Chapter 15
Specifics of Accumulation and Profile Distribution of Organic Carbon in Soils of Park and Recreational Areas of Rostov Agglomeration

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Abstract Artificial tree plantations of different ages in the city limits of Rostov-on-Don, Aksai and Bataysk were studied. In total, 22 monitoring sites were studied on the territory of park and recreational zones of the Rostov agglomeration. Geobotanical and soil research was carried out for each monitoring site. The study shows a statistically significant increase in the organic carbon content in the 0–10 cm layer of calcic chernozems of city recreational zones. There was on average of $4.23 \pm 0.88\%$ regarding to the chernozems of reserved and native areas of the Rostov agglomeration, where the content of C org. was $2.86 \pm 0.63\%$. The comparison of the C org. content in the surface 10-cm layer for studied forest parks was concluded that, regardless of the location and floral composition features, the difference in the organic matter content is small: C org. $= 4.23 \pm 0.88\%$. It was possible to identify a pattern associated with the planted forests age and the accumulated organic carbon amount in the surface horizon. In forest phytocenoses aged 70–90 years, the content of C org. in the surface layer was significantly higher ($4.40 \pm 0.78\%$) than in younger ones ($3.42 \pm 0.76\%$), whose age was 30–50 years. The profile distribution of organic carbon under woody vegetation has specific features. Some monitoring sites demonstrate a sharp decrease in the content of C org. (by 2–2.5 times) during the transition from the A horizon to the underlying horizon. The rest are characterized by a smoother distribution of organic carbon throughout the humus-accumulative strata, which is associated with a larger total biomass of herbaceous plants forming under the canopy of trees at these monitoring sites.

**Keywords** Calcic chernozems · Urban forest parks · Organic matter · Humus · Natural soils

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15.1   Introduction

The woody vegetation planting in the steppe zone is one of the manifestations of anthropogenic interference in the functioning of natural ecosystems, correcting the steppe biocenoses circulation (Canedoli et al. 2020; Huot et al. 2017; Morel et al. 2015; Yang et al. 2014). Therefore, the research of soil cover of urban forest parks is an important object for of long-term anthropogenic impact studying on steppe ecosystems (Velts and Lupova 2013). Overall, the landscaping development in cities is one of the factors that ensure the soil organic matter accumulation (Kimpe and Morel 2000). This tendency is especially observed in native treeless areas and cities developing in unfavorable conditions, for example, in the arid zone (Vodyanitskii 2015). Woody phytocenoses affect the temperature and hydrological soil regimes, the atmospheric precipitation composition, the number and activity of various organic matter destructors, form a sub-morphological flora which is different from the steppe and provide additional dead vegetation to the soil (Demakov et al. 2017; Gorbov and Bezuglova 2014; Vysotskiy 1962). It leads to organic matter accumulation changes and also increases the intensity of carbon inorganic forms migration and part of the water-soluble organic matter in the soil profile. However, the impact of the same plant species on the soil manifests itself differently in different biogeocenoses and largely depends on the physico-geographical conditions (Karpachevskiy 1981). The purpose of this work is to study the influence of the change of plant formations on the features of the accumulation and profile distribution of organic carbon in the conditions of a large agglomeration of the steppe zone.

15.2   Objects and Methods

The objects of the study were the natural soils of the parks and recreational zones of the Rostov agglomeration, applying to one subtype-ordinary carbonate chernozems (calcic chernozems), experiencing minimal influence of the anthropogenic factor (the soil cover has been preserved since the period of agrogenic use, the absence of modern human economic activity). The internal spatial structure of recreational zones at the monitoring sites (with an area of 100 m^2) allocated considering the dominant tree species, and their age was studied; visual assessment of the condition of tree and shrub plantations was carried out, also floral and geobotanical descriptions were carried out. Monitoring sites were laid on watershed areas to minimize the impact of the relief factor on soil properties. In the selected recreational areas, 16 full soil profiles were made, and surface soil samples were additionally taken from a ten-centimeter layer in ten-fold repetition for each monitoring site. As a control site, the sites on the territories of the exposition of the Botanic Garden of the Southern Federal University "Priazovskaya Steppe" (sites 3.4–3.5) were selected. It represents a 60-year-old old reservoir that was artificially subjected to the repatriation of steppe and red book species, as well as a virgin plot on the territory of a natural monument
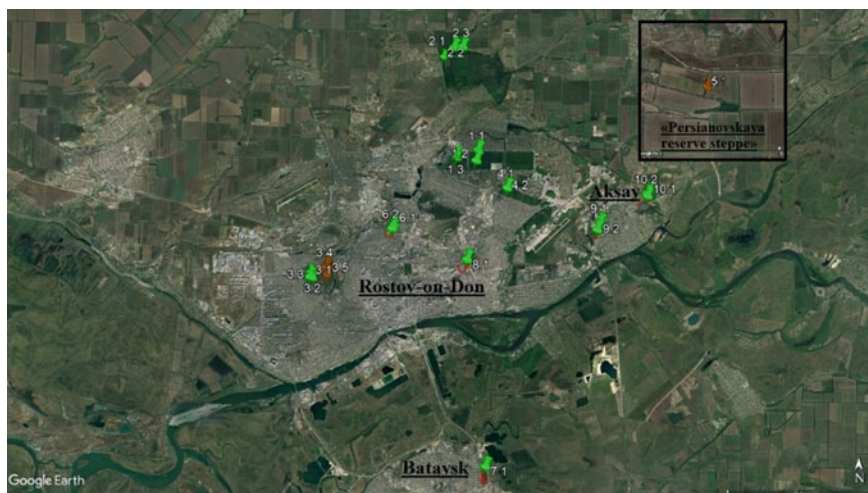
Fig. 15.1 Map of the location of monitoring sites

with a reserved regime "Persianovskaya reserved steppe" (site 5.1) 10 km from the city of Novocherkassk (Yu and Myasnikova 2014). In total, 22 monitoring sites were investigated (Fig. 15.1 and Table 15.1).

Visual assessment of the state of tree and shrub plantations was carried out according to the method of Alekseyev (1989), which allows interpreting the habitus of the plant as an indicator of environmental conditions. With an indicator from 100 to 80%, the vital state of the tree stand is considered as healthy, at 79–50% is weakened, at 49–20% is severely weakened and at 19% and below is completely destroyed.

Geobotanical descriptions were carried out for each park to assess species biodiversity. The projective coverage of a single geobotanical description site was determined visually and expressed as a percentage. The taxation (forestry) indicators of the tree tier were determined by eye, and the diameter and height of each tree under study were determined using a tape measure. The abundance of herbaceous plant species is indicated on the Brown-Blank scale (Braun-Blanquet 1951):

The biomorphological structure of the flora was determined by the system of life forms of K. Raunkier and the ecological and morphological classification of biomorphs of I. G. Serebryakov. In the distribution of species by ecological-cenotic groups (ECG) and geographical element, the indications of the "Flora of the Lower Don" (Zozulina and Fedyayevoy 1984), the "Summary of the flora of the Exposition of the Botanic Garden of the SFU "Priazovskaya Steppe" (Shmarayeva et al. 2021) and the Internet version of the database "Flora of vascular Plants of Central Russia" were considered". The criterion for the distribution of the species of the studied flora by ecological groups is the ratio to the degree of moisture and salinity of soils. The nomenclature of vascular plant species is given according to the regional determinant of flora (Zozulina and Fedyayevoy 1984, 1985). The species diversity

Table 15.1 Characteristic of studied monitoring sites

Monitoring sites	Number of site	Coordinates	Characteristic
Temernitskaya grove	1.1	N 47.294859° E 39.762646°	Large artificial forest plantation on the north-eastern outskirts of the city
	1.2	N 47.289895° E 39.761479°	
	1.3	N 47.291334° E 39.747751°	
Shchepkinsky forest	2.1	N 47.343712° E 39.744084°	Large artificial forest plantation on the north-eastern outskirts of the city
	2.2	N 47.340411° E 39.737190°	
	2.3	N 47.344121° E 39.750227°	
Botanic Garden of the Southern Federal University	3.1	N 47.232851° E 39.645382°	Coniferous nurseries
	3.2	N 47.233300° E 39.648200°	
	3.3	N 47.236400° E 39.645800°	Forest belt of oak near arable land
	3.4	N 47.237514° E 39.656652°	Control fallow plot
	3.5	N 47.234234° E 39.657186°	Control fallow plot
Ordzhonikidze village	4.1	N 47.277120° E 39.783838°	Large artificial forest plantation on the north-eastern outskirts of the city
	4.2	N 47.277600° E 39.784600°	
«Persianovskaya reserve steppe»	5.1	N 47.504655° E 40.152729°	Control fallow plot
K. Chukovsky Park	6.1	N 47.258397° E 39.704121°	Old city park
	6.2	N 47.256614° E 39.702811°	
Forest plantation of Bataysk	7.1	N 47.256614° E 39.702811°	Forest belt near the cemetery
N. Ostrovsky Park	8.1	N 47.242500° E 39.756389°	Old city park
Forest plantations of Aksai	9.1	N 47.261178° E 39.850075°	Independently arisen forest area
	9.2	N 47.257851° E 39.848214°	
	10.1	N 47.274444° E 39.883333°	Forest belt on the south-western border of Aksay

Table 15.1 (continued)

Monitoring sites	Number of site	Coordinates	Characteristic
	10.2	N 47.275556° E 39.883056°	

of plant communities and their complexes were evaluated according to the indicators proposed in the works of Whittaker (1972), which have become classic in modern ecology: α-diversity – (internal diversity of habitat for a description representing a homogeneous community), β-diversity (diversity between different communities along the gradient of the environment).

The organic carbon content was determined by two methods:

(1) a method for determining humus in soil according to Tyurin in the Nikitin modification with a colorimetric ending according to Orlov-Grindel (Mineyev 2001). The method involves the oxidation of humus with an excessive amount of chromium mixture ($K_2Cr_2O_7 + H_2O + H_2SO_4$) in a drying oven heated to 150 °C, followed by considering the trivalent chromium formed during the reaction. Accounting is carried out at a wavelength of 590 nm, providing maximum absorption of Cr^{3+} ions, in 10 mm cuvettes.

(2) high-temperature catalytic combustion on the carbon analyzer TOC-L CPN Shimadzu in the console for dry samples SSM-5000A. This method is based on high-temperature catalytic combustion of the sample and subsequent detection of the released carbon dioxide. The analysis of the sample realizes in two stages: Total carbon is determined by burning the sample at a temperature of 900 °C, inorganic—at 200 °C with the addition of orthophosphoric acid. Organic carbon is determined by subtracting from total—inorganic (Tagiverdiev et al. 2020). The advantage of this method is that the "side" result of the analysis is the determination of the amount of inorganic carbon in a dry sample.

The calculation of soil organic carbon reserves is carried out based on data obtained during laboratory analyses according to the following formula: reserve of carbon of C org. t/ha $= C * H * d$, where C is the content of organic matter, %; d is the thickness of the horizon (layer), cm; H is the density of the soil, g/cm^3.

Statistical data processing was performed using the software Statistica for Windows 10.0, MS Excel.

15.3 Results and Discussions

In the study of vegetation, 94 species of woody and herbaceous plants from 39 families belonging to 78 genera and three classes were identified: coniferous Pinopsida, dicotyledonous Magnoliopsida and monocotyledonous Liliopsida.

Shchepkinsky Forest is characterized by a very uneven distribution of herbaceous vegetation, depending on which species of trees and shrubs were planted. In total, 17 species from 15 families of flowering plants were noted here. *Glechoma hederacea* L. is abundant in the herbaceous tier and *Geum urbanum* L. (Table 15.2).

The highest species diversity of plants was noted in the Temernitskaya grove: 50 species of flowering plants from 28 families. The tree and shrub layers are dominated by representatives of the Fabaceae and Sapindaceae families (*Robinia pseudoacacia* L., *G. triacanthos*, *Acer negundo* L., *A. tataricum* L., *A. fruticosa*) (Table 15.3). In the grove, the plots represent a stage of a succession series, transitional to wheatgrass (background species—*Elytrigia repens* Desv.). The herbaceous tier is dominated by representatives of weedy-shrubby, weedy-meadow and shrub-forest vegetation.

Exclusively *Picea abies* (L.) H. Karst and *Pinus pallasiana* D. Don. grow in the nursery of the Botanic Garden of the Southern Federal University. The floral composition of the remaining tiers is almost identical and includes 28 species of herbaceous plants, shrubs and lianas from 19 families. The herbage is dominated by a representative of shrub-forest vegetation *Viola odorata* L. In addition, representatives of weed

Table 15.2 Dominant species of the tree tier of the studied monitoring sites

Monitoring sites	Species	Abundance	Projective cover, %
«Shchepkinsky forest»	*Glechoma hederacea*	3	30
Botanic Garden SFU	*Viola odorata*	5	75
«Temernitskaya grove»	*Elytrigia repens*	5	90
K.Chukovsky Park	*Poa bulbosa, Stellaria media*	5	85
N. Ostrovsky Park	*Alliaria petiolata*	5	85
Ordzhonikidze park	*Poa bulbosa*	4	55
Forest plantations of Aksai	*Chaerophyllum temulum*	5	90

Table 15.3 Dominant species of the grassy tier of the studied monitoring sites

Monitoring sites	Species	Average diameter (m)	Average height (m)
« Shchepkinsky forest»	*Quercus robur*	0.18	12.1
Botanic Garden SFU	*Picea abies, Pinus pallasiana*	0.17	3.6
« Temernitskaya grove»	*Robinia pseudoacacia*	0.17	8.1
K.Chukovsky Park	*Fraxinus excelsior*	0.15	6.6
N. Ostrovsky Park	*Morus alba*	0.09	4.2
Ordzhonikidze park	*Robinia pseudoacacia*	0.25	10.6
Forest plantations of Aksai	*Robinia pseudoacacia*	0.19	7.6

communities are noted in the herbage: *Chelidonium majus* L., *Physalis alkekengi* L. (abundance from 1 to 2 b.). Weed-psammophilic, weed, synanthropic, sun-meadow, meadow-steppe, weed-fringe-meadow and characteristic of the communities that have developed in this area were found: *Bromus tectorum* L., *Fumaria schleicheri* Soy. -Will, *Cirsium setosum* (Willd.) Besser, *C. canum* (L.) All., *Clematis recta* L., *Cynoglossum officinale* L. and *Securigera varia* (L.) Lassen. On another site mainly plantings of such woody plants as *Quercus robur* L., *A. campestre* L. and *A. pseudoplatanus* L. are presented.

Monitoring sites in the parks of Chukovsky and Ordzhonikidze are floristically like each other. The herbaceous cover is represented by dominant species such as *Poa bulbosa* L., *Stellaria media* (L.) Vill. and *Taraxacum officinale* Webb. Mixed woody vegetation dominates on the sites of the N. Ostrovsky Park and forest plantations in Aksai. In all the above-mentioned artificial plantings, such species as *Fraxinus americana* L., *F. excelsior* L., *A. pseudoplatanus*, *A. tataricum*, *A. negundo*, *Sorbus hybrida* L., *Morus alba* L., *G. triacanthos*, *R. pseudoacacia*, *Prunus domestica* L., *Syringa vulgaris* L., *Ulmus pumila* L., *Sambucus nigra* L., *Juglans regia* L., *C. coggygria*, *Cornus sanguinea* L. and *Euonymus europaeus* L. were planted. In the park named after N. Ostrovsky, seedlings of *Celtis occidentalis* L. (abundance of 4 b.) and *Alliaria petiolata* (Bieb.) Cavara et Grande (abundance of 5 b., in bulk) are represented in the mass.

As a control site, a site was selected on the territory of the exposition of the Botanic Garden of the Southern Federal University "Priazovskaya Steppe", on which steppe vegetation grows naturally for the zone with the dominance of species of the Poaceae and Asteraceae families. Studies were also carried out on the territory of the protected area "Persianovskaya Steppe", which is a virgin area where such families as Asteraceae, Poaceae and Fabaceae occupy a leading place in the flora.

The results of the assessment of the vital condition of trees showed that the highest indicator of the vitality of trees was found at the sites of the Shchepkin Forest—95.27%. The lowest indicator of tree vitality was recorded in Ordzhonikidze Park. Here, tree stands grow near the highway, which can significantly affect their condition (Table 15.4).

The soils of forest parks, compared with soils under steppe vegetation, have increase the humus-accumulative stratum thickness. These soils were characterized by pronounced agronomically valuable structure formation of the soddy horizon and decrease the effervescence depth in the B and BC illuvial horizons. Chemical analysis of soil samples of the 0–10 cm layer showed the following results. There is a statistically significant (U-criterion, $p < 0.05$) increase in the content of organic carbon in soils under woody vegetation, and on average it is $4.23 \pm 0.88\%$ ($N = 200$) relative to the chernozems of reservoir and virgin areas of the Rostov agglomeration, where the content of C org. is $2.86 \pm 0.63\%$ ($N = 25$) (Fig. 15.2).

Comparing the monitoring sites for the content of C org. in the surface layer, it can be concluded, that, regardless of the spatial position and features of the floral composition, the content of organic carbon shows similar values and does not show statistically significant differences among themselves. The highest median values in organic

Table 15.4 Vital condition of trees

Monitoring sites	Number of trees, %				Ln, %*	The vital state of the plantings
	Healthy	Weak	Severely weak	Completely destroyed		
« Shchepkinsky forest»	89.5	5.2	5.3	0	95.27	Healthy
Botanic Garden SFU	31.6	7.7	26.4	34.3	49.35	Severely weak
« Temernitskaya grove»	30	50	20	0	80	Healthy
K.Chukovsky Park	62.1	27.6	6.7	3.6	84.32	Healthy
N. Ostrovsky Park	38.5	46.1	7.7	7.7	74.23	Weak
Ordzhonikidze park	6.1	18.2	36.3	39.4	35.4	Severely weak
Forest plantations of Aksai	30.8	17.3	15.4	36.5	50.9	Weak
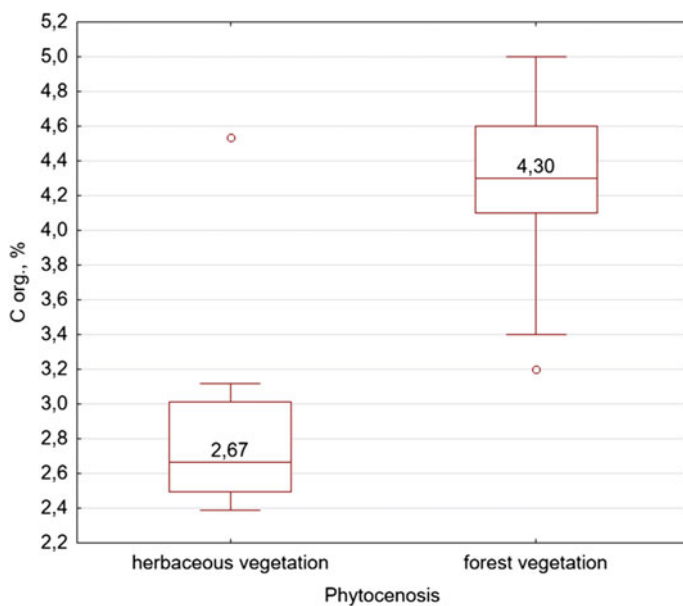
Fig. 15.2 Characteristics of median and interquartile range for C org., % for the surface ten-centimeter layer of soils under herbaceous and woody phytocenoses
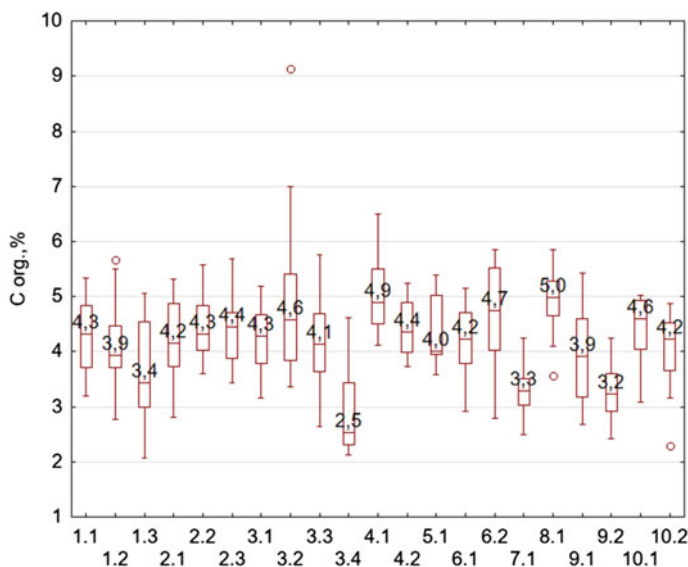
Fig. 15.3 Characteristics of median and interquartile range for C org., % at the studied monitoring sites in the surface ten-centimeter layer (Temernitskaya grove: 1.1–1.3, Shchepkinskiy forest: 2.1–2.3, Botanic Garden: 3.1–3.2—softwood nurseries, 3.3—oak grove, 3.4—reservoir, Ordzhonikidze: 4.1–4.2, Persianovskaya steppe: 5.1, K. Chukovsky Park: 6.1–6.2, N. Ostrovsky Park: 8.1, Aksai: 9.1–10.2)

carbon content were found in Ordzhonikidze (4.1)—4.9%, K. Chukovsky (6.2)—4.7%, N. Ostrovsky (8.1)—5.0% and the nursery of the Botanic Garden (4.6)—4.6% (Fig. 15.3). Two of the above-mentioned monitoring sites, namely Ordzhonikidze 4.1 and Park N. Ostrovsky 8.1, have a statistically significantly higher content of C org. compared with all other studied sites. The content of organic carbon at the monitoring sites in Temernitskaya grove (1.3) and Aksai (9.1, 9.2), on the contrary, is significantly lower than in other forest parks of the Rostov agglomeration.

Such a low content of C org. can be explained by the later formation of woody vegetation here, as evidenced by the age of *Robínia pseudoacácia*, which is the dominant tree layer in these areas. Thus, at the first stage of development of a forest area, a small amount of dead ground and root mass of plants enters the soil. It is due to the youth of the forest phytocenosis, and part of the humus formed before forest reclamation measures is mineralized. It should also be considered that for a long time (until the mid-70s of the last century) the plot 1.3 of the Temernitskaya grove belonged to the state farm and was used in agricultural activities, which could lead to a decrease in humus reserves and depletion of the soil with organic carbon. The totality of data on the history of the formation of woody vegetation, as well as geobotanical surveys at sites 9.1 and 9.2 of Aksai allow us to determine the age of trees in this forest area in 20–30 years. Interestingly, this site was formed spontaneously, without carrying out forest reclamation measures. Thus, it can be concluded that the age of

forest parks plays a decisive role in the accumulation of organic matter in the surface layer.

The profile distribution of total organic matter demonstrates two trends. On the one hand, peaks of humus accumulation in the surface turf horizon are possible, followed by a relatively sharp decrease in its content in the underlying thickness. It is demonstrated by soil profiles laid on the territory of coniferous nurseries of the Botanic Garden 3.1–3.2, Park N. Ostrovsky 8.1 and Aksai monitoring site 9.1. In the horizon AU content C org. decreases by 2–2.5 times compared to the turf horizon and further along the profile, and the distribution of organic matter of the studied sections has similar values. On the other hand, individual monitoring sites (Temernitskaya grove, Ordzhonikidze Park and Shchepkinskiy Forest sites, virgin and reservoir areas) are characterized by the absence of such a sharp decrease in C org. There are characterized by a smoother profile distribution of organic matter throughout the humus-accumulative strata. The graph of the profile distribution of organic carbon for the most representative sections is shown in Fig. 15.4. This distribution is associated with a higher total biomass of herbaceous plants forming under the canopy of trees, since the dying root system of weeds and meadow grasses provides direct entry of dead roots into the soil thickness and, therefore, a gradual decrease in humus content with depth. The different nature of the entry of dead plant into the soil leads to changes in the reserves of organic carbon. The largest reserves of organic matter in the meter thick were found in the parks of the Eastern Protective Ring: Shchepkin forest 2.2 = 284 t/ha, Temernitsky grove 1.1 = 280 t/ha and Ordzhonikidze = 270 t/ha. The lowest indicators were recorded in areas with young forest phytocenosis: Temernitskaya grove 1.3 = 178 t/ha Aksai 9.1 = 176 t/ha, as well as in the control reservoir chernozem of the Botanic Garden 3.4 = 175 t/ha (Fig. 15.5).

15.4   Conclusions

The data obtained now cannot entirely confirm the assumptions that the factor of different floral composition of forest parks is crucial in the process of accumulation of organic matter in the surface horizon. Thus, all the plant communities studied by us differ significantly in species diversity, the composition of the dominant species, both specially planted tree and shrub species and spontaneously appeared grasses and also in the degree of projective coverage and abundance. The presence of well-developed herbaceous vegetation does not always lead to an increase in this indicator in the turf horizon, which indicates the relevance of this study and the need for an integrated approach to assess the interrelationships of various components of recreational areas. Nevertheless, it was possible to identify a pattern associated with the age of planted forests and the content of organic carbon. In forest phytocenoses aged 70–90 years, the content of C org. in the surface layer is significantly higher ($4.40 \pm 0.78\%$) than in younger ones ($3.42 \pm 0.76\%$), whose age is 30–50 years. The difference between the soils of forest parks and steppe areas is also obvious in almost all the studied indicators. In forest phytocenoses, the content of organic carbon in the turf horizon

Fig. 15.4 Profile
distribution of C org., % in
the studied soil profiles.
Temernitskaya grove 1.1,
Shchepkinsky forest: 2.1,
nursery of coniferous trees of
the Botanic Garden 3.1,
reservoir plot 3.4, Aksai 10.2
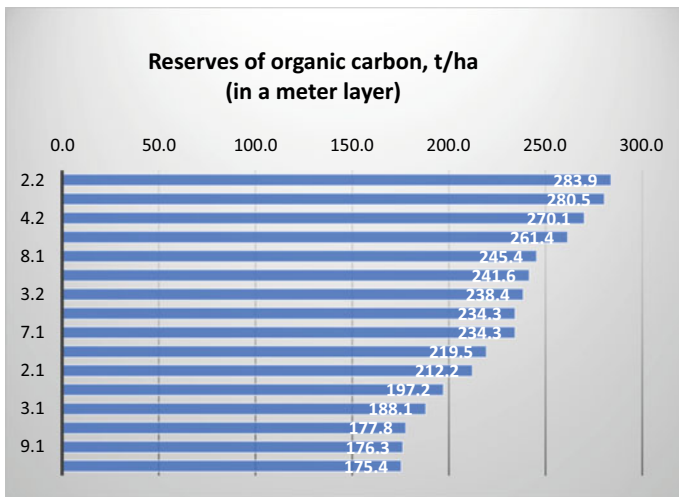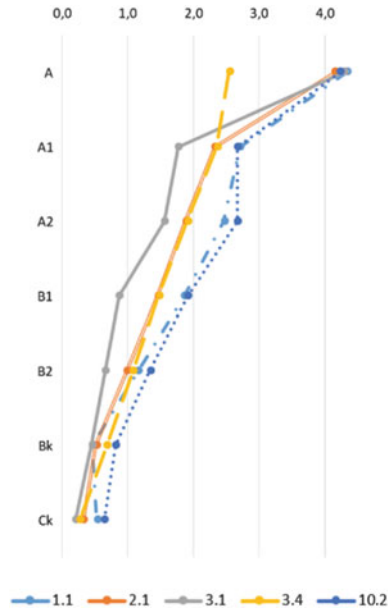
Fig. 15.5 Reserves of organic carbon in the meter layer, t/ha. (Temernitskaya grove: 1.1–1.3, Shchepkinskiy forest: 2.1–2.3, Botanic Garden: 3.1–3.2—softwood nurseries, 3.3—oak grove, 3.4—reservoir, Ordzhonikidze: 4.1–4.2, Persianovskaya steppe: 5.1, K. Chukovsky Park: 6.1–6.2, N. Ostrovsky Park: 8.1, Aksai: 9.1–10.2)

significantly increases. The humus profile of chernozems acquires the features of dark gray forest soil, which is expressed in a sharp decrease in humus with depth compared to the upper horizons.

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