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Ecological Status of Soils in Moscow Zoo

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Abstract—The quantitative assessment of the status of soils in Moscow Zoo was performed using traditional and original methods based on the differentiated system of indices. The studies were conducted in animal open-air cages and on plots available for visitors. The dynamics of the temperature and water–air regimes in the root-inhabited layer, the density, the acidity, and the salinity of the soils were studied. The level of the biological activity was assessed according to the intensity of the organic matter decomposition and the substrate-induced respiration. In the background of the rather satisfactory status of the soils, negative factors were found: a periodic excess or deficit of moisture and, for the most part, low biological activity (low respiration and decomposition of the lignin–cellulose test material). Recommendations for the improvement of the status of the soil cover in Moscow Zoo are proposed.

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INTRODUCTION

Nowadays, the problem of assessing the ecological status of and monitoring urban objects is most topical in modern urboecology. Urban soils perform a number of ecological functions, among which maintenance of fertility (maintenance of the growth and development of green stands), biodestruction of organic matter and waste, remediation of the main components of the environment (water and atmospheric air), maintenance of the biodiversity, etc., are the high priority ones. A complex of indices was elaborated for their quantification. These indices contain information about the physical and biological properties of urban soils, along with a gradation of their technogenic pollution and agrochemical criteria of their fertility [4]. As researchers have shown, the green areas in a town are not resistant to anthropogenic loads. Unfavorable physical (strong compacting, salinization, and an unfavorable water–air regime) and biological properties of soils are firstly responsible for the stunted growth and poor survival ability of plants. The specific microclimate within cities can change the life cycle of plants, thus provoking their growth and even flowering in unfavorable seasons.

The largest and most important objects from the ecological standpoint are parks, public gardens, and botanical and zoological gardens. The latter more often don't receive the attention of researchers studying the ecological status of urban territories and soils. These areas are exposed not only to systematic human loads (visitors) but also are influenced by animals that are permanently present on the same limited plots. Animals take part in the construction of their habitats via their effects on the soil cover and vegetation. This influence may be compared in intensity with the anthropogenic effect exerted on the urban parks. Such an edificatory function of animals consists in their effect on the physical (compaction, aeration), chemical (input of the products of life), and biological (the composition and activity of microflora) properties of soils; their actions may be of different directions (mechanical compacting and loosening of soil under the burrowing activity of animals). In this case, the stability of the zoocenosis is directly related not only to outer anthropogenic actions but also to the specific "zoological" factor affecting the soil cover and the whole urbocenosis.

Thus, the poor knowledge of the soils in zoological parks and the specific factors responsible for their structural–functional organization has determined the urgency of the present studies. The aim of this work was the complex assessment of the ecological status of the soils in Moscow Zoo using a system of criteria and modern instrumental methods elaborated at the Department of Physics and Amelioration of Soils of the Faculty of Soil Science of Lomonosov Moscow State University [4].

OBJECTS AND METHODS

Moscow Zoo is located on a gentle slope of the Moscow River valley at its confluence with the Presnya River. In the past, natural forests of linden, maple, elm, oak, and ash were typical for this region [2]. A considerable part of the Zoo soils is of artificial origin, and, according to the existing classification of urban soils, they are referred to as constructozems [1]. The investigations were conducted from August 2005 to August 2007. The samples were collected in open-air cages of musk oxen (*Ovibos moschatus*), white-tailed gnus (*Connochaetes gnou*), huanacos (*Lama guanicoe*), and bongos (*Taurotragus eurycerus*); in the cages of birds (cassowaries (*Casuarius casuarius*), emus (*Dromiceus novaehollandie*), black-necked cranes (*Grus nigricollis*), and different species of ducks (*Anas spp.*)); and outside the cages. Mixed samples were taken from the 0- to 20-cm layer using a cylindrical auger (its ring volume is about 100 cm^3). After drying of the samples and measuring the moisture and bulk density, the soils were analyzed for the electrical conductivity of their pore solution (Ec, dS/m), their acidity (pH), and their respiration.

The electrical conductivity of the pore solution was measured in a soil suspension (the soil to distilled water ratio was 1 : 5) using a portable conductometer (H1 98129 "Combo," HANNA). The result was corrected for $500/W_s$, where W_s is the moisture at the total water capacity in % [4]. The pH of the solution was measured simultaneously with the determination of the electrical conductivity using the same instrument.

The water–air regime was assessed using the index characterizing the degree of water saturation of the soil W/W_s, where W is the soil moisture in % and W_s is the total water capacity in % [4]. For ecological monitoring of the moisture content in the root-inhabited layer, the following method was used. A soil monolith from the root-inhabited layer with lawn grass was placed on a perforated plate with special holders for fixing an electronic weighing machine with a suspender (TH-312; Tsinghua Co., Ltd; China; weight accuracy 0.01 kg). The plate with the monolith was weighed periodically (once every 24 h)—it was lifted a bit from the soil surface. Using the data on the initial soil moisture (W) and the mass of the root-inhabited layer (m_l), the mass of the absolutely dry soil (m_s) was calculated using the formula

$$m_s = \frac{m_l 100}{100 + W}.$$

The current moisture and water reserves in the root-inhabited layer were calculated according to the changes in the weight of the plate with the soil. The content of water in the root-inhabited monolith was determined by the difference between the mass of the monolith and that of the absolutely dry soil. This amount was normalized to the mass of the absolutely dry soil (moisture) or to the plate area (reserves). Taking into account the parameters of the plate, the mass of the monolith, and the accuracy of the weighing, the accuracy of measuring the moisture dynamics was 0.2%. As the criterion W/W_s was calculated, the maximal moisture in the early spring after the snow thawing was accepted as the saturation moisture (W_s). The weighing of the soil in the spring allowed determining the moisture reserves in the soil, as well as in the snow cover in an elementary area.

Programmable Thermochron sensors (Dallas Semiconductor, USA) as a means for the primary monitoring of the physical environmental characteristics were used for the monitoring of the temperature regime [4]. The sensors were arranged in the shade of trees and in open areas under the lawn vegetation. The air and soil temperatures were measured at depths of 5, 10, and 20 cm automatically every 4 h (6 measurements for 24 h) during the whole year. After the measurements, the sensors were taken out of the soil. Using the special original iButton VieWer software (Maxim/Dallas, USA), the information concerning the temperature regime of the soil and atmosphere was gained.

Under the field conditions, the destruction of lignin–cellulose compounds was assessed. A wooden match was chosen as the test material. The choice of this test substrate was explained by the simple performance of the analysis using the unified mass material, on the one hand, and by the fact that the organic residues entering the soils of the open-air cages are of plant origin (plant residues, forage for animals) and close to this material in their composition, on the other hand. In addition, a considerable part of the organic garbage that is widespread in urban parks also consists of lignin–cellulose material (paper, matches, and ice-cream sticks). This experiment allows assessing the possibility of the soil microbial community to decompose organic residues, including garbage, that accumulate on the surface if the characteristic time of their destruction is more than a year.

The test material (wooden matches) of known mass (m) in 10 replicates was placed into the upper soil layer. The moisture of the test material (W) was preliminarily determined using the traditional thermal weight method; the mass of the absolutely dry substance was measured in the same way as in the monitoring of the water–air regime (see above). After 3 and 6 months, the material was taken out of the soil, dried to the absolutely dry state, and weighed using an electronic balance (Ohaus, USA) with an accuracy of 0.001 g. The loss of the mass allowed assessing the intensity of the test material mineralization using the constant of decomposition obtained according to the exponential model of biological destruction [3]. The data on the loss of the mass for a definite period were approximated using exponential trends: $m = m_0 e^{-kT}$, where k is the constant of the organic matter mineralization (yr^{-1}) and m_0 is the initial mass of the material. The half lifetime of the organic matter was determined using the k value according to the following equation: $T_{0.5} = \frac{\ln 2}{k}$ [3] [3].

The activity of the microbial biomass was determined by the intensity of the CO_2 emission using the method of substrate-induced respiration in fresh samples [5].

The statistical processing of the results was performed with help of Statistica 6.0 (StatSoft Inc., USA). The total sampling of the data was divided into classes according to different characteristics [4]. For each class, the probability of each characteristic investigated was calculated.

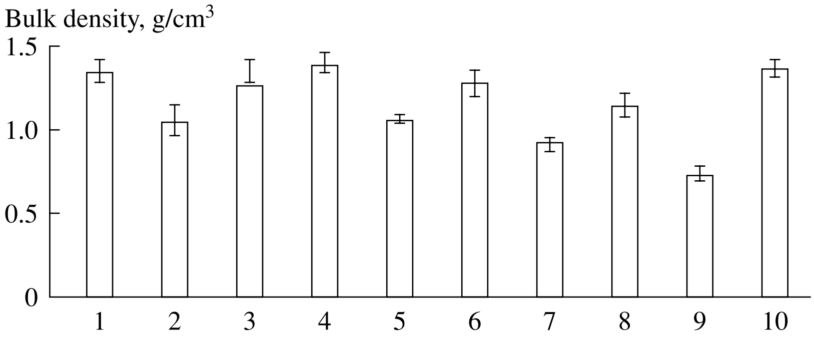

Fig. 1. The density of soils. The designations here and in Fig. 2: new territory: 1—footpath, 2—duck cage, and 3—bongo cage; old territory: 4—white-tailed gnu cage, 5—footpath, 6—musk ox cage, 7—cassowary cage, 8—emu cage, 9—black-necked crane cage, and 10—guanaco cage.

RESULTS AND DISCUSSION

It is common knowledge that urbanozems considerably differ from natural soils in their physical properties. The particle-size composition is an important characteristic and determines the productivity of urban soils, the degree of filtration, and the water-holding capacity. The soils in the open-air cages and outside them in the territory of Moscow Zoo are represented by light loams and loams that are optimal for most plants. However, the depth of the biogenic layer is not more than 10 cm. It is insufficient for plants and may be a reason (limiting factor) for the deficiency of nutrients and moisture [4].

The compaction of the soil affects the moisture absorption, the gas exchange, the development of the plant root systems, and the intensity of the microbiological processes. The optimal density of urban soils for the development of plants varies from 0.9 to 1.2 g/cm^3 [4]. Strong compaction of the soil in the root-inhabited layer leads to the creation of conditions close to anaerobic ones, especially in the period of prolonged spring and autumn rains. Under these conditions, the growth of fine (active) roots of woody and herbaceous plants is retarded and the natural regeneration of vegetation is disturbed [1, 4]. The density of the soils investigated varied from 0.6 (the cage of black-necked cranes) to 1.5 g/cm^3 (the cage of a white-tailed gnu) (Fig. 1). In the new territory (a plot with ducks), the soil density was lower and differed significantly from the others. The effects of Zoo visitors on the soil were comparable to the influence of antelope bongo. In the old territory, even-toed undulates (white-tailed gnus, musk oxen, and huanacos) most strongly affected the soil.

The comparison of the data from the two territories using the factor analysis (ANOVA, the factor is the type of animal) showed that the density of the soils in the bird cages was significantly lower than in the cages of the even-toed undulates. It was close to the density of the soils in the territory visited by people ($F = 34.11$, $P < 0.001$). The results of the ranking evidenced that 57% of the samples had the optimal values of the density, 29% were weakly compacted, and 14% showed medium density. Values of the density > 1.5 g/cm^3 were not revealed in the studied territory; some partial decrease in the moisture adsorption and aeration was possible, but it did not affect the plants of the Zoo.

Owing to the problem of soil salinization with electrolytes under urban conditions, an integral physical index of the electrical conductivity of the pore solutions was used [4]. Salinization is an adverse physical phenomenon, since salts in high concentrations create considerable osmotic pressure, thus lowering the availability of moisture. According to the results obtained, the soils of the Zoo are referred to nonsaline ones (Ec < 2 dS/m), and plants may not be depressed (Fig. 2). A single exception is an area outside the cages (a territory for visitors) with very weakly saline (2.26 dS/m) soils. In this case, some plants (bulbiferous, roses, fruit trees, and shrubs) sensitive to salinization may be depressed [3]. Theoretically, excretions of large animals (musk oxen, gnus, antelopes, etc.) could increase the salt concentrations in the soils. However, under the conditions of the normal water conductivity and abundant precipitation, soluble salts do not accumulate in the root-inhabited layers.

The acidity of the root-inhabited soil layers of the urban soils ranged widely, but the soils with neutral and weakly alkaline reaction predominated. In most cases, the reaction of the urban soils was greater than that of the reference zonal soddy-podzolic soils. The majority of specialists consider that this fact is related to the input of cement dust, rubbish, and deicing agents containing alkaline and alkaline-earth metals producing the corresponding reaction of the water solutions. Indirect evidence of this fact is the decrease in the pH values with depth in Moscow soils. The increase in pH values almost reaching the neutral ones favors the growth of most plants and activation of microorganisms and promotes the binding of some soluble compounds of heavy metals. However, further alkalization might lead to the formation of difficultly soluble forms of some nutrients and microelements. The acidity of soils beginning from pH values of 8–9 makes the soil unsuitable for the growth of most plants [1, 4].

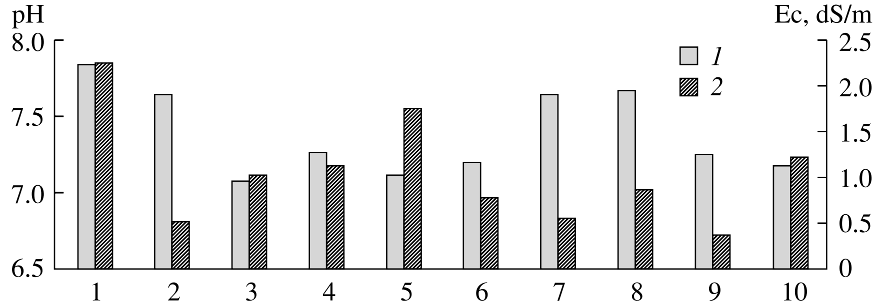

Fig. 2. The acidity and salinization of soils.

The soils of the Zoo had a neutral (60% of the samples) and weakly alkaline (40%) reaction. The weakly alkaline were the soils in the cages of the cassowary and emu, in the territory near the pond for waterfowl, and outside the cages (Fig. 2). The alkaline reaction of these soils appears to be due to the application of deicing agents, since snow taken away from paths of the Zoo often falls on these areas. Although the status of the soil cover is assessed as normal for the present, the salinization and acidity of these territories should be permanently controlled.

The temperature and water regimes determine the survival ability and development of green stands; therefore, long-term monitoring is needed of the regime parameters. The W/W_s criterion takes into account the specific features of the water–air regime of the soils. The latter can be characterized by both an excess and deficiency of moisture unfavorable for plants. A coefficient of $W/W_s > 9$ reflects excessive moistening of soils similar in texture, while $W/W_s < 0.3$ points to droughty conditions [4]. The monitoring of the water–air regime (the degree of moisture saturation using W/W_s) in the root-inhabited layer showed that, during the growing period of 2006, the moisture in most of the cases (66%) was optimal for plant growth. In 10% of the cases, an insignificant deficiency of moisture was noted; in 24% of the cases, the soils were excessively moistened. The data for the growing period were as follows: 55% of the values were within the optimum, 38% reflect a water deficiency, and 7% reflect excessive moistening (Fig. 3). A seasonal decrease in the soil moisture during the lack of precipitation appears to be characteristic of Moscow urban soils [3]. Since this factor is very important, the creation of stationary irrigation systems is recommended, as well as artificial drainage of the territories covered with vegetation, in order to provide a favorable water–air regime for the soils and optimal conditions for both the plants and inhabitants of the Zoo.

Based on the data of monitoring the temperature regime (Fig. 4), the conclusion was reached that, on the whole, the situation in the Zoo is favorable for the development of plants. In the winter, the root-inhabited layer of the soils is not frozen for a long time; in the summer, even in the droughty period, extreme temperatures are not observed. Over the whole depth of the soils, on the average, 5% low temperature (0–5°C) values were recorded, and 16% of the values characterized moderately cold (5–10°C) temperatures. Values of high (20–30°C) temperature were found only for 1% of the measurements [4]. On the whole, in the Zoo, the temperature conditions for plants and soil microflora are normal.

The biological properties and parameters characterizing the functioning of the soils studied are given below. The results of the respiration intensity measurements testify to the low biological activity (Fig. 5) and inhibition of the soil microflora. According to the scale proposed, very low (<2 mg O_2/kg/yr) biological activity was recorded in 43% of the samples; low (2–4 mg O_2/kg/yr) biological activity was determined in 57% of the samples [3]. Despite the great amounts of organic matter entering the soil from the animals, the low biological activity can evidence the possible presence of pollutants of both mineral and organic origin [6, 7]. Since, in the last years, the number of cars has increased, the heavy metal contents have also became higher in the urban soils [1]. In addition, it is not inconceivable that

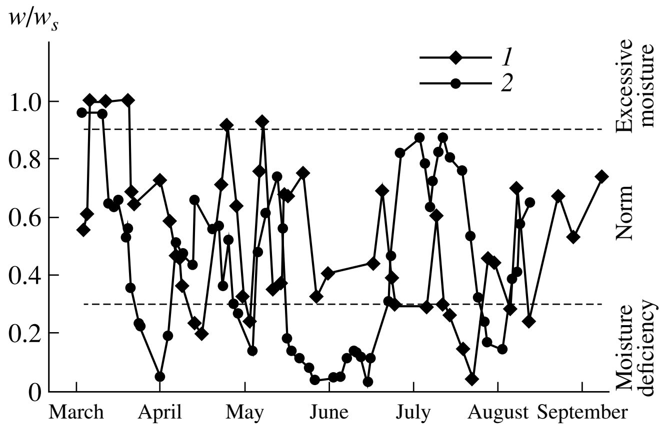

Fig. 3. Changes in the water–air regime of the soils for the growing periods of 2006 (*1*) and 2007 (*2*).

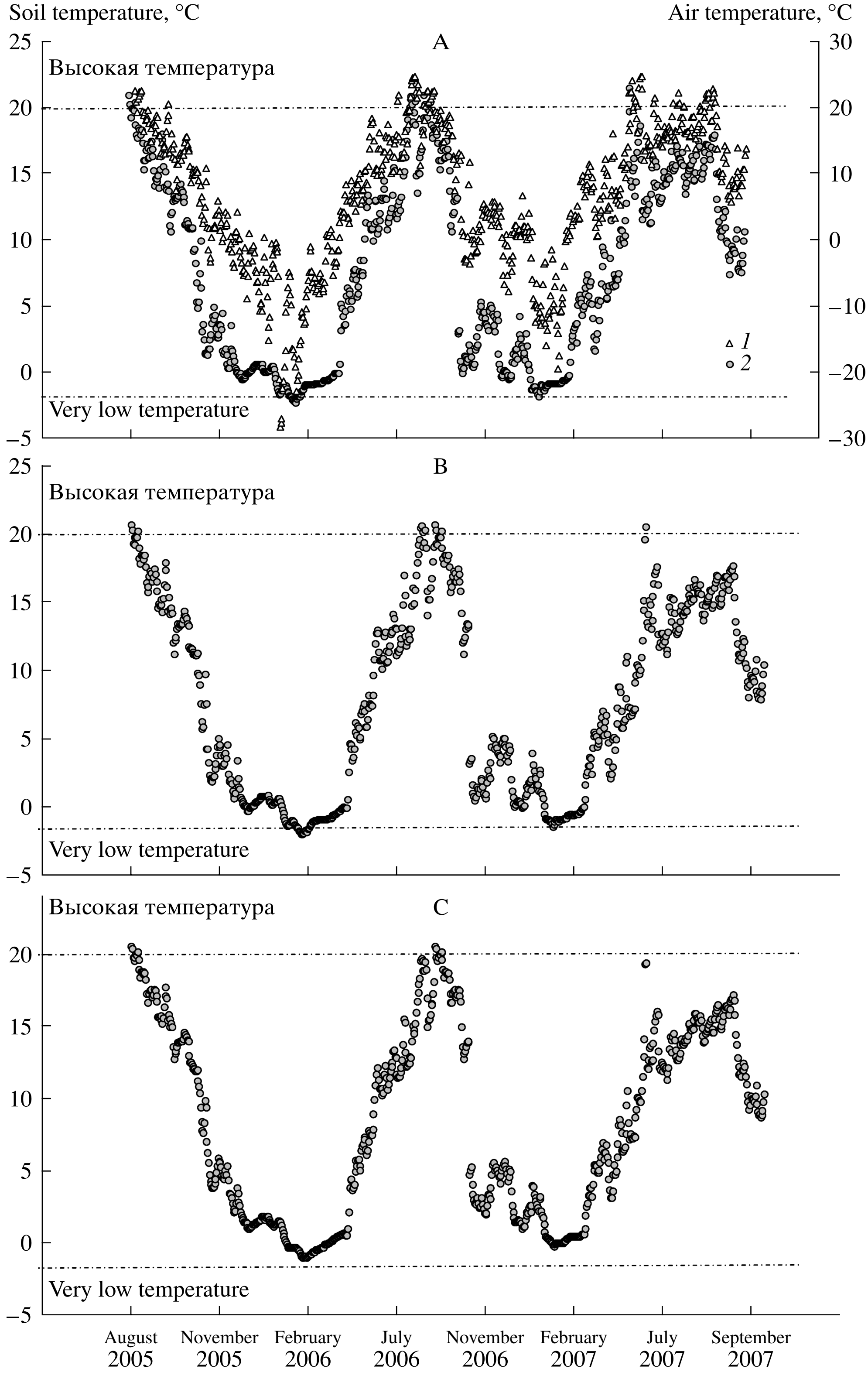

Fig. 4. Changes in the temperature regime of the air and soils in the shade for the study period. A—soil (*2*), depth of 5 cm and atmosphere (*1*); B, C—soils, depths of 10 and 20 cm, respectively.

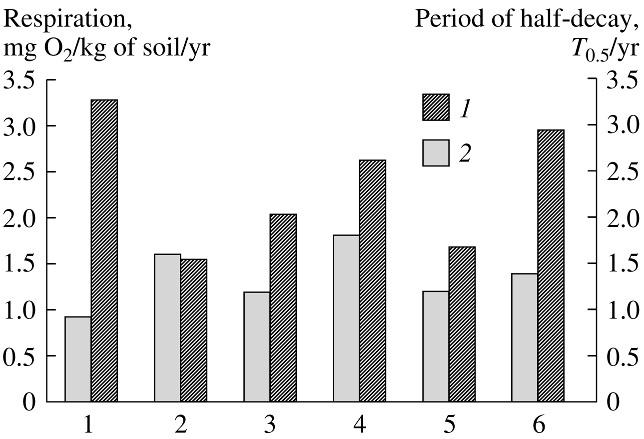

Fig. 5. The biological activity of the soils: respiration intensity (*1*), half-decay period (*2*). Designations: 1—musk ox cage; 2—white-tailed gnu cage; 3—black antelope; 4—footpath; 5—duck cage; 6—guanaco cage.

specific biotoxins of microbial and animal origin have entered the soils with metabolites.

Similar results that attested to the inhibition of the biological activity in the soils studied were obtained in the course of the field experiment on the destruction of the test substrate (matches). The lowest biological activity was registered in the soils of the paths (half lifetime 1.8 ± 0.4 yr) and of the musk oxen's open-air cage (0.9 ± 0.1 yr). In the other cages, the data on the biodestruction were equalized and varied from 1.2 ± 0.05 to 1.6 ± 0.09 yr. At the same time, the results of the test for the biodestruction and respiration intensity confirm the insufficient activity of the microbial cenosis in the soils studied. The negative trend revealed for the soils of the Moscow Zoo can have significant consequences for green plantations and animals (the inhabitants of the open-air cages). The low microbiological activity of the soils under the green plantations means inhibition of the natural cycle of nutrients and a gradual decrease in their productivity. From the aesthetic standpoint, the low biological activity of the soils in the Zoo results in the difficult decomposition of organic substances (waste of animal origin and garbage) and can cause unfavorable consequences: the accumulation of organic waste on the soil surface, bad smells, etc. The inhibition of the biological activity of the soils may be accompanied by the growth of infectious diseases of the interior organs and skin of animals [9], since, in these soils, hazardous compounds and pathogenic microflora accumulate, as well as germinative forms of animal and human parasites, eggs of helminthes, larvae of animal and human parasites, etc. [8]. One can recommend conducting sanitary–epidemiological studies and performing an analysis of the pollutant concentrations in the soils investigated. As the toxicity and infection of the objects will be confirmed, measures for their remediation to improve the ecological situation for both the animals and visitors to the zoo should be elaborated. The application of biostimulators (humates and strains of useful cultures of microorganisms) in the background of mechanical treatment and washing of the soils is recommended for the optimization of the biological activity of the soils.

CONCLUSIONS

(1) In the territory of the Moscow Zoo, artificial soils—sandy–loamy and loamy constructozems with a filled humus layer 10 cm thick—predominate.

(2) Unfavorable physical conditions for the development of plants and microflora (a deficiency of water and/or air) in the Moscow Zoo sporadically develop, and the probability of their appearance may reach 35–45%.

(3) The temperature regime of the soils is rather favorable; the frequency of occurrence of low and high temperatures unfavorable for plant roots does not exceed 10–16%.

(4) No strong compaction and salinization of the soils in the Zoo was revealed. The soils of the Zoo differ significantly from the majority of urban soils, for which these features are characteristic.

(5) The soils have a neutral reaction and are more rarely weakly alkaline in the absence of or with weak salinization with electrolytes in the open areas along the roads available for visitors.

(6) A low biological activity correlating with the weak decomposition of organic matter in all the soils was determined. This fact appears to be a result of technogenic pollution of the soils or accumulation of exotoxins of microbial origin.

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