Shrinkage curves of monoliths from genetic horizons of Vertic Solonetz

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Abstract. Statistical cumulative distributions of indices for shrinkage curve of 324 monoliths from Vertisols and Vertic Solonetzes are created. Natric and vertic horizons have similar range of shrinkage indices, with that natric ones have higher values of pore volume weakly changed during water evaporation and lower bulk density at shrinkage limit.

1. Introduction
Vertic Solonetz (WRB-2014 (update 2015) [1]) is a particular soil group with a soil profile comprising diagnostic horizons and properties of both Solonetzes in the solum and Vertisols in the subsoil. The solum consists of two horizons: solonetzic-eluvial SEL (it is the index from Russian soil classification system [2]) and solonetzic horizon BSN (or ASN). In WRB [1] the analogous ones are albic material and natric horizon, respectively. In the middle part of the soil profile there are small slickensides from the depth of 40-70 cm and a vertic horizon is a bit deeper. Carbonate segregations and soluble salt accumulations are usually observed in the profile.

Swelling during soil moistening and shrinkage after soil drying are distinctive features of both soil groups: Vertisols and Solonetz. There are many references about shrink-swell phenomena in Vertisols [3-7] and a few about Solonetz [8]. Two soil groups have both similar and specific properties, but possible dissimilarity of physical properties of natric and vertic horizons have not been discussed. There are different models for soil shrinkage [9-11]. They are useful for comparison of shrinkage curves of monoliths from different genetic horizons of Vertisols and Vertic Solonetz.

2. Objects and methods
324 monoliths from different genetic horizons of 26 soil profiles Pellic Vertisols (Stagnic) with variable content of soluble salts, exchangeable sodium and carbonates, Vertic Solonetz (Clayic), Haplic Solonetz (Albic, Loamic, Cutanic, Differentic), Vertic Stagnosols (Clayic), Vertic Chernozems (Clayic) were studied. Monoliths were collected from soils located at the Oka-Don Lowland (Panino District, Voronezh Region), at the northern slopes of Kalach Upland (Kamennaya Steppe, Talovaya District, Voronezh Region), at the Volga Upland (Penza, Tambov, Samara Regions), at the Volga-Akhtuba Floodplain (Astrakhan Region), at the Yankul Depression (Stavropol Region), at the marine embedded plain at the Kerch Peninsular.

Soil bulk density was determined in the field conditions by special auger with volume of cutting cored cylinder 212 cm³ (diameter 8.21 cm, height 4.00 cm) in five replications. Formation sampling was carried out at the period of relatively strong natural soil moistening when cracks were absent.
High value of initial soil moisture allows determination of shrinkage curves with two or three segments: linear range of volume decreasing during water content decreasing (normal shrinkage), transitional segment of shrinkage curve and shrinkage limit after drying.

Shrinkage curve of a monolith was determined in the laboratory by slow drying in closed small carton and daily measuring of sample weight (instrumental error 0.01 g) and geometric parameters of cylindrical monolith (calipers with vernier error 0.1 mm). Diameter was measured for 6 positions turning at 30°, height - for 4 positions. Monolith volume was calculated using mean values of diameter and height, water content - using converse curve of weight loss after final drying at 105°C.

Shrinkage curves were created in two forms: (1) bulk density as a function of moisture; (2) void ratio as a function of moisture ratio. Void ratio (e) is a ratio of pore volume to solid phase volume. Moisture ratio (Θ) is a ratio of water volume to solid phase volume [9].

Shrinkage curve was characterized by several indices: (1) bulk density, moisture, void (e) and moisture (Θ) ratios of initial monolith after sampling; (2) coefficients (a, b) of linear regression e = a + b Θ for segment of normal shrinkage; (3) void ratio e(Θ=0.8) at Θ=0.8 calculated by linear regression; (4) value e air(0.8) as a ratio of pore volume filled by air to solid phase volume at moisture ratio Θ=0.8 that characterizes approximately upper quarter of normal shrinkage range, e air(0.8) = {e(Θ=0.8)} – 0.8; (5) bulk density and void ratio e(Θ=0) in dry state (Θ=0); (6) moisture ratio Θ shr for beginning of shrinkage limit calculated by using inverse relationship Θ = a’ + b’ e at the value e(Θ=0).

All indices with their statistics were collected in data base. Monoliths were grouped using soil names and types of soil horizons. Empirical statistical cumulative distributions of indices were created for three groups of soil horizons: 1 - upper horizons without eluvial, solonetzic properties and slickensides; 2 - natric horizons and solonetze subhorizons (existence of clay cutans on aggregate faces in combination with exchangeable sodium percentage more than 5%) without slickensides; 3 - middle and bottom horizons with slickensides. Calculations were carried out in Excel.

3. Results and discussion

Profile distribution of bulk density at natural high moisture in Vertic Solonetz from different areas is not uniform. Subsoil horizons with slickensides have pretty narrow variable range of bulk density at high-moistened state: from 1.30-1.35 to 1.40-1.48 g cm⁻³. Opposite, natric horizons have a wide range of bulk density values both within one soil profile and in summation of several profiles. Total variation range of bulk density for natric horizons is from 1.0 to 1.5 g cm⁻³ at moisture 28-40% (w).

All horizons from Vertic Solonetz and Vertisols have shrinkage in evidence after drying. Examples of shrinkage curves for 4 horizons of Vertic Solonetz (profile V-920, Kamennaya Steppe) are represented at figure 1. Bulk density of monoliths in dry state increased up to near upper possible limit about 1.85-1.95 g cm⁻³ for horizons with slickensides. Bulk density of dry monoliths from natric horizons is also high, but it does not exceed 1.65-1.8 g cm⁻³.

Statistical cumulative distribution of void ratio e(Θ=0) at the shrinkage limit for natric horizons skews toward higher values as compared with one for vertic horizons. Although the tails of both distributions at the percentiles less than 10% and more than 95% are similar (figure 2 A). Mode of e(Θ=0) for natric horizons (0.61) is 1.3 times more than mode of e(Θ=0) for vertic horizons (0.47).

Linear segment of normal shrinkage for vertic horizons is near the line of equal values of e and Θ (figure 1 B). Value of e air(0.8) characterized pores with air varies in 80% from 0 to 0.2 with mode 0.11 and maximum 0.45 (figure 2 B). Value of e air(0.8) for natric horizons varies basically from 0.09 to 0.45 with mode 0.24 and maximum 0.62.

These results are arguments to conclude that natric horizons have a more complex structural state than that for vertic horizons. This structural state in natric horizons is maintained by the volume frame of clay cutan rete (or net) on all the structural surfaces that conserves part of the pore space without full collapse of the structure after shrinkage limit.
Figure 1. Monolith bulk density - weight moisture relationship (A) and void ratio - moisture ratio relationship (B) for 4 horizons: Nudinatric Vertic Stagnic Protosalic Solonetz (Clayic, Columnic, Cutanic, Humic, Hypernatic): 1, 2 - natic horizon (depth of 2-6 and 12-16 cm); 3 - dark humus solonetzic quasigleyic horizon (28-32 cm); 4 - vertic quasigleyic carbonate horizon (70-74 cm).

Vertic horizons have the lowest values of intercept in linear regression for normal shrinkage segment and, vice versa, the highest values of regression slope (coefficient "b") (figure 3 A). Relationship for natic horizon is inverse: the higher values of intercept and the lower values of slope. Therefore, natic horizons have more pores which volume changes disproportionately to water volume than vertic horizons. Whilst, pore volume change in vertic horizons approximately corresponds to the water volume change during soil drying.

But then, relative skew of cumulative distributions of coefficient "b" for both horizon groups is small (0.06-0.09) compared with total variability range (from 0.46 to 0.98 for natic and from 0.57 to 1.07 for vertic horizons) and similar amplitude (about 0.5). It means that the difference of the structural state of natic and vertic horizons on the normal shrinkage stage is not large. There is only a weak trend.

Several forms of shrinkage curves are known [9-11]. The form of relationship void ratio - moisture ratio for Vertisols is a broken curve with two linear segments: the first one in the range of the high water content - normal shrinkage, the second one is a pretty horizontal after shrinkage limit. Sometimes there is a smoothed transition between two segments instead of their strong conjunction [10,11]. Shrinkage curves for studied vertic horizons of clay soils at the East-European Plain have a form like Vertisols from other regions of the world.
Solonetzes with loamy texture and without vertic properties through the whole soil profile have weakly developed shrink-swell behavior. Their surface solonetzic-eluvial horizons SEL hardly change volume within a full range of moistening.

**Figure 3.** Empirical statistical cumulative distributions of coefficients "b" (A, 1-3) and "a" (A, 4-6) linear regression e = a + b Θ for normal shrinkage segment (A) and moisture ratio Θ_{shr} for beginning of shrinkage limit (B) for three groups of soil horizons: 1, 4, 7 - upper horizons without eluvial, solonetzic properties and slickensides; 2, 5, 8 - natric horizons and solonetzic subhorizons; 3, 6, 9 - horizons with slickensides.

Consequently, natric horizons from the solum and vertic horizons from the subsoil in Vertic Solonetz have similar physical properties that limit the usage of these soils, on the one hand, and there is a trend in shrinkage indices and bulk density between these horizons, on the another. Possible reason is the following: natric horizons have a volume frame of clay cutan rete on all the structural surfaces, and vertic horizons – an ordered arrangement of plate clay particles due to strong vertical and lateral stresses during swelling and a local shear strain.

4. Conclusions
Vertic horizons from subsoil of Vertisols, Vertic Solonetz and other Vertic soils have the most compact status at the shrinkage limit and a well expressed linear segment of normal shrinkage at the high soil water content.

A form of shrinkage curve for studied vertic horizons from soils at the East-European Plain coincides qualitatively with that for clay shrink-swell soils (Vertisols) at the other regions of the world.

Solonetzic clay horizons (or natric horizon in WRB [1]) formed in the soil profile of Vertic Solonetz have approximately similar variation range of shrinkage indices as compared with vertic horizons. With that, natric ones have higher values of pore volume weakly changed during water evaporation, lower bulk density at the shrinkage limit and a more gentle linear segment of normal shrinkage. It means that a structural arrangement of the natric horizon provides a conservation part of the pore space without full collapse of the structure after shrinkage limit. Possible reason is the volume frame of clay cutan rete on all the structural surfaces in the natric horizon and an ordered arrangement of plate clay particles due to strong vertical and lateral stresses during swelling and local shear strain in vertic horizon.

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