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DEGRADATION, REHABILITATION, AND CONSERVATION OF SOILS

Physical Properties of Urban Soils in Rostov Agglomeration[1]

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Abstract—Transformation of particle-size composition, structure, and density of soils upon urbopedogenesis is considered for Rostov agglomeration. Various soils are compared by horizons. It is found that the share of sand fractions increases in upper and middle horizons of migration–segregation chernozems (Calcic Chernozem (Hyperhumic, Loamic)), above all, at the expense of particles of 0.05—0.001 mm in size; with the coarse medium sand fraction 1—0.25 mm being diagnostic for urbopedogenesis. The reason is the introduction of sandy particles upon urban construction, arranging water conduits and other utility lines, as well as the use of icing-control sandy mixtures. The Dolgov-Bakhtin schedule appears to be the most appropriate for assessing the structure of urban soils. Dry sieving testified to the decreasing amount of agriculturally valuable aggregates in all compared pairs of horizons in the sequence of urban soils: under forest vegetation → under steppe vegetation → in the buried massif of urbosoils. The water stability of aggregates decreases in the sequence: soils under steppe vegetation → buried horizons of urbosoils → soils under forest vegetation. The following sequence of urbic horizons (UR and RAT) shows a decrease in the share of agriculturally valuable fractions and an increase in their water stability: heavy-textured UR → light-textured UR → RAT. The density of natural soils varies insignificantly within the city territory, with its urbostratified soils (Calcic Chernozem Novic (Technic Loamic) in residential areas often manifesting the maximal density.

Keywords: urbostratozem (Urbic Technosol (Mollic Loamic)), migration-segregation chernozem (Calcic Chernozem (Hyperhumic, Loamic)), particle-size distribution, soil structure, density

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INTRODUCTION

Physical properties of soils are an important fertility-controlling parameter, providing the base for the sustainable land use under urban conditions; however, they attract insufficient attention in present-day investigations [1, 21, 25]. A lot of analyses of physical properties of urban soils are performed as supplementary to the assessment of chemical pollution in soils, while the transformation of physical properties proper being disregarded [14, 23, 24, 30]. Craul [19, 20] and Grubler [22] were among the first to summarize information on physical properties of urban soils; they noted the degradation of structure, increasing density, hindered aeration and filtration in soils.

The particle-size distribution under urban conditions is dually transformed: on one hand, it may result from the purposeful alteration aimed at achieving certain physical properties of soils, e.g., upon arrangement of lawn constructozems [5]; on the other hand, it may result from occasional impacts, e.g., sand introduction upon urban construction, laying water pipelines and other service lines, application of icing-control sand mixtures [14].

In the opinion of a number of authors [20, 25], the soils in cities are compacted due to:

1. partial structural disturbance;

2. low content of humus, which is a structure-forming agent;

3. urban soils with a low content of organic substance are characterized by a low number of microorganisms, which favor structure arrangement in soils by raising its porosity;

4. “heat islands” in cities reduce the number of freezing-thawing cycles in soils, which also prevents the formation of stable structure;

5. mechanical impact compacts the soils considerably, in the wet state, in particular.

Thus, the available data in this sphere of urban soil science attest to the ongoing stage of developing ideas about the principal regularities of urban soils patterns and properties. Therefore, it appears necessary to assess physical properties at the horizon level; to consider the possible subdivision of urbic horizons into groups according to particle-size distribution for their statistical processing and to consider the validity of comparing their physical properties with those of undisturbed chernozems’ horizons.

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OBJECTS AND METHODS

The research is aimed at the study of specific physical properties of soils in the Rostov-on-Don agglomeration under the conditions of urban pedogenesis and at the assessment of possible interpretation of data on particle-size distribution and structural state for understanding the transformation degree of urban soils. The soils of different transformation level were the object of study, including urbostratozems and replantozems (Urbic Technosol (Loamic, Mollic)), urbic stratified chernozems (Calcic Chernozem (Loamic, Novic, Technic)) and migration-segregation chernozems (Calcic Chernozem (Loamic, Hyperhumic)) under the forest and steppe vegetation of recreational zones. Note that the bulk of Rostov-on-Don and Aksai area as well as the territories of adjacent settlements are situated within the Azov Plain watersheds and on gentle slopes of terraces on the right bank of the Don River. The sampling included the profiles at the watersheds composed of marine Neogene deposits and covered by thick (up to 20 m) Quaternary loess-like loams [13]. A total of 20 profiles have been studied; and the statistical analysis included the data on 153 horizons.

The changes in particle-size distribution were analyzed by the sedimentation method proposed by Kachinskii using 4% sodium pyrophosphate as a dispersing agent (GOST 12536-79); the structural status was assessed by soil sieving in dry and wet condition according to the Savvinov method [3, 18], and the density was measured by the cutting ring method (GOST 5180-84). Structural status was evaluated by various schedules developed in Russia, i.e., by Dolgov and Bakhtin, Kuznetsova, and Agrophysical Research Institute (API criterion) [18].

The particle-size distribution in humus horizons was compared among the groups of native chernozems in recreational zone (AU, AJ, BCA) and chernozems buried under the urban technogenic deposits ([AU], [AJ], [BCA]). To analyze the regularities in grain-size distribution that occurred in urban soils proper, the urbic horizons were subdivided into two groups, conventionally designated as heavy-textured (with the content of physical sand less than 60% (heavy UR)) and light-textured (with the content of physical sand above 60% (light UR)). This subdivision is necessary because, in our opinion, the heavy-textured urbic horizons are closer genetically to native soils as they are formed predominantly of the natural soil substances. Light-textured horizons, on the contrary, originate mainly from the introduced non-soil material.

RESULTS AND DISCUSSION

Comparing the humus-accumulative AU and AJ horizons with their buried analogues, we may note that the sum of coarse and medium sand fractions (1–0.25 mm) differs in these two groups of samples. This value is higher in the buried natural horizons of urban chernozems than in recreational zone chernozems, which permits us to conclude about the noticeable part of urbopedogenesis in soil transformation. The share of 1–0.25 mm fraction is higher, above all, due to the application of gravel-sandy mixture (3–0.14 mm in size) upon engineering construction [21], and also due to the application of icing-control sand mixture in winter. It appears important that this trend is typical not only for AU and AJ horizons but also for other groups compared, i.e., BCA–[BCA] and C–[C]. However, only 31.6% of the total sampling from the buried [C] horizon shows the statistically reliable higher values in the content of 1–0.25 mm fraction as compared to native soils. A more detailed study of what profiles proper manifest the elevated amount of sand fraction in the [C] horizon proved that all of them are confined to diggings for urban water conduits, where pipes are usually backfilled with sand. In the C horizon of urban soils, the content of sand particles (1–0.25 mm) does not exceed 0.2% (whereas they are absent in loess-like loam at the CisAzov Plain). An increase in the content of this fraction in surface and medium horizons results from anthropogenic pedoturbations and, probably, from the penetration of surface material anthropogenically enriched in sandy fractions along fissures, which are typical of migration-segregation chernozems (Calcic Chernozem (Loamic, Hyperhumic)) upon soil drying up in summer. Taking into consideration that grains of 1–0.25 mm in size are absent in migration–segregation chernozems (Calcic Chernozem (Loamic, Hyperhumic, Loamic)) [4, 9], this fraction identified in surface and medium horizons of urban soils appears to be diagnostic; i.e., its content points to the degree of urbopedogenesis development. This fraction was found even in natural soils in the city, which proves that the soil texture becomes lighter in all soils within the urban agglomeration (Table 1).

Reliably different average values according to the Student's criterion between the urban soil horizons and native chernozems by the total content of physical sand or physical clay fractions may serve as an index of general transformation of particle-size distribution. According to this index, only the C and [C] horizons show a high value of Student's criterion, i.e., 2.9, with the standard value being equal to 2.0 (for $n = 35$; $P = 0.05$). However, the comparison of horizon pairs AU, AJ–[AU], [AJ] in the chernozems in recreational territories and those buried in urbostratified soils by the content of other fractions testifies to the reliable difference (with the significance level <0.05) for the coarse silt fraction (0.05–0.01 mm); whereas the comparison between C and [C] horizons shows the reliable difference for the medium silt (0.01–0.005 mm), fine silt (0.005–0.001 mm) and fine sand (0.25–0.05 mm) fractions. Note that the content of silt fractions decreases on average in the buried horizons. The content of clay fraction (<0.001 mm) in urban soils changes

Table 1. Average particle-size distribution in different horizons of chernozems and urbostratified soils in Rostov agglomeration (n = 15–30).

Horizon	Size (mm) and content (%) of fractions							
	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01	>0.01
AU, J	0.7	16.9	28.4	9.3	15.5	29.2	54.0	46.0
[AU, J]*	3.7	21.7	22.3	7.9	14.6	29.9	52.3	47.7
BCA	0.3	17.1	24.5	9.5	16.8	31.8	58.0	42.0
[BCA]*	2.5	20.3	21.4	7.3	14.9	33.8	55.9	44.1
C	0.2	11.6	25.3	10.3	19.7	33.0	62.9	37.1
[C]*	1.8	22.6	23.7	6.8	14.8	30.3	51.9	48.1
URT	4.8	23.1	18.6	9.5	14.3	29.7	53.5	46.5
URL	19.2	37.2	15.6	3.2	7.0	17.7	27.9	72.1

* Buried horizons are shown in brackets [2].

unevenly as compared to their native analogues: its amount rises somewhat in the [AU], [AJ], and [BCA] horizons, and it decreases in the [C] horizon.

The comparison of particle-size distribution in different urbic horizons with the natural horizons of chernozems in recreational areas attests to an increase in the value of total transformation index in the group of heavy-textured urbic horizons (URT) in the following sequence: AU, AJ → BCA→ C; with the reliable difference (P = 0.05) being manifested only in the URT–C pair. However, if to consider the Student's criterion value by fractions, one can see that the URT horizon manifests affinity to the AU, and AJ horizons, showing the reliable difference with the content of all physical-sand fractions; the more so, to the BCA horizon, since in the latter case the difference is reliable only for two fractions, i.e., 1–0.25 and 0.05–0.01 mm. This fact supports the assumption about surface and medium chernozem horizons taking a large part in the formation of heavy urbohorizons, because just these horizons provide the basis for the URT horizon development. This is caused by cutting the upper layer upon building-up procedures and its subsequent use for replanting and backfilling grass plots. The URT-C pair manifests the reliable difference in the content of all fractions with the confidence probability level of 0.95 except for 0.01–0.005 and <0.001 mm fractions. In all analyzed pairs of horizons, i.e., URt-AU, AJ; URT-BCA; URT-C the content of sandy fractions (1–0.25; 0.25–0.05) rises in the URT horizon; the share of coarse silt fraction (0.05–0.01) falls, with the medium silt fraction being the most stable (0.01–0.005 mm).

The sampling of light-textured urbic horizons (URL) differs reliably from that of the native horizons for all particle-size fractions. The index of total transformation is inversely distributed to that in the URT horizon sampling; and it decreases in the set: AU, AJ → BCA → C. The general trend is preserved of the increasing content of sandy fractions and of decreasing the share of silt and clay particles.

The soil structure is the index controlling a lot of important soil properties and processes, i.e., air-water properties, thermal regime, microbiological processes, and carbon emission [28, 29]. In a city, structured soils contribute to the ecological sustainability, as they resist degradation and they are able to absorb and transform various kinds of pollutants more intensely [7, 8, 13, 16, 17]. The analysis of structural status of soils in Rostov agglomeration is presented in Table 2. For the structural status assessment, the soils were conventionally subdivided into 3 groups: (1) migration–segregation chernozems (Calcic Chernozems (Loamic, Hyperhumic)) under forest; (2) migration–segregation chernozems (Calcic Chernozems (Loamic, Hyperhumic)) under steppe; and (3) urbostratozems (Urbic Technosols (Loamic, Mollic)) and urbostratified chernozems (Calcic Chernozems (Loamic, Novic, Technic, Loamic)). In the third group, the urbic horizons were considered by the URL and URT groups as well as the reclamation compost-humus horizon (RAT).

Note that it appears difficult to study the structural status of urban soils using the routine methods [1]. The errors may occur due to the presence of stony fraction, which may be not always extracted completely upon the analysis. Different evaluation schedules were applied for solving this problem. As is seen from the data obtained, the water stability criterion API cannot be used for the evaluation schedule, because it provides too wide intervals, so that all studied groups of horizons fit one grade. The estimation of structural water stability according to Kuznetsova method [18] appears to give overestimated results, since the majority of horizons are graded as those with good and perfect structure, which is not true judging by their morphology. Therefore, the evaluation schedule proposed by Dolgov and Bakhtin [18] seems to be the most suitable according to the gradations limits; it

Table 2. Assessment of the structural status of chernozem and urbostratified soil horizons in different land-use zones of Rostov agglomeration

Group	Horizon	Assessment of structural state according to the Dolgov-Bakhtin schedule				API criterion		Assessment by Kuznetsova's criterion	
		air-dry		water-stable					
		%	Score	%	score	%	score	%	score
1	AU, AJ	66.1	Good	61.5	Good	179.4	Good	61.5	Excellent
2	AU, AJ	57.9	Good	66.6	Good	223.8	Good	66.6	Excellent
3	[AU, AJ]	51.7	Satisfactory	62.1	Good	261.5	Good	62.1	Excellent
1	BCA	60.6	Good	54.1	Satisfactory	193.7	Good	54.1	Good
2	BCA	53.9	Satisfactory	59.1	Satisfactory	241.7	Good	59.1	Good
3	[BCA]	48.1	Satisfactory	59.4	Satisfactory	287.1	Good	59.4	Good
1	C	61.0	Good	33.9	unsatisfactory	113.0	Good	33.9	Satisfactory
2	C	49.0	Satisfactory	38.8	unsatisfactory	221.1	Good	38.8	Satisfactory
3	[C]	46.9	Satisfactory	56.9	Satisfactory	271.0	Good	56.9	Good
UR heavy		50.9	Satisfactory	51.4	Satisfactory	237.6	Good	51.4	Good
UR light		47.5	Satisfactory	57.8	Satisfactory	247.8	Good	57.8	Good
RAT		40.4	Satisfactory	65.7	Good	297.0	Good	65.7	Excellent

RAT means reclaimed compost-humus horizons.

also permits assessing the status of dry soil structure and its quality by the water-stability index separately.

The comparison of structural status of air-dry aggregates in natural horizons of all soil groups showed that the values of structure coefficient decrease in the sequence: soils under forest - soils under the steppe vegetation - buried urbostratozem horizons. In our opinion, this regularity is related to the specific ingress, accumulation and composition of organic matter in soils under the forest. According to the studies, in forest zone under the planted wood, the content of humus increases and the degree of humification rises in the surface Asod horizon, because the bulk of organic litter under trees comes to the surface, whereas in steppe of great importance is the root system of herbs [6]. This fact influences the soil structure: even visual study of morphological properties of soils reveals the prevalence of granular structural units in the AU horizon of chernozems under the tree vegetation.

Determination of aggregate water stability has led to a somewhat unexpected result. In the subsoil, the maximal water stability is observed in chernozems under grass vegetation. This is quite expectable, since the fallow soils under herbs manifest a stable structure typical for a steppe, with high water stability being its specific feature. Urbic stratified chernozems (Calcic Chernozems (Loamic, Novic, Technic)) display a somewhat lower values of water stability index; however they are higher than those in chernozems under trees. This is caused by the fact that with changing vegetation and microclimate under the tree canopy, microbial cenosis also changes, the share of humic acids decreases, and the share of fulvic acids rises [6]. Al these changes are accompanied by the transforming aggregate quality decreasing the water stability of the structure.

For anthropogenically transformed horizons, a total amount of agriculturally valuable fractions decreases and, on the contrary, their water stability rises in the series: heavy UR → light UR → RAT.

Consistency is the next aspect of the structural arrangement of soil solids, with the (bulk) density being its central characteristics. A number of works point to the rising density of urbostratozems to 1.4–1.6 g/cm^3, mainly due to trampling them down and introducing stony fraction [11, 12, 15, 16, 24, 27]. A high bulk density hampers growth and development of plants, resulting in top drying of trees [10].

Chernozems under the grass (fallow sites) are characterized by the typical for zonal soils values of density (Table 3). Its average value for this soil group is equal to 1.1 g/cm^3 in the layer 0–25, being lower in general in the subsoil (1.06 g/cm^3).Chernozems are denser under trees, and this index varies insignificantly along the profile, being equal on average to 1.23 g/cm^3. This fact may result from the loosening effect of tree root systems, since no trenching plowing was done before tree planting. The density of the buried humus-accumulative horizons [AU], [AJ] in urbostratified chernozems (Calcic Chernozems (Loamic, Novic, Technic)) constitutes 1.5 g/cm^3 on average, which usually fits the BCA horizon in native chernozems. This is probably caused by the compacting effect of the overlying horizons, with the physical pre-burial overcompaction of [AU] and [AJ] horizons being not excluded.

Table 3. Density of chernozems and urbostratified soils in urban areas of Rostov agglomeration

Soils, land-use zone	Horizon	Bulk density g/cm^3, $M \pm m$	Difference from the arable analogue	Increment of the equilibrium density of soil, % of initial/degradation degree
Migration-segregation chernozems (Calcic Chernozems (Loamic, Hyperhumic)), fallow	AU	1.13 ± 0.05	0	0/0
Migration-segregation chernozems (Calcic Chernozems (Loamic, Hyperhumic)) of forest-park zones	AU, AJ	1.23 ± 0.02	+0.10	8.85/0
Urbostratified chernozems (Calcic Chernozems (Loamic, Novic, Technic))	[AU] [AJ]	1.5 ± 0.01	+0.37	32.74/3
Urbostratified chernozems (replantozems) (Calcic Chernozems (Loamic, Novic, Technic)). Residential area	RAT	1.65 ± 0.09	+0.52	46.02/4
$LSD_{0.05}$			0.31	

The degradation degree is estimated as 3 by the 4-rank schedule. The compost-humus horizons of replantozems in the residential area show the highest density, because these soils are confined to the districts built up with multistory buildings, where the surface horizons bear a high recreational load, which causes the regular anthropogenic overcompaction. The degradation level of the studied replantozems is equal to 4 according to this parameter. Chernozems of the forest-park territories tend to increase their density in the AU and AJ horizons as compared to chernozems of abandoned fields. The density in the buried horizons [AU] and [AJ] of urbostratified chernozems (Calcic Chernozems (Loamic, Novic, Technic)) is statistically significantly higher than that in the old-arable soil.

CONCLUSIONS

(1) Appearance of coarse- and medium-grained sand particles (1–0.25 mm) in the surface and middle horizons of chernozems may be regarded as a diagnostic feature of urbopedogenesis, because these fractions are absent in native migration-segregation chernozems (Calcic Chernozems (Loamic Hyperhumic)) at the watersheds in Rostov agglomeration. This fraction is found in all studied soils within the Rostov agglomeration. In general, the content of sandy fractions increases and that of silty particles decreases with the growing intensity of urbopedogenesis.

(2) BCA horizons most often form the basis for the heavy-textured urbic horizons in the Rostov agglomeration territory. Medium silt (0.01–0.005 mm) is the particle-size fraction, which is the least variable under urbopedogenic impact in these horizons.

(3) The Student's criterion exceeding the critical values for the studied sampling for the total content of physical clay (or physical sand) fraction between native soils and anthropogenic horizons may serve as an indicator of particle-size distribution transformation in the course of urbopedogenesis. This parameter differs radically in heavy- and light-textured urbic horizons. For the heavy-textured urbic horizons, their difference from the native horizons increases in the sequence: AU, AJ → BCA → C; and it decreases in the same sequence for the group of light-textured urbic horizons.

(4) The scheme proposed by Dolgov and Bakhtin appears to be the most appropriate for assessing the structure of urban soils. The sum of agriculturally valuable air-dry aggregates decreases in the set of soils: under forest vegetation → under steppe vegetation → buried horizons of urbosoils. The sum of water-stable aggregates decreases in the set of soils: under steppe vegetation → buried urbosoil horizons → under forest vegetation. For anthropogenic horizons, the total amount of agriculturally valuable fractions decreases, and the water stability increases in the sequence: heavy UR→ light UR → RAT.

(5) The density in chernozems (Calcic Chernozems (Loamic, Hyperhumic)) of recreational zones changes insignificantly; it is higher in urbostratified soils (Calcic Chernozems (Loamic, Novic, Technic)); soils of residential zones in cities have the highest density.

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