Environmental properties of Phaeozems humus horizons of the Voronezh upland oak forest (Russia)

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Abstract. Within Voronezh city there is a green zone, the core of which are forest clusters of natural origin. The study sites are located in the recreational area of an upland oak forest. In such conditions, the forest litter and the upper soil horizon first experience transformation. All results were processed by StatSoft STATISTICA for Windows 10.0. In this study we found that low-thickness forest litter was formed in the Voronezh oak forest, in which the average content of macronutrients was (%): C – 2.91, N – 1.11, K – 0.32, and P – 0.18. These elements can be arranged in a variation series C > N > K > P. It is established that the edaphotope of oak forests of the forest-steppe has a favorable regime for the destruction of organic substances and the accumulation of decomposition products. The content of macronutrients in the forest litter and the upper part of the humus horizon is arranged in the same row N > K > P, which indicates their genetic relationship. The obtained data on the ecological state of the forest litter and the humus horizon of the gray forest soils of the oak forests of the megalopolis are important for understanding the biological cycle under conditions of technogenic and recreational loads.

1. Introduction

Forest litter plays an important role in maintaining balance in forest ecosystems and contributes to their sustainable functioning. However, in the conditions of a megalopolis with the increasing participation of the technogenic factor and recreational pressure, it is difficult for forest ecosystems to fully perform their functions. The Voronezh upland oak forest is included in Voronezh ecological framework and part of it, with an area of 7046.5 ha, is a reserve of regional significance according to the decree of the Voronezh Region Government (17th of April, 2013) N321 “On the formation of the State nature reserve of regional significance “Voronezh Upland Oak Forest”. At the same time, this island forest area within a large metropolis performs an important recreational function, which entails a corresponding load. Thus, according to the results of the study of the recreational load on the territory of the Olympic forest Park, the initial stages of digression are characteristic of almost 47% of the forest area, the same number are at the pre-threshold level (the third stage – the path network is relatively thick, light-loving species predominate in the grassy cover, meadow grasses begin to appear, the litter thickness decreases, the renewal of the forest is still satisfactory on the extra-path areas) and experience the maximum permissible recreational loads. For 6.5% of the territory, exorbitant impacts are observed, leading to
irreversible degradation processes. In this regard, the study of the ecological state of organichorizons of grey forest soils of the Voronezh upland oak forest is of high scientific and practical importance.

The heterogeneous structure of forests contributes to the formation of resistance to abiotic, biotic and anthropogenic disturbances. Foreign studies from 1973 to 1991 showed that the structural diversity of forests is a response to sulfur dioxide emissions [1]. An important aspect of the study of forest ecosystems is the analysis of their rational use, restoration and management. In the long term, the lack of an adequate management system for forest ecosystems will lead to their degradation and loss of ecosystem and landscape functionality [2, 3]. The oak forests of the studied territory have an ‘island’ character, which is due to the natural course of forest landscape genesis. However, in modern conditions, their dynamics are closely dependent on natural and anthropogenic factors. Forest ecosystems of urbanized territories are more susceptible to diseases and pests. Therefore, at present, much attention is paid to the study of the resistance of the stand to negative environmental factors. For an integrated approach to the study of forest ecosystems, it is important to have information about their edaphic conditions.

In modern studies of forest ecosystems, the role of forest litter in soil-forming processes is of great importance. It is established that patterns of C and N release varied with litter species and soil type. Mix species treatment resulted in larger DOC and N pulses compared to pine and oak treatments. The majority of the DOC, N, and P leached was retained by the soils. When litters were added to the soils, a greater proportion of the C was lost as CO₂, while litter incubated alone lost more C as DOC. This result demonstrated the importance of the soil microbial community affecting the patterns of litter mineralization. Total N concentration and C:N ratio of the litter species were significantly correlated to C loss [4]. In modern conditions of climate change, the study of soil ecology, problems of forest restoration and the study of soil properties are especially relevant [5, 6].

For the practical solution of the problems of conservation and protection of forest ecosystems, detailed studies of all their components are necessary. Our studies of the ecological state of the organic horizons of grey forest soils are complex and cover three clusters of the Voronezh upland oak forest, which are more susceptible to recreational stress. For the first time, studies of the content of the main macronutrients in the forest litter of forest soils of the Voronezh region were conducted. Without them, it is impossible to assess the extent of the biological cycle in the island forests of the forest-steppe. The results obtained will serve as a starting point for future research in the framework of ecological monitoring of forest ecosystems of urbanized territories of Voronezh and will allow for a comparative analysis of forest litter of various forest biotopes of a typical forest-steppe and beyond.

The purpose of these studies is to conduct a quantitative assessment of the content of the main macronutrients in the forest floor, the ecological state of the humus horizon of the grey forest soils of the upland oak forest within Voronezh.

2. Methods and materials

For the present study, three sites of the Voronezh upland oak forest were selected: the Olympic Forest Park, Voronezh State University (VSU) Botanical Garden of the B M Kozo-Polyansky, and the Voronezh Central Park. Samples of organic horizons (forest litter at full capacity and humus horizon at a depth of 0-20 cm) were collected for all sites in three-fold repetition: Olympic Forest Park (51°7531970 N, 39°1957580E, 51°7558772N, 39°1959771E, 51°7595298N, 39°1968354E), VSU Botanical Garden (51°7119760N, 39°2069640E, 51°7113500N, 39°2079850 E, 51°7106150N, 39°2090630 E), Voronezh Central Park (51°7012420N, 39°2179560 E, 51°7026790N, 39°2190180 E, 51°7025860N, 39°2148560 E).

pH of saline extract (KCl) was determined by potentiometric method for KCl soil extract, the sum of exchangeable bases (Ca²⁺ + Mg²⁺) was determined by complexometric Giedroyc’s method, hydrolytic acidity was determined by Kappe’s method with CH₃COONa, humus content was determined by Tyurin’s method (K₂Cr₂O₇ solution was used as an oxidizer), mobile forms of phosphorus and exchangeable potassium were determined Chirikov’s method (0.5N CH₃COOH) with ending on the Photoelectrocolorimeter KFC-3KM ‘UNICO’ (United Products and Instruments, USA), hydrolyzable
nitrogen was determined Kornfeld’s method (1N NaOH), K₂O by Chirikov method with ending on a flame photometer) were studied in soil samples. Ash content was determined in the forest litter using the dry ash method (a muffle furnace), phosphorus in the plant ash of using the Denizet method (dissolution of phosphoric acid in plant ash by 25% HCl), total nitrogen and potassium in one extract (the litter is burned by concentrated H₂SO₄ and after nitrogen was determined by the Photoelectrocolorimeter KFC-3KM ‘UNICO’ (United Products and Instruments, USA) and potassium was determined by flame photometric method), and organic carbon by Anstet method (burning of the litter in a sulfur-chromium mixture and subsequent continuation was determined by Mora salt titration).

All results were processed by StatSoft STATISTICA for Windows 10.0.

Physical and chemical properties (рН КСl by potentiometric method, exchange bases by Giedroyc method, extractable acidity by Kappen method), macronutrient concentrations (organic carbon by Tyurin method in Simakov modification, NO₃ by Cornfield method, P₂O₅ by Chirikov method with ending on the Photoelectrocolorimeter KFC-3KM ‘UNICO’ (United Products and Instruments, USA), K₂O by Chirikov method with ending on a flame photometer) were studied in soil samples. Ash content was determined in the forest litter using the dry ash method, phosphorus in the plant ash of using the Denizet method, total nitrogen and potassium in one extract, and organic carbon by Anstet method. All results were processed by StatSoft STATISTICA for Windows 10.0.

3. Results and discussion
We have already studied the current ecological state of forest soils and the patterns of their distribution within the typical forest-steppe of the Voronezh region, but the edaphic conditions of the forest ecosystems of the Voronezh upland oak forest and their ecological state are still insufficiently studied, and there is no information about the chemical composition of forest litter in these objects [7].

The Northern Upland oak forest is the largest forest area covering the right bank of the Voronezh River Valley. The dominant position in the landscape structure of the oak forest belongs to the slope type of terrain (50%), the share of flat-interfluve-terraced accounts is about 40%. The main background of flat interfluve is grey medium-loamy soils on loess-like carbonate loam (Classification and Diagnostics of soils of Russia, 2004) or Anorendzic Phaeozems (Loamic) (World Reference Base (WRB) for Soil Resources, 2014). Combinations of their eroded counterparts lie on the lower parts of the slopes. Within the slopes, conjugate transitions from transeluvial geochemically subordinate landscapes in the upper part to transeluvial-accumulative landscapes in the lower part are clearly distinguished. Water-accumulative stratozems (eroded soils) were formed along the bottoms of the beams [8]. Flat-interfluve-terraced landscapes meet in a narrow strip along the eastern border with a slope type of terrain. The main part of them is represented by a fresh oak forest. Grey medium loamy soils were formed on loess-like carbonate loams under the forest communities consisting of *Quercus robur* L., *Acer platanoides* L. and *Tilia cordata* Mill. and the grass cover of *Carex pilosa* Scop., *Aegopódium podagrária* L. They have the following morphological characteristics:

O 1-2 cm. The litter layer consists of oak leaves of oak of different degrees of decomposition.

AY 0-20 cm. Dry, grey with a brownish tint, fine-grained, medium loamy, on the faces of structural separations marked whitish plaque silica powder, densely intertwined roots of herbaceous vegetation, slightly compacted, the transition is noticeable.

AEL 20-40 cm. Fresh, grey, finely nutty structure, light loamy, the roots of herbaceous vegetation, abundant worm activities, puddled, transition noticeable by color.

BEL 40-120 cm. Slightly moist, dark brown, heavy loam, nutty-prismatic, there is a silica powder on the surface of soil aggregates, dense, thin-pore, single roots, the transition is noticeable.

BT 120-150 cm. Moist, brown, heavy-loamy, lumpy-prismatic, compacted, thin-pored, gradual transition to the parent rock.

C₁ 150 cm and deeper. Moist, brownish-yellow carbonate loam.

In the soils of forest ecosystems, the upper soil horizon performs such important functions as a protective and depot of nutrients, which, as the litter is decomposed, enter the soil and replenish their balance for the root nutrition of plants. Therefore, the thickness of the forest floor and its chemical
composition are important for maintaining an equilibrium balance of macronutrients and ash elements in the ‘plants-soil-plants’ system in forest ecosystems. The thickness of the forest floor in the upland oak forest in all study plots was 1-3 cm with the average value of the sample population of 2.06 cm (table 1).

Table 1. Environmental properties statistical indicators of Anorendzic Phaeozems (Loamic) organic horizons of the Voronezh upland oak forest (sample size=9, t-test=2.31).

| Indicator               | Mean   | Variation range | SD   | Mean confidence interval | SD   | Quartile range | Coefficient of variation, % / t-test actual |
|-------------------------|--------|-----------------|------|--------------------------|------|----------------|------------------------------------------|
| Thickness, cm           | 2.06   | 1.00-3.00      | 0.23 | 1.53-2.58                | 0.68 | 1.5-2.5        | 33/9                                     |
| Organic carbon, %       | 29.1   | 22-39           | 1.72 | 25-33                    | 5.2  | 27-32          | 18/17                                    |
| Total nitrogen, %       | 1.11   | 0.50-1.50       | 0.14 | 0.79-1.43                | 0.42 | 1-1.5          | 38/8                                     |
| Total potassium, %      | 0.32   | 0.25-0.45       | 0.02 | 0.26-0.38                | 0.07 | 0.25-0.38      | 22/16                                    |
| Total phosphorus, %     | 0.18   | 0.07-0.27       | 0.03 | 0.11-0.25                | 0.09 | 0.07-0.26      | 50/6                                     |
| Ash content, %          | 1.40   | 5.30-16.70      | 1.18 | 9.68-15.12               | 3.53 | 10.6-15.2      | 28/11                                    |
| pH KCl                  | 6.2    | 6.0-6.2         | 0.02 | 6.12-6.22                | 0.07 | 6.2-6.2        | 1/310                                    |
| Ca²⁺ / a                | 13.3   | 12.5-14.2       | 0.19 | 12.9-13.8                | 0.57 | 13-13.8        | 4/70                                     |
| Mg²⁺ / a                | 1.7    | 1.0-2.3         | 0.15 | 1.39-2.06                | 0.44 | 1.5-2         | 25/11                                    |
| Ca²⁺ + Mg²⁺             | 15.1   | 13.9-16.4       | 0.32 | 14.3-15.8                | 0.96 | 14-15.8        | 6/47                                     |
| Extractable acidity a   | 2.2    | 1.2-4.4         | 0.31 | 1.49-2.93                | 0.93 | 1.6-2.3        | 42/7                                     |
| Basesaturation, %       | 87.2   | 76.0-93.0       | 1.65 | 83.4-91.1                | 4.94 | 86-91          | 6/52                                     |
| Organic carbon, %       | 4.3    | 1.8-6.7         | 0.53 | 3.08-5.54                | 1.60 | 3.90-4.60      | 37/8                                     |
| NO₂ / a                 | 5.5    | 3.2-7.4         | 0.42 | 4.53-6.45                | 1.25 | 4.8-6.1        | 22/13                                    |
| P₂O₅ / a                | 1.1    | 0.6-1.5         | 0.11 | 0.86-1.36                | 0.32 | 0.9-1.3        | 29/10                                    |
| K₂O / a                 | 2.2    | 1.0-4.3         | 0.38 | 1.37-3.10                | 1.13 | 1.3-3         | 50/6                                     |

*mg-EQ/100 g of soil.

The mean confidence interval is 1.53-2.58 cm. Such values allow us to classify the forest floor of grey forest soils of upland oak forest as very low-power (< 5 cm). This is facilitated by the decomposition of the litter, which is represented by rapidly decaying leaves of broad-leaved oak, maple, and linden trees. The variability in the thickness of the forest floor is significant (the coefficient of variation is 33%), which is natural for forest ecosystems, especially within the recreational zone. The quartile range was 1.5-2.5 cm, which includes 50% of observations. The actual values of this indicator are as close as possible or coincide with the expected normal frequencies, which allowed the identified patterns to be transferred to the general set of values of the thickness of the forest floor in the ecosystems of the Voronezh upland oak forest.

An important condition for the sustainable functioning of ecosystems is the closeness and equilibrium balance of biochemical cycles of the macronutrients. Therefore, the content will depend on the
availability of these nutrients in the soils. The content of the main macronutrients (carbon, phosphorus, nitrogen, potassium) and the ash content of the forest floor were studied in the studied plots.

The total carbon content is 29.1% with a confidence interval of 25.1-33.1. The range of variation falls within the range of 22-39%, which corresponds to the average variability with a coefficient of variation of 18%. 50% of the values fall within the range of 27-32%. The actual values reflect the general pattern of normal expectation, but several actual values of this indicator deviated from it.

The total nitrogen content in the forest floor is 1.11% with a confidence interval of 0.79-1.43. The wide range of variation of 0.50-1.50% caused a significant variability of 38%. The second place in the triad of nutrients (nitrogen, phosphorus, potassium) in terms of quantity was taken by potassium with an average total content of 0.32%. The range of variation was 0.25-0.45% with a coefficient of variation of 22%, while the quartile range of 0.25-0.38% showed the interval in which half of the obtained values fell. Phosphorus accounts for an average of 0.18% with a range of variation of 0.07-0.27 and significant variability (the coefficient of variation is 50%). A half of the values fit into the range of 0.07-0.26%.

The ash content of the forest floor is 12.4% on average, with a variation of 5.3-16.7%. The significant variability of the indicator is due to the heterogeneity of the stand in key areas. The most typical values of this indicator fit into the confidence interval of the average 9.68-15.12%. The quartile range is in the range of 10.6-15.2%. Despite the significant variability of the total content of nitrogen, phosphorus and potassium in the studied objects, the distribution of the theoretical values fully reflected the actual picture. The exception was phosphorus. All statistical characteristics of the power and chemical composition of the forest floor are reliable, t-test actual>t-test for all indicators. The analyzed samples are homogeneous, as evidenced by a coefficient of variation of less than 33%. The exceptions were the samples for nitrogen (38) and for phosphorus (50). Their content is characterized by a high degree of spatial heterogeneity.

The first soil horizon of grey forest soils that receives nutrients as a result of their eluviation after the decomposition of the forest floor is humus-eluvial. The ability of soils to retain and accumulate nutrients depends on its chemical properties. Grey forest soils of upland oak forest contain an average of 13.3 mg-eq/100 g of calcium exchange. The range of variation of this indicator was 12.5-14.2. The content of this element is characterized by insignificant variability (coefficient of variation less than 10%). The quartile range of 13.0-13.8 mg-eq/100 g of soil includes a half of all values for this indicator. The share of exchangeable magnesium accounts for an average of 1.7 mg-eq/100 g of soil. The range of variation is in the wide range of 1.0-2.3, which is confirmed by the significant variability of the trait with a coefficient of variation of 25%. However, 50% of the values fall within the range of 1.5-2.0 mg-eq/100 g of soil. The sum of the exchange bases did not exceed the maximum value of 16.4 mg-eq/100 g of soil. Grey forest soils in terms of the content of this indicator are characterized by a slight variability of 6%. The hydrolytic acidity of these soils varies in a wide range with a variation range of 1.2-4.4 mg-eq/100 g of soil, which is confirmed by a high coefficient of variation of 42%, while the quartile range is quite narrow 1.6-2.3 mg-eq/100 g of soil. All the above indicators are reflected in the value of the degree of soil saturation with bases, which is calculated. Its average value was 87.2%, which makes it possible to classify the grey forest soils of the upland oak forest to the category with an increased degree of availability of exchange bases. This is very good for forest soils, as it determines their high buffer capacity.

The exchange acidity (pH\text{KCl}) of organic horizons determines the rate of interaction of atmospheric moisture with soil colloids, living organisms, soil air and transformation into a solution. Changes in the pH, both in the acidification and in the alkaline side, can limit the growth and activity of soil fauna, and, accordingly, the rate of decomposition of dead organic matter. It is known that the optimal values for most soil organisms are in the range of 6-8, for fungi 3-5. In the studied soils, the value of the exchange acidity is characterized by insignificant variability and fell into a narrow range of variation of 6.0-6.2, which corresponds to a neutral reaction of the medium. Thus, a favorable regime is created for the functioning of the soil biota, which contributes to the rapid processing of detritus. All physical and chemical properties are characterized by the uniformity of the samples (coefficient of variation < 33), with the exception of the sample for hydrolytic acidity. Its heterogeneity is confirmed...
by a high value of variability (42%) and at a stable pH is due to the nature of the actual acidity. It is formed in the process of decomposition of organic matter in the soil, the secretions of root systems and the processes of microbiota activity. All these factors are very dynamic and contribute to the uneven formation of the actual acidity.

To characterize the chemical composition of the humus horizon of grey forest soils, the contents of total carbon and the forms of mineral compounds available to plants – alkaline hydrolyzable nitrogen, mobile phosphorus and exchangeable potassium were determined. The macronutrients content in the soil is directly dependent on their content in the forest floor, which, in turn, is influenced by the composition of vegetation and microclimate [9, 10]. In the studied soils at a depth of 0-20 cm, the amount of total carbon was on average 4.3% (high) with a range of variation of 1.8-6.7%. Such content falls into a wide range from low to high. However, the confidence interval starts at 3.08%, which allows us to narrow the range from medium to high security. The studied soils fell into the same category according to the quartile range of 3.3-5.4. The availability of the studied soils with the main macronutrients is very low in all indicators. The confidence intervals of nitrogen, phosphorus, and potassium content were 4.53-6.45, 0.86-1.32, 1.37-3.10 mg/100 g of soil, respectively. The variability in all chemical parameters is characterized by significant variability with a coefficient of variation of 22-50%.

The presented results were obtained for the first time for the forest ecosystems of the Voronezh upland oak forest, so there is no comparative analysis of them with earlier data. In this regard, the next stage of our research will be to discuss the ecological indicators of organic horizons in upland, eroded and above-floodplain-terrace oak forests in order to trace the influence of spatial variation of the above-listed indicators.

4. Conclusion
In the forest ecosystems of the Voronezh upland oak forest, a low-power forest floor was formed, in which the average content of macronutrients is (%): C – 29.1, N – 1.11, K – 0.32, P – 0.18. They can be arranged in a variation series C > N > K > P. The ash content of the litter was 12.4%. The most variable indicators are the content of nitrogen and potassium. Similar studies within the typical forest-steppe of the Voronezh region have not been conducted before, so it is not possible to compare the results with previous findings. Our results will serve as a base line for further research in this area and will be the first in the database on the chemical composition of the litter of oak forests in a typical forest-steppe of our region.

The chemical properties of the humus horizons of the studied soils form a favorable regime for the destruction of organic substances and the accumulation of decomposition products, forming a reserve of nutrients in the root layer. The greatest spatial variability was found for hydrolytic acidity.

The chemical parameters of the whole topsoil reflect the ability of soils to meet the needs of plant communities for humus and mineral nutrition. According to the content of organic carbon, the studied soils fell into the range from medium to high – humus, which creates a favorable regime for highly demanding tree species, which includes *Quercus robur* L. Unfortunately, there are no gradations on the availability of mineral nutrition for various tree species, and it is not correct to use the gradations developed for agricultural crops in relation to tree species. Therefore, we can only state that the studied soils in the upper 20-centimeter layer contain 3.2-7.4, 0.6-1.5, 1.0-4.3 mg/100 g of soil of alkaline hydrolyzable nitrogen, mobile phosphorus and exchangeable potassium, respectively. This content allowed us to arrange them in a variation series N > K > P, which is comparable to the sequence of the total content of nitrogen, potassium and phosphorus in the forest floor, thereby demonstrating a genetic relationship between the forest floor and the mineral soil.
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