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PHYSICAL PROPERTIES OF URBAN SOILS

Aggregate Composition as Related to the Distribution of Different Forms of Carbon in Soils of Rostov Agglomeration

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Abstract—The aim of this work was to study the transformation of soil structure in the course of urban pedogenesis and to assess the relationship between the size of aggregates and the content of carbon of organic matter and of carbonates. We analyzed soils of Rostov agglomeration and compared the composition of aggregates in Calcic Chernozems and urbostratozems on buried chernozems (Urbic Technosols). We determined the aggregate composition by the Savvinov method and the carbon content on a TOC-L CPN Shimadzu spectrometer. Differences in the composition of aggregates of various genetic horizons were revealed by the Student criterion and the graphical analysis of the dependence of the percentage of structural fractions on the content of organic and inorganic carbon, smoothed by the least square method. It was found that the portion of air-dry fraction >10 mm in the urbic and buried horizons increased reliably by 30% or more as a result of a decrease in the portion of fractions 7–0.5 mm. Significant differences in the content of water-resistant fractions were observed only in the AU–[AU] pair horizons: the fraction of water-stable aggregates >3 and 2–1 mm decreased, and the contribution of aggregates 0.5–0.25 mm increased significantly in the buried horizon. This was probably related to the pre-burial urban dispersion of soil structure. The distribution of aggregates by fractions was not related to the content of organic and inorganic carbon. However, there were values of these kinds of carbon for each structural fraction, in which the intensity of structure formation decreased. It was manifested in a sharp decrease in the content of the fraction in the buried profiles relative to native ones.

Keywords: aggregate composition, Calcic Chernozems, Urbic Technosol, anthropogenic transformation, soil organic carbon

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INTRODUCTION

Intensive urbanization requires comprehensive study of urban pedogenesis and of the anthropogenic transformation of soils [15, 28]. The aggregate composition of soil is a result of a complicated system of diverse interactions. It determines the water-air and temperature soil regimes, affects the microbiological activity of soils, and ensures the availability of nutrients for plants [3, 21, 31, 32]. Urban pedogenesis is accompanied by a decrease in soil ability to perform its ecological functions, which primarily concerns the absorption and neutralization of pollutants of various kinds and the prevention of their migration to adjacent media and contaminating soils of farmlands in the suburbs [1, 12, 30]. Thus, the study of soil structure under transformation occurring in the course of pedogenesis is an urgent task of modern soil science.

The aim of this study is to compare the ratio between structural fractions in different horizons of Calcic Chernozems and Urbic Technosol on Chernozems in the Rostov agglomeration and to determine the role of carbon in structure-forming processes.

OBJECTS AND METHODS

The study was performed in Rostov agglomeration, which is the largest one in the south of Russia. The city of Rostov-on-Don is its administrative center. A larger part of Rostov-on-Don, Aksai, and adjacent urban settlements are located on the interfluves of the Azov Plain and on gentle slopes of terraces on the right bank of the Don River. We studied soils with different degrees of anthropogenic transformation: untransformed or slightly transformed chernozems (Calcic Chernozems (Loamic, Pachic) of urban recreational zones and urbostratozems on chernozems (Urban Technosols) [19, 26, 34].

The studied soil types were characterized by soil pits located on watersheds with a thick (to 20 m) layer of Quaternary loess-like loam on marine Neogene sediments [6, 9, 10]. In total, 35 soil pits were studied, and the statistical analysis included data on 196 horizons.

According to the methodological approach, the sampling included dark-humus soil horizon (AU), carbonate-accumulative horizon (BCA), soil-forming rock (C), and their buried analogues ([AU], [BCA], and [C]), which were then compared. The urbic hori-

Table 1. The content of structural fractions in genetic horizons of soils of the Rostov agglomeration (dry sieving) ($M \pm m$ are given here and in the following tables, where M is the arithmetic mean, and m is the error of the mean, n = 33–52)

Horizon	Content of aggregate fractions, %; size of fractions, mm								
	>10	10–7	7–5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25
URh	37.9 ± 4.3	11.3 ± 2.2	10.3 ± 2.0	12.3 ± 2.3	4.7 ± 0.8	10.8 ± 2.8	5.3 ± 1.3	3.5 ± 0.9	3.9 ± 0.9
URl	31.3 ± 5.7	9.7 ± 1.8	9.9 ± 1.8	10.8 ± 2.1	4.7 ± 1.1	8.2 ± 2.0	6.3 ± 1.3	9.1 ± 5.4	10.0 ± 3.5
AU	18.3 ± 2.6	10.4 ± 0.8	12.0 ± 0.6	16.8 ± 1.1	7.8 ± 0.9	14.4 ± 1.3	9.1 ± 0.8	5.8 ± 0.6	5.4 ± 0.7
[AU]	35.0 ± 3.5	9.4 ± 1.5	8.9 ± 1.5	11.2 ± 1.9	5.6 ± 1.1	10.0 ± 2.8	7.7 ± 1.3	5.9 ± 1.1	6.3 ± 1.0
BCA	18.8 ± 3.5	12.8 ± 1.2	12.8 ± 1.1	15.3 ± 1.5	6.9 ± 0.6	12.6 ± 1.4	8.4 ± 0.7	5.9 ± 0.7	6.5 ± 0.9
[BCA]	30.6 ± 4.6	12.0 ± 1.1	9.9 ± 1.2	11.8 ± 1.7	6.4 ± 1.0	9.4 ± 1.8	7.1 ± 0.9	5.9 ± 0.9	6.9 ± 1.0
C	20.7 ± 3.7	11.0 ± 1.4	10.6 ± 1.2	12.6 ± 1.2	6.7 ± 0.9	12.1 ± 1.7	9.5 ± 1.4	7.7 ± 1.1	9.1 ± 2.6
[C]	32.8 ± 3.4	11.1 ± 1.8	9.0 ± 0.8	10.9 ± 1.1	6.4 ± 1.3	9.3 ± 1.9	8.0 ± 1.3	5.7 ± 1.2	6.8 ± 1.1

zons were grouped into two clusters according to the content of particles <0.01 mm: heavy-textured URh (40–60%) and coarse-textured URl (10–40%). This division is based on the genesis of urbic horizons: heavy horizons are formed of the material of natural chernozems, and coarse horizons are mainly composed of filled material (the content of particles <0.01 mm in native chernozems is 60–70%) [6, 7].

The structural status was determined by the Savvinov method: successive sieving of dry soil sample (dry sieving) and its sieving in water (wet sieving) on sieves with different mesh diameters [8].

Total (TC), inorganic (IC), and organic carbon (TOC) have been determined in the soil sample, using the TOC-L CPN Shimadzu carbon analyzer in the SSM-5000A auxiliary device for dry samples. The analysis is based on high-temperature catalytic combustion of the sample and subsequent detection of the released carbon dioxide. The analysis comprises two stages of sample combustion: at a temperature of 900°C (determination of the total carbon) and at 200°C with the addition of orthophosphoric acid (for inorganic carbon). Organic carbon was determined by subtraction of inorganic carbon from the total carbon [35].

The statistical analysis was based on the Student criterion to identify significant differences between the horizons in the content of structural fractions [14]. Since the regression analysis did not reveal the relationships between the studied parameters, we used the graphical analysis of the correlation between the content of particular structural fractions and of organic and inorganic carbon interpolated by the least square method in the STATISTICA program. This analysis enabled us to reveal changes in the relationships between soil structure and the content of organic and inorganic carbon.

RESULTS AND DISCUSSION

Table 1 presents the results of statistical processing of data on the aggregate composition (dry sieving) of particular genetic soil horizons in Rostov agglomeration. The urbic horizons are characterized by specific coarse angular blocky structure (>10 mm [18]), the portion of which is higher both in heavy (the Student criterion for compared pair URh–AU is 5.1 at $n = 69$; $P = 0.05$; $t_{cr} = 1.99$) and coarse-textured horizons (the Student criterion for compared pair URl–AU is 4.3 at $n = 64$; $P = 0.05$; $t_{cr} = 1.99$). The content of granular fractions (3–2 and 1–0.5 mm) in these horizons becomes lower, and that of fractions 0.5–0.25 and <0.25 mm increases in the URl and decreases in the URh horizons. The difference between the urbic and the dark-humus horizons of chernozem in the content of these structural units is also statistically significant.

The analysis of the structural composition of urban soils shows that direct correlations between the aggregate composition and the carbon content are not always recorded. For example, the organic carbon content in the urbic horizons is second only to that in the AU horizons, while the content of fraction >10 mm in the urbic horizons is significantly higher than in the AU, BCA, and C horizons. This is related to higher density of urbic horizons [6] as a result of an increased anthropogenic load on them. The data on the fraction <0.25 mm, the content of which is 2.6 times higher in the coarse-textured urbic horizons, explain the greater amount of organic carbon in these soils (Table 2).

Many authors point to the relationship between the organic carbon content and the structural status of soils [2, 4, 23, 27, 29]. An increase in the percentage of agronomically valuable water-stable fractions parallel to the organic carbon content has been revealed in some soils of Great Britain [33]. However, the data of a three-year-long experiment performed under alfalfa (*Medicago*) on the ordinary chernozem in Rostov oblast show that these correlations are seasonal and depend on weather conditions. The general correlation between the content of water-stable aggregates (WA) and the total amount of organic carbon is very slight or absent, while in autumn with cool and rainy weather, there is a direct dependence of WA on the humus con-

Table 2. The mean content of organic and inorganic carbon in genetic horizons of soils of the Rostov agglomeration and Student's *t*-test (t_{cr} = 2–2.04) for the compared pairs of horizons

Parameter	Horizon							
	AU	[AU]	BCA	[BCA]	C	[C]	URh	URl
n (sampling)	52		47		33		37	
TOC	3.01 ± 0.33	1.31 ± 0.11	0.75 ± 0.14	0.73 ± 0.09	0.29 ± 0.07	0.27 ± 0.03	1.97 ± 0.39	2.44 ± 0.25
Student's *t*-test	4.1		0.2		0.4		0.8	
IC	0.23 ± 0.12	0.23 ± 0.07	1.41 ± 0.21	1.27 ± 0.15	1.87 ± 0.13	1.48 ± 0.06	0.50 ± 0.11	0.59 ± 0.13
Student's t-test	0.9		0.8		3.5		0.6	

Table 3. Mean content of structural fractions in genetic horizons of soils of the Rostov agglomeration (wet sieving)

Group	Size of structural fraction (mm), content,%					
	>3	3–2	2–1	1–0.5	0.5–0.25	<0.25
URh	12.1 ± 3.7	3.6 ± 1.9	8.8 ± 1.8	11.3 ± 1.5	17.5 ± 3.6	46.7 ± 4.4
URl	15.2 ± 3.3	2.9 ± 1.7	8.7 ± 1.3	8.8 ± 1.1	22.8 ± 2.0	41.6 ± 4.1
AU	15.7 ± 3.2	4.5 ± 0.8	12.3 ± 1.5	14.1 ± 1.2	15.2 ± 1.9	38.2 ± 3.8
[AU]	7.3 ± 2.5	4.5 ± 1.9	9.4 ± 1.6	14.6 ± 2.1	21.9 ± 2.5	42.3 ± 3.2
BCA	4.6 ± 2.1	2.8 ± 1.6	8.5 ± 1.1	13.9 ± 2.5	19.4 ± 2.0	50.8 ± 3.3
[BCA]	3.1 ± 0.8	3.5 ± 1.9	9.5 ± 1.8	13.1 ± 2.6	20.2 ± 2.6	50.6 ± 3.3
C	2.9 ± 1.2	1.6 ± 1.4	5.5 ± 1.0	6.5 ± 1.5	14 ± 2.6	69.5 ± 3.1
[C]	2.6 ± 1.1	3.6 ± 1.6	9.1 ± 1.1	8.5 ± 1.4	16.4 ± 3.7	59.8 ± 3.8

tent (r = +0.512), which is related to changes in its composition [4].

Wet sieving (Table 3) shows better water stability of aggregates in urbic horizons as compared to those in the horizons of native and buried profiles and does not confirm the expected quality of structural units in urban soils. This is probably explained by the contamination of the surface horizons by aromatic hydrocarbons of petroleum products, which is very typical for urban soils, near streets with heavy traffic in particular [16, 17, 22, 24]. Organic substances of aromatic pollutants are mainly hydrophobic [25], and according to the newest concepts, hydrophobic–hydrophilic relations in soil play an important role in structure formation [20]. If amphiphilic organic substances attach their hydrophilic part to a mineral particle, and their hydrophobic part interacts with hydrophobic parts of another amphiphilic organic particle, the aggregate is resistant to the destructive effect of water [32].

The burial of chernozems under urbic layers also affects water stability of aggregates. The content of water-stable aggregates >3 and 2–1 mm in the group of AU horizons is significantly higher as compared to [AU] horizons (the Student criterion is 2.4 and 2, respectively, at n = 67; P = 0.05; and t_{cr} = 1.99), and the content of the fraction 0.5–0.25 mm is lower. In the middle and deep BCA–[BCA] and C–[C] horizons, significant differences in the status of water-stable fractions are not revealed.

Various types of regression analysis (linear, logarithmic, quadratic, and multiple) have not revealed any reliable dependences, and we cannot correlate the relationship of organic and inorganic carbon content with the aggregate composition of soils. The determination coefficient R^2 does not exceed 0.2, which points to a slight effect of carbon on the content of structural fractions.

It should be pointed out that under the conditions of urban pedogenesis, the regression model cannot describe the complicated relationships between the content of the structural fractions and carbon, which are well pronounced in natural soils [2, 4, 23, 27, 29, 33].

These relationships were visually assessed by a graphical analysis of the isopleths of the content of aggregate fractions on the phase plane with the coordinates of organic and inorganic carbon content in soil interpolated by the least square method (Fig. 1). This approach revealed a significant transformation of the correlations as a result of soil burial. The share of coarse angular blocky aggregates (>10 mm) increases parallel to the carbon content in the profile of native chernozem (Fig. 1a (I)) and contrary to it in the buried profile (Fig. 1a (II)). The content of this fraction in the latter profile is close to zero in a wide range of organic (1.5–3%) and inorganic (1.4–2%) carbon

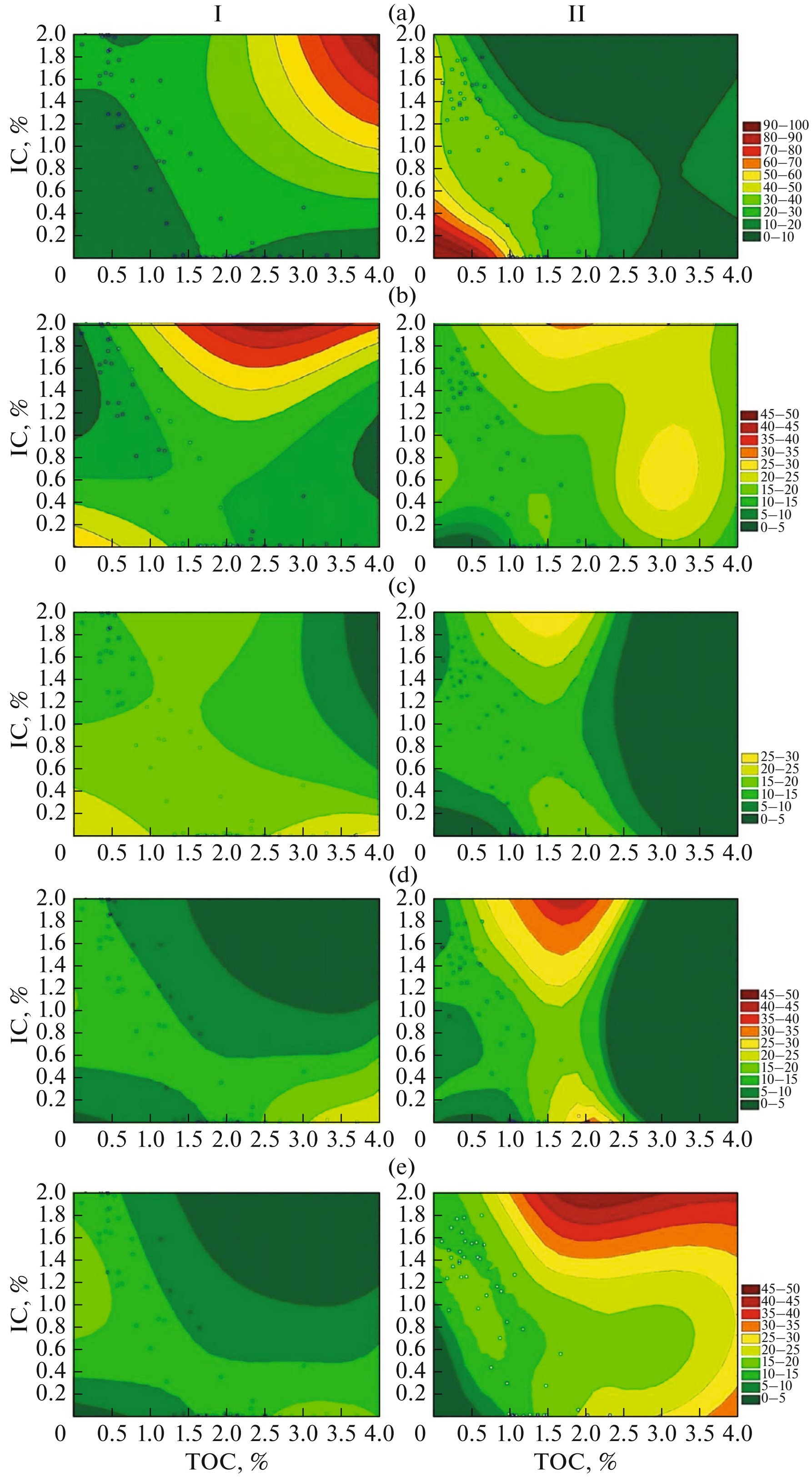

Fig. 1. Changes in the content of air-dry fractions of aggregates: (a) >10 mm, (b) 7–5 mm, (c) 5–3 mm, (d) 2–1 mm, and (e) 1–0.5 mm in the phase coordinates of the contents of organic and inorganic carbon in the native (I) and buried (II) soil profiles.

contents and more sharply increases after the plateau in the region of 23–30%.

Fig. 1b shows the relationship between the studied parameters and the amount of aggregates 7–5 mm. In the native and buried profiles, the maximal content of this fraction is allocated to the area of high organic and inorganic carbon content. However, in the region of low TOC and IC, the plots differ: the fraction content gradually increases in the native profile and sharply decreases in the buried profile.

Figure 1c describes the matrix of correlations for the aggregate fraction 5–3 mm. An axis of the high fraction content is pronounced in the buried soil profile at the level of 1.5–2% of TOC and throughout all IC values. The decrease in the fraction content in both directions from this axis is sharper in the direction of increasing TOC. Such axis is also seen in the native soil profile, but the pattern is smoother, and there is an increase in the fraction content at the small content of inorganic carbon.

The diagrams in Figs. 1c (5–3 mm) and 1d (2–1 mm) reflect similar regularities of the shift of the maximal and minimal content of fractions during burial.

Figure 1e (1–0.5 mm) also reflects sharp deformations of the correlation between the structural-aggregate fraction and organic and inorganic carbon in buried horizons. The native profiles are characterized by a gradual rise to a plateau and by a decrease in the content of fractions in the area of combined minimal and maximal values.

Thus, it may be concluded that the burial of the soil profile changes correlations between the structural-aggregate fraction and the content of organic and inorganic carbon. Numerous peaks usually appear, the diagram becomes more complicated, and there are areas of a sharp decrease in the content of fractions in comparison with the similar fractions in native chernozem, but similar features still remain. In few cases, the diagrams for coarse fractions in the buried and native soils are opposite. The difference is mainly related to a decrease in the total amount of organic carbon in buried profiles, in its labile components (carbohydrates, proteins, and water-soluble humus) in particular [5, 10, 12]. There are studies, showing that these substances play a significant role at the initial stages of structure formation [2, 26]. Thus, it may be assumed that the structure formation is slowed down in the areas of a sharp decrease in the content of fractions on the phase planes, reflecting the ratio between the content of organic and inorganic carbon in buried soils. These areas are unique for different structural fractions.

CONCLUSIONS

An increase in the portion of the air-dry fraction >10 mm both in the urbic and buried horizons is a clear evidence of urban pedogenesis at the macro-structure level. According to the data of dry sieving, coarse-textured (URl) urbic horizons differ from heavy-textured (URh) ones by higher content of fractions 0.5–0.25 and <0.25 mm. Standard relationships between the soil structure and the content of organic and inorganic carbon are not recorded in urbic horizons. The processes of structure formation in them are probably more strongly affected by the soil texture, compaction, and the presence of hydrophobic pollutants.

In comparison with native soils, the buried part of the urban soil profile is characterized by a tendency to an increase in the content of coarse angular blocky aggregates as a result of higher portion of agronomically valuable aggregates 7–5, 5–3, 2–1, and 1–0.5 mm. The water stability of the structure is a more constant parameter. The comparison of native and buried horizons shows a significant increase in the content of fraction 0.5–0.25 mm in the buried dark-humus horizons due to lower content of aggregates >3 mm and 2–1 mm.

Regression models cannot be used to describe the effect of different carbon forms on the content of structural fractions.

The graphical analysis shows that the relationships between the content of structural fractions and the amount of organic and inorganic carbon interpolated by the least square method are transformed as a result of soil burial. It is assumed that in native soils, each structural fraction is characterized by its own range of values on the phase plane with the coordinates of organic and inorganic carbon content, where the structure formation is intensive. The buried profiles are characterized by areas of a sharp decrease in the content of structural fractions in comparison with similar horizons of native soils.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. N. A. Azovtseva and A. V. Smagin, “Dynamics of physical and physicochemical properties of urban soils under the effect of ice-melting salts,” Eurasian Soil Sci. **51**, 120–129 (2018).

2. Z. S. Artem'eva, *Organic Matter and Granulometric System of Soil* (GEOS, Moscow, 2010) [in Russian].
3. S. A. Barber, *Soil Nutrient Bioavailability: A Mechanistic Approach* (Wiley, New York, 1984; Agropromizdat, Moscow, 1988).
4. O. S. Bezuglova, *Humus Status of Soils of Southern Russia* (North-Caucasian Scientific Center of Higher School, Rostov-on-Don, 2001) [in Russian].
5. O. S. Bezuglova, "Analysis of buried soils of urban landscapes," in *Composition and Properties of Soils and Paleosols under Various Pedogenic Conditions and Methods for Their Study* (Novosibirsk, 2018), pp. 13–16.
6. O. S. Bezuglova, S. S. Tagiverdiev, and S. N. Gorbov, "Physical properties of urban soils in Rostov agglomeration," Eurasian Soil Sci. **51**, 1105–1110 (2018).
7. O. S. Bezuglova and M. M. Khyrkhyrova, *Soils of Rostov Oblast* (Southern Federal Univ., Rostov-on-Don, 2008) [in Russian].
8. A. F. Vadyunina and Z. A. Korchagina, *Methods for Studying Soil Physical Properties* (Agropromizdat, Moscow, 1986) [in Russian].
9. *Geology of the USSR*, Vol. 46: *Rostov, Volgograd, and Astrakhan Oblasts, and Kalmyk ASSR*, Part 1: *Geological Description*, Ed. by F. A. Belov (Nedra, Moscow, 1969) [in Russian].
10. S. N. Gorbov, Doctoral Dissertation in Biology (Moscow, 2018).
11. S. N. Gorbov and O. S. Bezuglova, "Specific features of organic matter in urban soils of Rostov-on-Don," Eurasian Soil Sci. **47**, 792–800 (2014).
12. S. N. Gorbov, O. S. Bezuglova, K. N. Abrosimov, E. B. Skvortsova, S. S. Tagiverdiev, and I. V. Morozov, "Physical properties of soils in Rostov agglomeration," Eurasian Soil Sci. **49**, 898–907 (2016).
13. M. I. Dergacheva and V. S. Zykina, *Organic Matter of Fossil Soils* (Novosibirsk, 1988) [in Russian].
14. E. A. Dmitriev, *Mathematical Statistics in Soil Science* (Librokom, Moscow, 2010) [in Russian].
15. G. V. Dobrovol'skii and E. D. Nikitin, *Conservation of Soils as an Important Biosphere Component* (Nauka, Moscow, 2000) [in Russian].
16. S. A. Dubrovskaya, "Ecological and geochemical characterization of contamination of urban soils with heavy metals and petroleum products," Izv. Orenb. Gos. Agrar. Univ., No. 1 (39), 167–169 (2013).
17. Yu. A. Zavgorodnyaya, E. A. Bocharova, and E. I. Kol'tsov, "Determination of soil pollution degree with hydrocarbons by automated accelerated extraction in subcritical conditions," Ekol. Prom. Ross., No. 2, **30–33** (2012). https://doi.org/10.18412/1816-0395-2012-2-30-33
18. S. A. Zakharov, *A Course of Soil Science* (Moscow, 1931) [in Russian].
19. L. L. Shishov, V. D. Tonkonogov, I. I. Lebedeva, and M. I. Gerasimova, *Classification and Diagnostic System of Russian Soils* (Oikumena, Smolensk, 2004) [in Russian].
20. E. Yu. Milanovskii, Doctoral Dissertation in Biology (Moscow, 2006).
21. P. H. Nye and P. B. Tinker, *Solute Movement in the Soil-Root System* (Blackwell, Oxford, 1977; Kolos, Moscow, 1980).
22. N. B. Naumova, "The content of organic carbon in soil," Pochvy Okruzh. Sreda, No. 1 (2), 98–103 (2018).
23. *Scientific Theory of Soil (Land) Degradation of Agricultural Lands of Russia and Development of Their Fertility System in Adaptive-Landscape Land Farming*, Vol. 1: *Theoretical and Methodological Principles of Prevention of Soil (Land) Degradation* (Dokuchaev Soil Science Inst., Moscow, 2013) [in Russian].
24. A. A. Okolelova, "The control of petroleum products in soil," in *Proceedings of the II International Scientific Conf. "Modern State of Chernozems"* (Southern Federal Univ., Rostov-on-Don, 2018), Vol. 2, pp. 150–158.
25. A. A. Okolelova, O. S. Bezuglova, and N. G. Kasterina, "Petroleum products in soil: terms and accounting," Zhivye Biokosnye Sist., No. 4 (2013). http://www.jbks.ru/archive/issue-4/article-16.
26. T. V. Prokof'eva, M. I. Gerasimova, O. S. Bezuglova, K. A. Bakhmatova, A. A. Gol'eva, S. N. Gorbov, E. A. Zharikova, N. N. Matinyan, E. N. Nakvasina, and N. E. Sivtseva, "Inclusion of soils and soil-like bodies of urban territories into the Russian soil classification system," Eurasian Soil Sci. **47**, 959–967 (2014).
27. V. M. Semenov and B. M. Kogut, *Soil Organic Matter* (GEOS, Moscow, 2015) [in Russian].
28. T. A. Trifonova, N. V. Mishchenko, and D. A. Budakov, "The use of an information analytic system in soil-ecological studies," Eurasian Soil Sci. **40**, 18–25 (2007).
29. D. V. Khan, *Organomineral Compounds and Soil Structure* (Nauka, Moscow, 1969) [in Russian].
30. V. A. Kholodov, N. V. Yaroslavtseva, Yu. R. Farkhodov, V. P. Belobrov, S. A. Yudin, A. Ya. Aydiev, V. I. Lazarev, and A. S. Frid, "Changes in the ratio of aggregate fractions in humus horizons of chernozems in response to the type of their use," Eurasian Soil Sci. **52**, 162–170 (2019).
31. R. J. Hanks and G. L. Ashcroft, *Applied Soil Physics: Soil Water and Temperature Applications* (Springer-Verlag, New York, 1980; Gidrometeoizdat, Leningrad, 1985).
32. E. V. Shein, N. V. Verkhovtseva, G. S. Bykova, and E. B. Pashkevich, "Aggregate formation in a kaolinite suspension during microbiological modification of clay surface," Eurasian Soil Sci. **53**, 349–354 (2020).
33. K. Chaney and R. S. Swift, "The influence of organic matter on aggregate stability in some British soils," J. Soil Sci. **35**, 223–230 (1984).
34. IUSS Working Group WRB, *World Reference Base for Soil Resources 2014, International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, World Soil Resources Reports No. 106* (UN Food and Agriculture Organization, Rome, 2014).
35. S. S. Tagiverdiev, S. N. Gorbov, O. S. Bezuglova, and P. N. Skripnikov, "The content and distribution of various forms of carbon in urban soils of southern Russia on the example of Rostov agglomeration," Geoderma Reg. **21**, e00266 (2020).

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