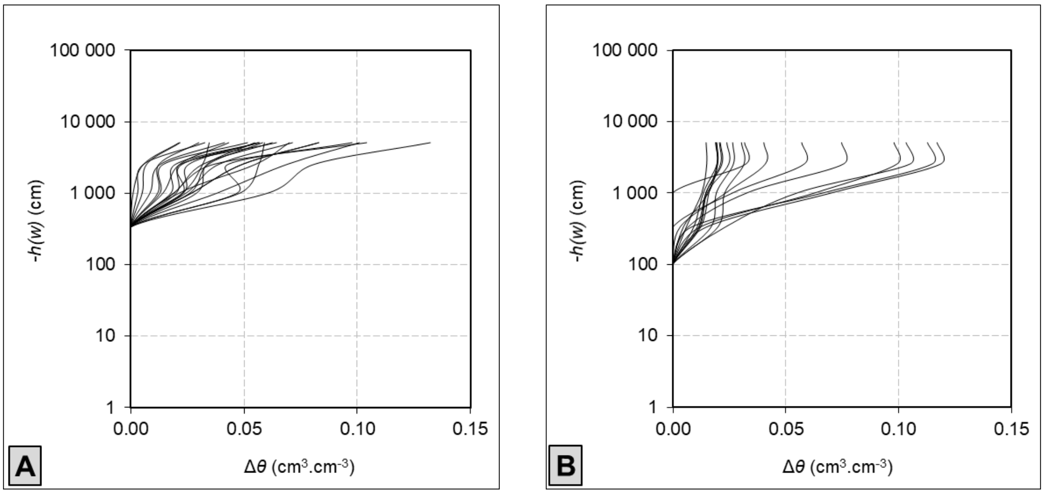

Fig. 8. Deviations of the samples volumetric moisture $\Delta\theta$ at soil moisture potential $-h(w)$ in two investigated localities: A) Senné, B) Poľany); source: own study

visible deviations start at a potential of –336 cm. The maximum deviation $\Delta\theta$ in the Senné locality is 0.13 $cm^3 \cdot cm^{-3}$ in sample S16 with a clay content of 84% and in the locality Poľany is 0.12 $cm^3 \cdot cm^{-3}$ in sample S41 with a clay content of 66%. Both samples contained the most clay in the examined localities. These deviations were observed at a moisture potential of –5097 cm. In the locality Poľany there is a slight decrease in the deviations at the final moisture potential, which can represent a measurement error.

The Figure 9 shows the linear trends between $\Delta\theta$ and clay content at individual moisture potential values. The increasing nature of the trends means an increase in the volumetric moisture deviations depending on the clay content of the samples. As the moisture potential increases, the steepness of the linear trends increases too, that indicate to increasing of the $\Delta\theta$ values in individual samples. Correlation coefficient values increase with increasing moisture potential (Tab. 1). For silt and sand, the correlation coefficient values are negative and trends decline. This means that the smaller the silt and sand content, the greater the $\Delta\theta$ deviations resulting from the higher clay content.

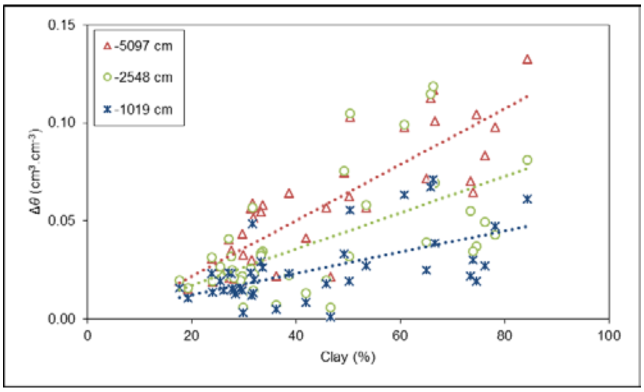

Fig. 9. Linear trends of $\Delta\theta$ with clay fraction at soil moisture potential $-h(w)$; source: own study

CONCLUSIONS

The effect of volume changes on the course of water retention curves was investigated on 42 soil samples taken from the locality Senné and Poľany in the East Slovakian Lowland. Linear regression showed the highest degree of tightness between the linear extensibility coefficient and clay fraction of soil. The percentage of shrinkage of soil samples during drainage increased depending on the clay content and soil moisture potential. From the comparison, the most significant influence of the clay fraction on changes in the volume of soil samples can be unambiguously confirmed. The next result was the quantification of the differences between the reduced and real soil moisture content. The real volumetric moisture was calculated with volumetric changes and represented a correction of the reduced volumetric moisture when determining the water retention curves. The differences in the measured points of the water retention curves are significant in terms of further investigation of their application in mathematical models that do not take into account the effect of volume changes of heavy and extremely heavy soils.

The benefit of the obtained results lies in the specification of the methodology of measurement of SWRC and information on the retention properties of heavy soils. This enables to eliminate the errors resulting from numerical simulation of soil water regime by mathematical models which were caused by incorrectly determined course of SWRC because the volume changes were disregarded. Under these results, it will be possible to specify and characterize those soils in which the volume changes affect their retention characteristics and dynamics of water regime.

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