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Relationship between van Genuchten's parameters of the retention curve equation and physical properties of soil solid phase**

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A b s t r a c t. Van Genuchten parameters α, n, θ_s, θ_r were determined for 24 Phaeozems and 54 Gleysols samples taken from surface, subsurface and subsoil horizons. No evident dependences between van Genuchten's α, n, θ_s, θ_r parameters and the physical properties of Phaeozems soil samples were observed, which was due to a similar genesis and similar properties of soil solid phase. Analysis of Gleysols, on the other hand, revealed dependences between the physical soil properties and van Genuchten's parameters resulting from different geneses of these soils and, hence, different physical properties of soil solid phase.

The obtained results should be considered as preliminary and further studies on a larger number of soil samples are planned.

K e y w o r d s: water retention curve, van Genuchten's parameters, pedotransfer functions

INTRODUCTION

A knowledge of the hydrophysical properties of soil is necessary in many disciplines of science from agriculture to ecology. Hydrophysical characteristics of soil *ie* the water retention curve and hydraulic conductivity in saturated and unsaturated zones can be measured experimentally and/or estimated using mathematical or statistical models.

Specification of the water retention curve is necessary for studying water availability for plants, plant water stress, infiltration, drainage, melioration as well as water and solutes movement in the soil (Kern, 1995). Water retention is one of the most important soil features. It governs the conditions of plant growth, development and yield as well as the availability and uptake of nutrients and toxic substances by plant root systems (Reinhard, 2001; Walczak *et al*., 2000; Walczak *et al*., 2001).

Determination of soil water characteristics is time- and labour-consuming and requires the use of expensive and specific equipment. For these reasons, methods for the estimation of the hydrophysical properties of soils have recently been intensively developed.

Many semi-empirical and statistical equations (pedotransfer functions) describing the water retention curve have been proposed in the literature (Kutilek and Nielsen, 1994). These equations contain parameters which, generally, have no direct physical sense and are mainly used as fitting parameters to match function to experimental points. However, Guber *et al*. (2004) postulated that the physical correlate of van Genuchten's parameter n is the impact content of small aggregates in soil and that the parameter α relates to the content of large aggregates.

One of the most popular is van Genuchten's equation (van Genuchten, 1980):

$$\theta_e = [1+(\alpha|h|)^n]^{-m}, \qquad (1)$$

where: $\theta_e = (\theta-\theta_r)/(\theta_s-\theta_r)$ – effective water content; θ – water content; α, n, θ_r, m – equation parameters; θ_s – saturation soil moisture; θ_r – residual soil moisture, and:

$$m = 1 - 1n^{-1}. \qquad (2)$$

Most of the researchers try to find equations describing the water retention curve using the simplest set of measurable parameters of soil solid phase such as particle size distribution, bulk density, or organic matter content.

In the 1990s, Wösten and Lilly (2004) created the European soil data base, HYPRES (HYdraulic PRoperties of European Soils), containing van Genuchten's parameters for soils in European Union countries, classified according to texture classes.

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The next step was correlation of these parameters with selected physical parameters of soil solid phase.

In 2004, similar investigations were performed by Rajkai *et al*. (2004) for Hungarian soils. The researchers correlated van Genuchten parameters $\alpha, n, \theta_s, \theta_r$ (Eq. (1)) with soil bulk density and contents of organic matter and sand, silt, and clay fractions. Different techniques were used to find correlations such as linear regression, nonlinear regression, multivariate nonlinear optimization and nonlinear global optimization. Additionally, the authors used logarithms and squares of the original soil properties for correlations using the polynomial regression technique. They found that close to the inflection point (at about pF2.3-pF2.5 *ie* around field capacity) the measured retention data are in a good agreement with calculated ones.

Some authors have estimated the water retention curve using porosity parameters such as bulk density, pore volume or texture (Ahuja *et al*., 1985; Kern, 1995; Nemes *et al*., 2004; Timlin *et al*., 2004; Van Genuchten *et al*., 1985). Many other correlation models have been elaborated to estimate the water retention curve basing on multiple regression techniques such as Gupta-Larson's model (Gupta *et al*., 1979), Rawls-Brakensiek's model (Rawls *et al*., 1982) or Walczak's model (Walczak *et al*., 2004).

The aim of this work was to check if there exists any dependence between physical soil properties and van Genuchten's parameters.

MATERIAL AND METHOD

78 nondisturbed samples taken from surface, subsurface and subsoil (parent material) horizons of 27 profiles of Phaeozems and Gleysols were studied (Walczak *et al*., 2002). The investigated Phaeozems were formed from silt and were situated on weak slopes, flow rills or flat planes with good outflow. They had appropriate moisture conditions or were periodically water-logged. The pH ranged from 6 to 7. The sampled Gleysols were formed from very different parent material: silts, sands, loam and clay, and were situated on boundaries of flow rills and flat planes with limited outflow. These soils were mostly periodically waterlogged and even over-moistened. The pH ranged from 5.5 to 7 (Gliński *et al*., 1991).

The ranges of chosen physical properties of the studied Phaeozems and Gleysols are presented in Table 1.

The measurements of static hydrophysical characteristics of the studied soils *ie* relation between soil water potential and water content, were made within the range from 0.1 kJ m^{-3} (0.01 kPa) to 1 500 kJ m^{-3} (1600 kPa) for the eleven points in the process of drying. The standard pressure chambers, made by Soil Moisture Equipment Corp., Santa Barbara, California, USA, were used.

Van Genuchten's equation was fitted to the experimental water retention curves using a self-written computer program estimating the studied parameters by least square methods.

RESULTS AND DISCUSSION

Figures 1 and 2 present correlations between the values of water content for the investigated soils measured and calculated from van Genuchten equation. The determination coefficient ranges from 0.872 to 0.995 for Phaeozems and from 0.899 to 0.997 for Gleysols. These results are very satisfactory and show that the estimation procedure works well.

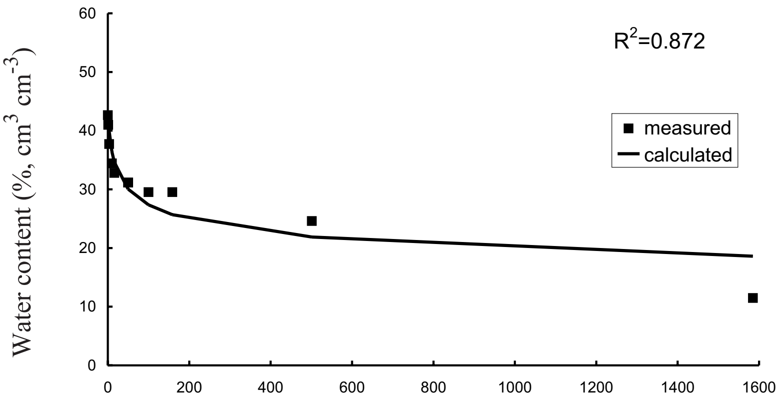
Figures 3 to 6 illustrate the distribution of parameters α, n, θ_s and θ_r in the three soil layers from which the investigated materials were taken.

The range of parameter α for Gleysols (Fig. 3) is from 0.012 to 0.6557 and is larger than for Phaeozems which is from 0.004 to 0.1336. For Phaeozems subsoil layers and for Gleysols' surface and subsoil layers, values of α are similar within each group. For three Gleysols, these values are distinctly higher than in the other Gleysols. Values of α are higher in subsurface layers of every investigated soil.

T a b l e 1. Ranges of chosen physical parameters of the investigated soils

Soil/layer	Grain size distribution (%, dia in mm)			Bulk density (g cm^{-3})
	1- 0.1	0.1-0.02	< 0.002	
Phaeozems				
surface	0-18	41-68	32-57	1.24-1.57
subsurface	0-7	50-59	35-48	1.15-1.64
subsoil	0-12	48-64	26-52	1.54-1.65
Gleysols				
surface	7-83	14-72	3-36	1.07-1.85
subsurface	5-94	0-45	2-66	1.24-1.95
subsoil	7-97	1-34	0-86	1.47-1.95

a



b

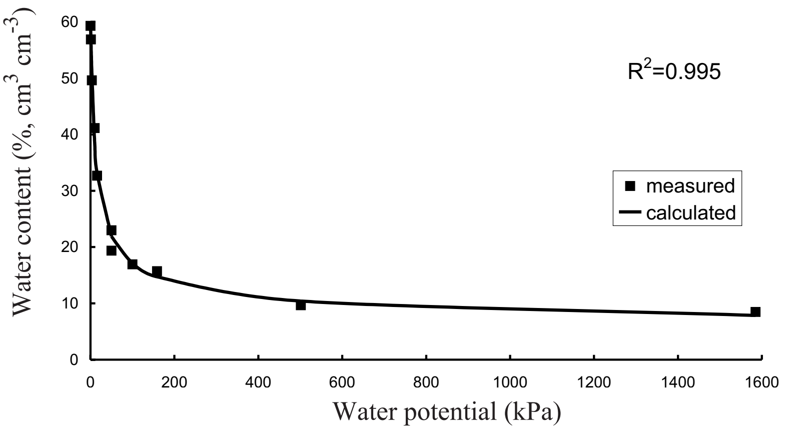


Fig. 1. Correlation between measured and calculated values of water content for Phaeozems: a) the worst and b) the best.

The value of parameter n is more variable for Phaeozems and ranges from 1.089 to 1.6381 (Fig. 4). For surface and subsurface layers of Gleysols, the differences in n are small; however, for subsoil layers, these differences are significant. For Gleysols, the differences in parameter n are larger and range from 1.17 to 3.41.

Parameter θ_s is different for both soils and soil layers (Fig. 5). Its value ranges from 0.2646 to 0.5928.

Parameter θ_r (Fig. 6) does not differ significantly for Phaeozems. Its value changes in general from 0.00001 to 0.00005, and only for two soils θ_r values equal 0.045 and 0.038. For Gleysols, θ_r varies markedly in surface and subsurface layers and ranges from 0.00001 to 0.1. For subsoil materials, the differences between the values of parameter θ_r are not large. The values range from 0.00001 to 0.037894.

The differences between the values of van Genuchten's parameters for the investigated soils may be governed by the differences in their physical and chemical properties. It seems that the granulometric fraction content has the greatest influence on these parameters. Figures 7 to 10 present relationships between van Genuchten's parameters and the content of particular granulometric fractions in the investigated soils.

From Figures 7a, 8a, 9a, one can see that the differences in parameter α are small for all except three Gleysols. The soils in question (Fig. 1b) show greater differences in granulometric composition. Figure 7b shows that an increase in sand content leads to an increase in the value of parameter n. In general, the sand content in Gleysols is much higher than in the studied Phaeozems, which contain only small amounts of sand (Table 1). Therefore, for chernozems, the

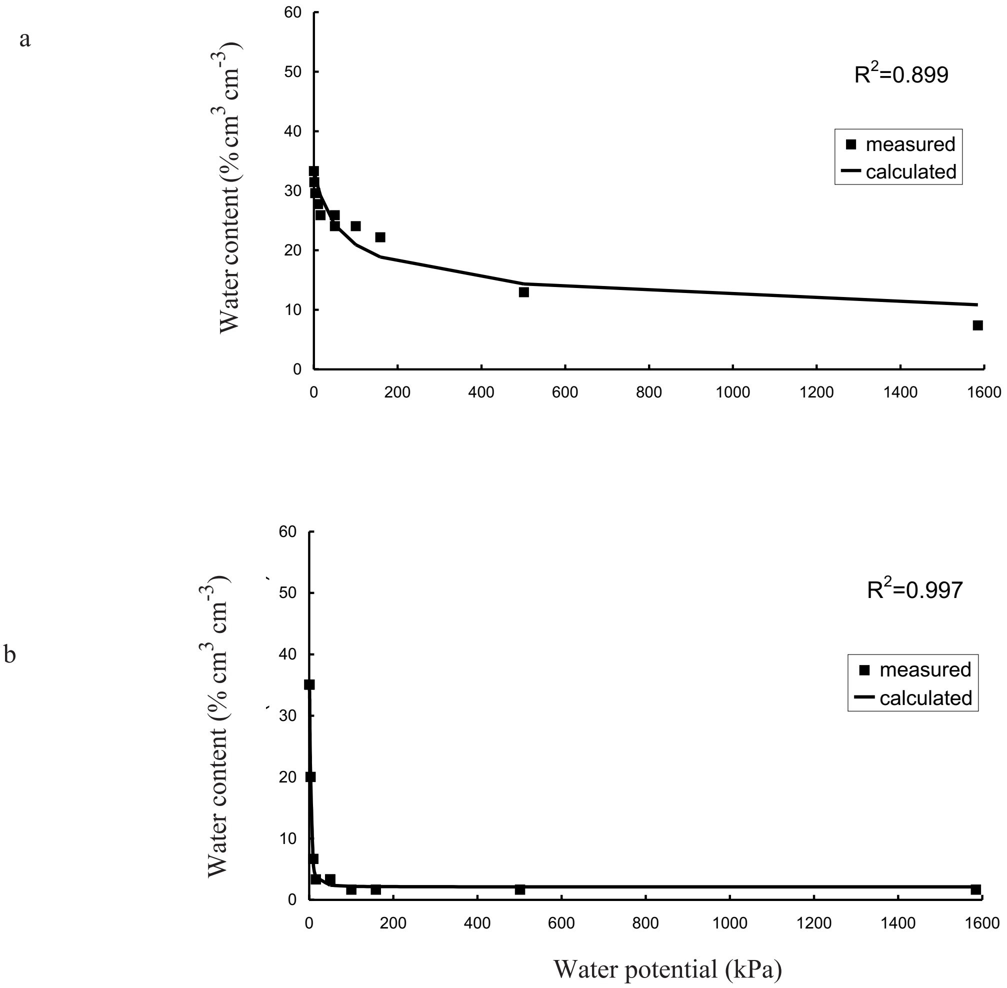


Fig. 2. Correlation between measured and calculated values of water retention content for Gleysols: a) the worst and b) the best.

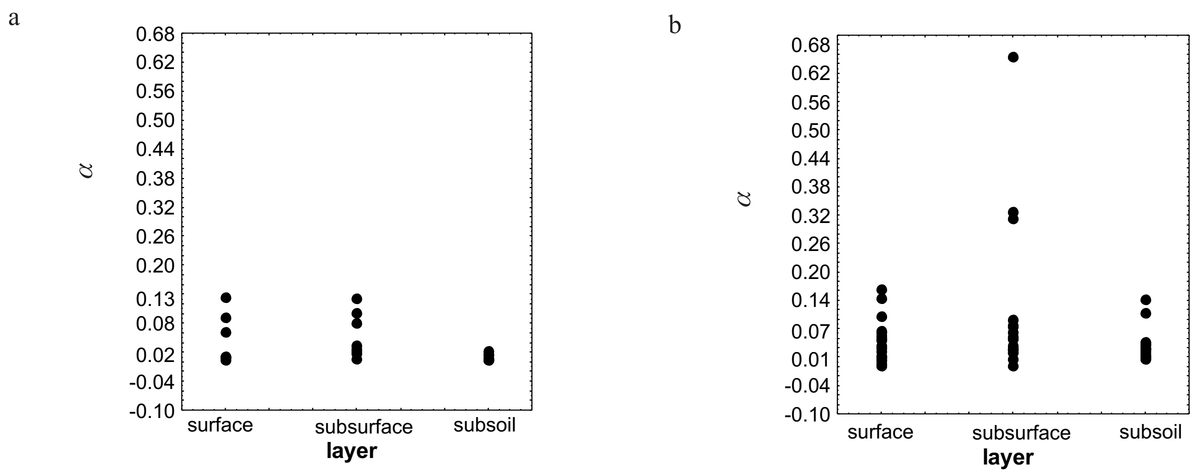


Fig. 3. Values of α for three investigated layers for: a) Phaeozems and b) Gleysols.

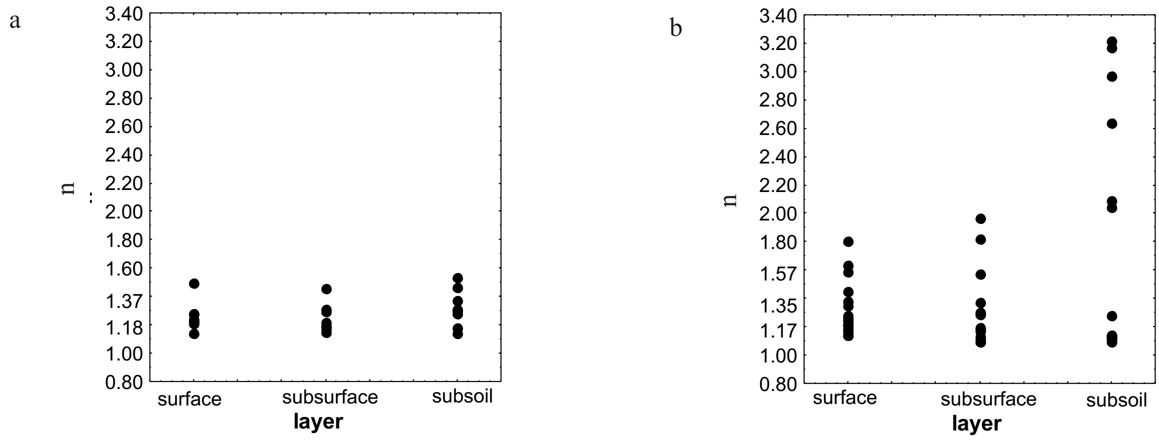


Fig. 4. Values of n for three investigated layers for: a) Phaeozems and b) Gleysols.

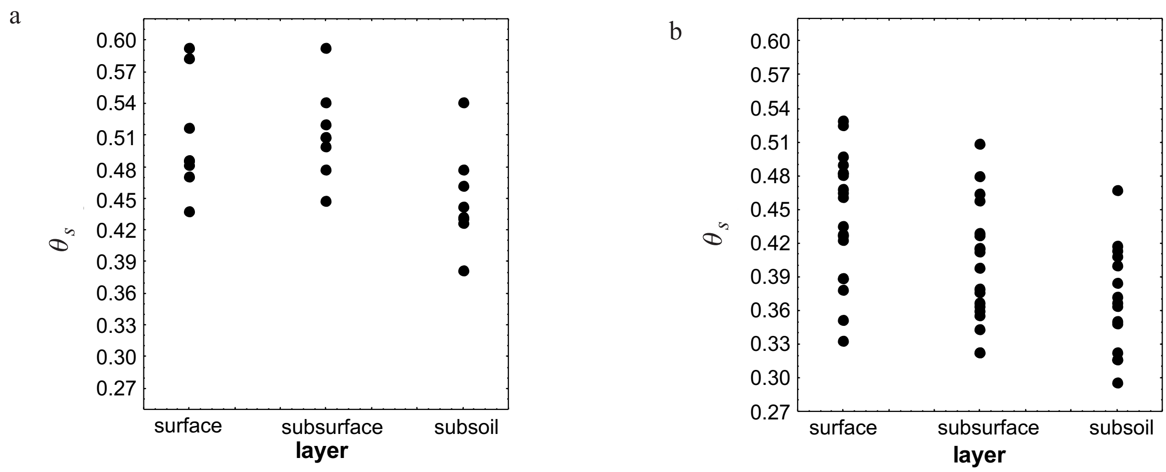


Fig. 5. Values of θ_s for three investigated layers for: a) Phaeozems and b) Gleysols.

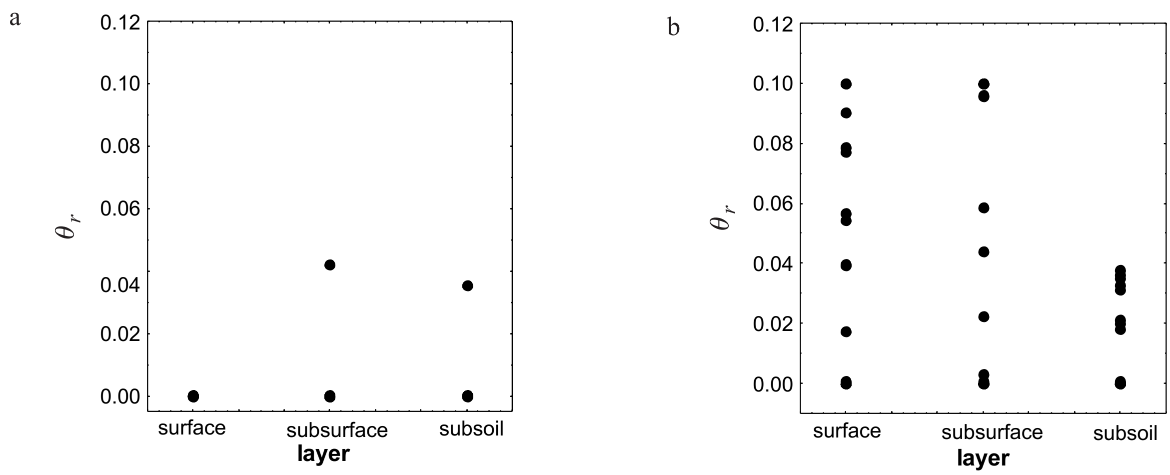


Fig. 6. Values of θ_r for three investigated layers for: a) Phaeozems and b) Gleysols.

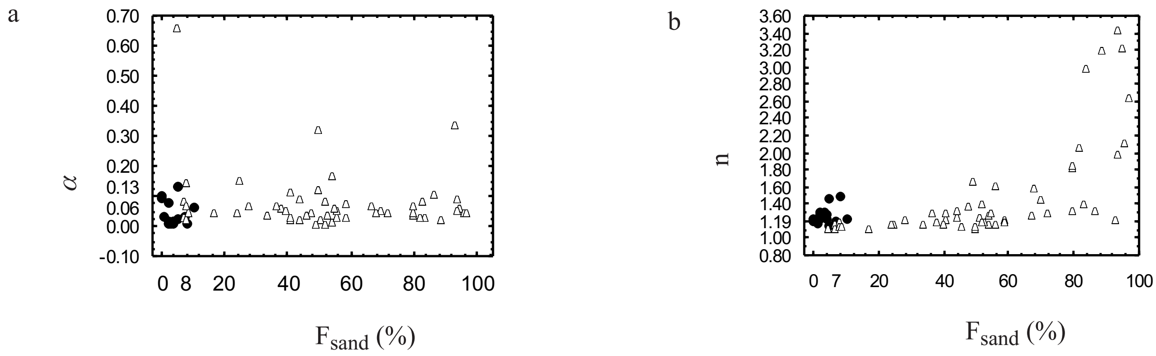


Fig. 7. Parameter versus sand content for: a) α and b) n.

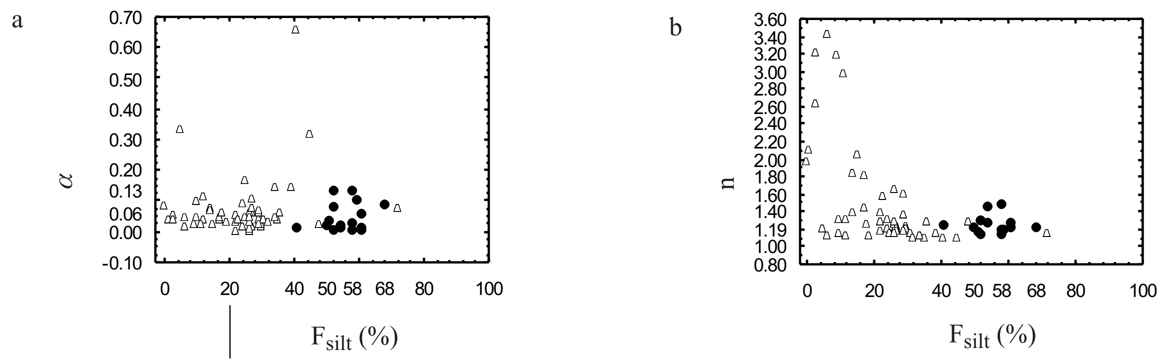


Fig. 8. Parameter versus silt content for: a) α and b) n.

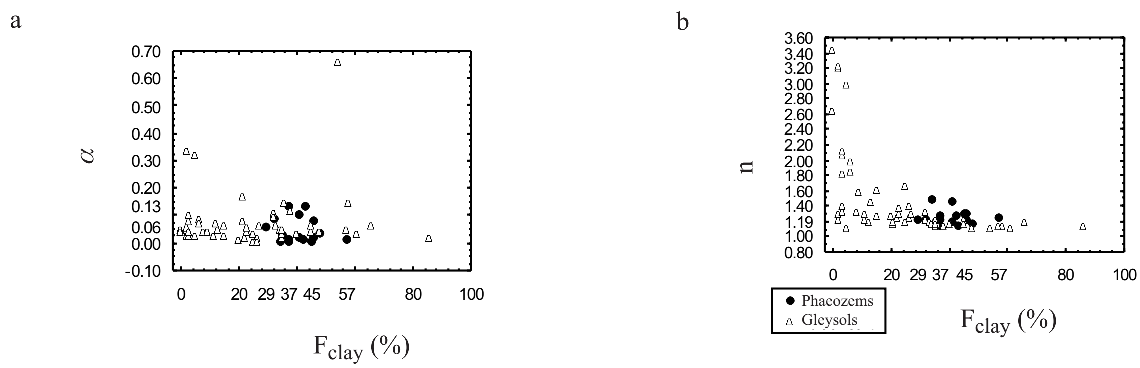


Fig. 9. Parameter versus clay content for: a) α and b) n.

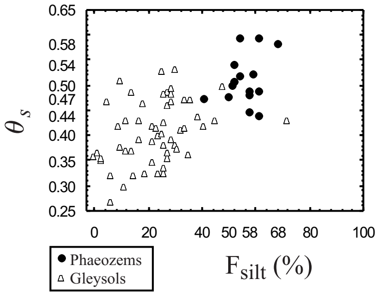


Fig. 10. θ_s parameter versus silt content.

value of parameter n is rather uniform. In Figs 8b and 9b, one can see that with the increase in silt and clay content, the value of parameter n decreases for Gleysols, which is consistent with the previous finding.

The silt content increases saturation moisture θ_s (Fig. 10) as it increases soil porosity.

CONCLUSIONS

1. No evident dependences between van Genuchten's α, n, θ_s, θ_r parameters of the retention curve equation and soils' layers were noted. However, for subsoil layers of Gleysols, the differences of parameter n were significant and varied from 1.17 to 3.41.

2. For Phaeozems, due to similar genesis and non-varying properties of soil solid phase, the dependences between van Genuchten's α, n, θ_s, θ_r parameters and physical-chemical properties were not observed.

3. The soil solid phase parameters of Phaeozems and Gleysols did not influence parameter α. However, soils Nos 16, 22, 43 differed more in their granulometric composition, which implies a significantly higher value of parameter α.

4. Parameter n increases significantly with a sand content increase and decreases with an increase in silt and clay contents. Also, parameter θ_s increases with a silt content increase.

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