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SOIL CONDITIONS IN THE GREEN AREAS OF SAINT PETERSBURG

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Currently, there is a high rate of urbanization, resulting in the degraded natural environment, especially the soil. The article presents the results of 25-year investigations of the silvicultural soil characteristics of the ecosystems of St. Petersburg of varying degrees of urbanization. The metropolis territory was flooded by the waters of the Littorina Sea a few million years ago. Some terraces with different levels A.S.L. after the dereliction of the sea were formed. The authors propose the urban ecosystems classification for St. Petersburg, based on the similarity of the morphological and ecological features of the biotope, and give a brief characteristic of an anthropogenic effect. The urban ecosystem soils are presented by the fill ground, contaminated with heavy metals and compounds of sodium and chlorine and contain construction debris and wood residues. 4 degrees of an anthropogenic effect on the metropolis natural ecosystems are obtained: low-disturbed (urban forests), averagely disturbed (city parks), highly disturbed (gardens and parks) and degraded (line plantings and plantings of habitable territories). The boundaries of the urban ecosystems are numerous waterways. The ecological state of soil and plant resources is estimated according to a set of criteria: botanical, biochemical, soil, spatial and dynamic. Representative objects with laying out of at least 5 soil profiles in the specific areas for each ecosystem are selected and examined. Control samples were taken from the upper soil horizons. They were the basis to establish in the laboratory the silvicultural parameters of the root zone in a 5-fold repeatability. The exchangeable and hydrolytic acidity, total absorbed bases, degree of base saturation, humus level, mobile nitrogen and labile phosphorus, exchange potassium and sodium, chloride and physical clay content, humidity, soil density and a groundwater level were determined. These silvicultural parameters of the root zone of soil were compared for the selected urban ecosystems. The soils in the urban ecosystems vary according to the particle size distribution, agrochemical properties and transformation ratio of the soil profile. They are in need of the urgent measures for their improvement. A sustaining tactic of the natural ecosystems is proposed.

Keywords: urban ecosystem, garden, park, forest park, linear plantation, residential area, physical and chemical property of soils.

Introduction. A typical feature of the modern era is the rapid urbanization. It modifies or destroys the natural environment from both the quantitative side (capture of new lands) and qualitative (environmental degradation). In St. Petersburg the environmental problems, associated with the deterioration of habitats of five million residents due to the insufficient and poor ecological condition of the soil and plant resources, are escalating. More than ten varieties of soils, differing in properties and a fertility level on the territory of St. Petersburg are determined. Little attention is paid to the analysis of the processes of establishing, formation and regulation of the natural and anthropogenic urban ecosystems of St. Petersburg. Soil and vegetation complexes of the megalopolis are investigated poorly and fragmentary [2, 4]. The level of an anthropogenic impact on the soil and plant complexes varies considerably by eco-polarities of the metropolis [3, 6]. Complex research at the ecosystem level of this important regional issue is conducted for the first time.

The soil cover of St. Petersburg due to its geographical location has several features. The territory of St. Petersburg was under the influence of the see and was flooded by the waters of the Littorina Sea a few million years ago. After the retreat of the sea the lake-glacial terraces with different levels of altitude were formed. The floodplain soil formation process has stopped due to the "dressing" of the embankments in stone. In addition, the soil profile is disturbed as a result of the human activities. It is formed on the alluvial soils and filled grounds mainly of the light particle-size distribution and contains the inclusions in the form of construction debris, wood residues, heavy metals, sodium and chlorine compounds because of the use of the technical salt as a deicing agent in winter.

Materials and methods. Taking into account the agglomeration features, degree of the soil cover disturbance and sanitary condition of tree and shrubbery vegetation we distinguished different soil and vegetation urban ecosystems that are the synonymous of the geographical concept of "a standard urbanized zone" [3]. Not only the urban green areas, but also the suburban forest-parks are included in the urban ecosystems, as the urbanization effect extends far beyond the city boundaries. Urban ecosystems boundaries in St. Petersburg are numerous waterways.

In St. Petersburg on the basis of the similarity of morphological and ecological features of an anthropogenic biotope [1, 3] the ecosystems of different levels are distinguished (table 1).

Megaecosystem is a complex of a soil-vegetation cover of a large agglomeration and its suburban forest parks. The scale of perturbations exceeds the diameter of an area of over 100 km.

Macroecosystem consists of a soil and vegetation cover of the suburban areas of St. Petersburg at a distance of 60 km from the city center. The scale of disturbances does not exceed an area of 50-100 km^2.

Mezo ecosystem is formed by the vegetation of the city with the area exceeding 100 ha (parks, large gardens).

Microecosystem includes the vegetation of residential territories and linear plantations along the highways. These artificial plantations of trees and shrubs do not form a closed stand canopy.

Table 1

Classification and characteristics of St. Petersburg urban ecosystems

Type of ecosystem	Type of vegetation	Degree of anthropogenic disturbance	Biological productivity	Level of stability	Tactics of sustaining
Megaecosystem	City and forest park plantations	Medium	Medium	Medium	Increasing the area of plantations, enguring bio-diversity of plants, care for them, applica-tion of organic fertilizers in the soil, etc.
Macroecosystem	Forest parks	Moderate	High	High	
Mezo ecosystem	Parks and gardens	Medium	Medium	Low	
Microecosystem	Plantings of residential areas	High	Low	Low	
	Linear plantings, clumps and groups	Very high (degraded)	Very low	Very low	

Ecosystem of each morphological level has its circulation of elements. Its basic substances and energy components are the energy, gas composition of the atmosphere, water, soils, autotrophic plants and heterotrophic organisms. The nature and direction of the environmental changes vary and depend on several variables: a) the size of the system (the larger it in size, the less it depends on the external influences); b) exchange of matter and energy intensity (the higher the inflow and outflow of matter and energy in the ecosystem, the more intensive this process); c) the balance of autotrophic and heterotrophic processes in the ecosystem (in strong disequilibrium, the external inflow of matter and energy in the ecosystem is increased to recover it); d) a stage and a level of the ecosystem development [3]. In the bio cycle process the variety of substances and sustainability increase in the ecosystems, the balance and self-regulation are maintained, which is based on the "feedback", regulating the composition, quantity and productivity of the living components of the ecosystem [3, 4]. Man introduces the significant changes in the ecosystems by creating the urban infrastructures that change the habitat of plants and humans, form the urban ecosystems. We conducted our system researches in view of the proposed classification of the urban ecosystems.

Ecosystems dedicated in St. Petersburg vary in size, metabolic and energy rate, age and ecological conditions of trees and shrubs, amount of autotrophic and heterotrophic organisms, level of air, water and soil pollution, its physical and chemical properties.

For each ecosystem the representative objects of the research were chosen: macroecosystem – Kurortny Forest Park; mezo ecosystem – the parks (Tikhiy otdykh,

Aleksandrino, Sosnovka, Aleksandrovskiy, Babolovskiy, Ekaterininskiy, Otdel'nyy, Pavlovskiy, Dubki) and gardens (Vasileostrovets, Kamskiy, a garden named after 9th of January); microecosystem – plantations of the residential areas (municipal units (MU) "Strelna", "Peterhof", "Pavlovsk") and linear plantations (6 boulevards and 9 streets in various districts of the city).

Physical and chemical properties of soils were investigated according to the standard methods: the mechanical structure – by Kachinsky method; the reaction of the soil environment in saline suspension on the potentiometric base – by pH-meter 673 M; physical clay was determined according to the GOST 12536-79; the exchangeable acidity – by Daikuhara method; hydrolytic acidity – by Kappen method; total absorbed bases – by Kappen-Gilkovits method. Carbon of organic compounds was determined according to Tyurin method in the modification of Nikitin and Fishman with the humus calculation by Wolff-Sprengel method; nitrogen of the easy hydrolysable organic compounds was estimated by Kornfeld method in the modification of Dinchev and Badzhov and clarifications of the Agrochemistry Department of V.V. Dokuchaev Soil Science Institute; the definition of labile phosphorus was carried out by Kirsanov reaction according to Denizhe method in the modification of Truog and Meyer; and exchange (mobile) potassium was determined by Kirsanov reaction by the flame photometry method (flame photometer FPM).

At least 5 soil profiles were carried out in the forest parks, and 14 – in the historical part of the city. Parks in the central part of the city are the subjects of the intense anthropogenic impact. So, the low, average and high degrees of soil disturbance in this mezo ecosystem are determined.

Results and discussion. Table 2 shows the averaged parameters of the ecosystem soil profiles of the silvicultural properties of soils that allow us to make the following generalizations.

In the forest-park macroecosystem the superficial and cryptopodzolic soils are characterized by a strongly acid reaction, increased potential acidity, low content of absorbed bases and a low degree of the soil colloidal complex saturation. The supply of soil by humus varies greatly, but the level of humus is favorable for the forests; there is a lack of nutrients, especially of nitrogen. Acid-base properties of soils and their nutrient status indicators are typical for the natural light coniferous and deciduous-coniferous associations formed on the sands or sandy loams under normal moisture.

In the park mezo ecosystem of the historical part of the city the different degrees of soil disturbance are recognized. Turfy cohesive sandy low-clayed anthropogenically transformed soils often with the second humus (buried) horizon on the sandy loam sediments dominate in the soil cover of the center of St. Petersburg. In the historical part of the city we have identified three groups of soils according to the levels of the anthropogenic impact.

Table 2

Soil Silvicultural Properties of the Ecosystems of St. Petersburg

Silvicultural parameters of a root zone	Units	City megaecosystem							
		Macro Ecosystem. Forest-parks	Mezo ecosystem					Microecosystem	
			Parks of megalopolis			Satellite towns	Gardens of the historical center	Phytocenosises of residential areas	Linear plantations
			Historical city center						
			Degree of soil disturbance						
			Low	Average	High				
pH of saline suspension	–	3.3-4.5	4.5-6.4	5.2-5.8	5.3-6.7	4.3-5.8	6.3-6.8	5.0-7.5	6.2-7.1
Exchangeable acidity	mg-eq/100g	1.1-3.8	0.1-1.7	0.2-0.3	0.1-0.2	0.3-1.1	0.1-0.2	0.1-0.3	0.1-0.2
Hydrolytic acidity	mg-eq/100g	4.7-8.0	1.5-6.8	1.9-4.2	1.3-1.8	5.1-14.7	1.7-2.1	0.5-2.6	0.5-0.7
Total absorbed bases	mg-eq/100g	1.1-1.6	8.7-28.2	11.6-20.8	5.2-43.7	9.8-17.8	30.5-47.0	3.3-22.9	30.0-48.0
Adsorptive capacity	mg-eq/100g	6.3-9.1	15.5-29.7	15.8-22.7	7.0-45.0	23.0-24.5	32.6-48.7	5.9-23.4	30.7-48.5
Degree of base saturation	%	12-25	56-95	73-92	74-97	40-78	94-97	56-98	98-99
Humus content	%	2.9-6.2	3.7-10.0	2.6-8.5	1.5-13.7	3.1-5.3	5.5-7.8	3.5-5.6	4.9-9.6
Mobile nitrogen	mg/100g	1.1-1.7	3.0-4.9	3.2-4.3	2.8-6.2	2.6-5.1	2.7-3.9	1.4-2.5	2.8-4.3
Labile phosphorus	mg/100g	4-6	18-23	15-23	14-27	8-10	19-24	14-17	24-35
Exchange potassium	mg/100g	3.2-4.7	5.5-7.5	4.5-10.5	3.6-17.0	9.8-17.5	16.0-21.0	6.0-15.0	19.0-27.0
Exchangeable sodium	mg/100g	5.1-15.0	10.0-15.0	17.0-20.0	20.0-23.0	10.0-18.0	20.0-25.0	13.0-37.0	40.0-70.0
Chloride content	$1 \cdot 10^{-3}$ %	1-2	2-3	2-4	2-5	2-3	6-9	4-7	20-40
Physical clay	%	7-13	7-25	8-19	8-13	21-43	5-10	10-30	7-10
Soil density	g/cm^3	1.1-1.2	0.9-1.1	1.1-1.2	1.0-1.3	1.2-1.3	1.0-1.2	1.2-1.4	0.9-1.2
Soil moisture	% from SM	35-48	45-70	40-65	30-70	40-80	50-70	30-60	45-65
Groundwater level	m	1.0-1.2	0.2-1.2	0.8-1.4	0.7-1.5	0.8-1.0	0.9-1.0	0.7-1.3	1.0-1.4

Up to 43 % of the territory is occupied by highly disturbed soils. In the structure of such soils the bulk humus layers ranging 18…59 cm are presented, as well as the buried organic-mineral (sometimes peat) horizons. Waste of construction materials containing calcium carbonate (broken stone, lime, etc.) affect the soil acidity. In soils, located outside the building areas, the buried horizons have slightly acidic, but more often near-neutral reaction. Different amounts of humus and nitrogen are accumulated in the upper soil layers. The amount of humus decreases down the soil profile.

Total provision by the nitrogen compounds in the soil profile within the root system layer is sufficient. Buried humus horizons are an additional source, supplying trees with nitrogen compounds. Phosphorus nutrition regime is favorable for plants; procuring of soils by potassium varies from a low to a high level. Despite the strong disturbance of soils, procuring of soils by phosphate does not fall below 14 mg/100 g. The main fund of highly disturbed lands of St. Petersburg consists of the soils with widely varying fertility.

Averagely disturbed soils in the soil cover of the historical center of St. Petersburg (27 % of the total area) are characterized by the large depth (73-112 cm, at least – 44 cm) of the humus layers and by the light particle-size distribution (sandy loam or cohesive sandy). Thick humus-accumulative horizons consist of humus-gleyish, humus-gleyic and typical humus-accumulative subhorizons without the gleying indicators (Ag, AG, A). Water saturation affects on the soil acidity. The acidity decreases down the soil profile reaching the minimum parameters in loose sandy sediments underlying the turf sandy loamy gleyic soil.

Averagely disturbed soils are classified as anthropogenically bulk varieties with the thick humus-accumulative horizon which is divided into 2-3 humus layers. In depth the gley formation process is enhanced: gleyish subhorizons are replaced by the gleyic ones. Turf deep-podzol sandy loam gley soil based on the sandy loam sediments we can add to the group of the averagely disturbed soils according to the morphological characteristics and profile structure. Humus layer of that soil is of clearly bulk origin. Soil supply by humus and nitrogen is medium; minimum content of humus is in the podzolic horizon that is typical for the turf-podzol soils. Averagely disturbed soil is well supplied with phosphorus, but supply with potassium is low, sometimes is medium.

The third group is represented by the low disturbed soils (30 % of the total area) having significantly differentiated profile with several genetic horizons. Humus-accumulative horizons are formed under the influence of the anthropogenic factors. Often we observe the soils with the homogeneous humus-accumulative horizons according to their mechanical composition: light loamy (up to 60 cm) or cohesive sandy (up to 35 cm). Humus content varies noticeably. Procuring of soils by the humus compounds is so different, that is estimated at four levels: not enough supplied soils, averagely, well and highly supplied. The actual soil fertility of this soil group we have evaluated ambiguously due to the different content of mineral nutrients in the soils. Low disturbed soil is well supplied with nitrogen of easy hydrolysable organic compounds. The content of labile phosphorus in the organic-mineral soil layers varies

in the frame of increased and high degree of supply. The low or insufficient degree of supply by exchange potassium is typical for the low disturbed soil group.

Analysis of the results of the long-term soil research leads to the conclusion that the soil cover of parks of the historical center of St. Petersburg consists of turfy sandy loam or cohesive sandy (rarely loamy) gleyish and gleyic (less gleyed) soils based on the sandy deltaic sediments. Based on the results of the long-term research for the first time for St. Petersburg we composed the soil cartograms of the mezo ecosystem according to the hydromorphic feature degree, mechanical composition, acidity, humus content, hydrolyzable nitrogen, exchange potassium and labile phosphorus.

In the gardens of the historical center (mezo ecosystem) there are more fertile sandy soils than in the urban parks. They are characterized by a reaction close to neutral, low potential acidity, high saturation of absorbed bases. Soils of the gardens are well supplied with humus, phosphorus and potassium, and averagely with nitrogen.

In the park mezo ecosystem of the satellite towns the degree of the soil disturbance is lower, despite the fact that the parks of the open-air museums "Tsarskoye Selo" and "Pavlovsk" are intensively visited by sightseers. The soil profiles of the suburban areas are marked by weighting of the mechanical composition: the soil layers with the average loamy composition dominate, and the soil overwetting is observed. Judging by the particle size distribution the soils are characterized by high potential fertility.

Parks of the satellite towns are located on the soils, to a lesser extent changed by the anthropogenic impact than the urban plant communities. According to the morphological nature and silvicultural properties the soils of the suburbs parks take an intermediate position between the soils of the forest parks and the soils of the city center. They have lower acidity and higher base saturation than the soils of the forest parks, but do not reach the acid-base indicators of the soils of the historical center parks. Soils of the satellite towns have the acidic or low-acidic reaction, increased potential acidity and the average degree of base saturation. An important feature that distinguishes them from other soils of the mezo ecosystem is the loamy particle size distribution. Soils of the suburban parks are moderately supplied by humus and mineral nutrient elements. Their trophogenic fertility is higher than of the soils of the forest parks. They are better supplied with potassium, but contain less phosphorus than the soils of the parks in the central part of the city.

Microecosystems of residential areas are characterized by a very high soil density of the heavy-loamy composition; surface cracking of the top soil in the summer period; low humusness and a strong disturbance of the organic-mineral soil horizons. The humus layer in many parts of the territory was removed due to its shallowness and the mineral horizon A_2B was exposed. Heavy loam soil is characterized by the acid reaction. It is not enough supplied by humus. Supply of soil by nitrogen of the light hydrolyzed organic compounds is average, by labile phosphorus is very high and by exchange potassium is low. Mineral nutrition regime is unfavorable for plants: a shortage of potassium on the background of nutrient imbalance is observed.

Soil of residential areas can be classified as a sod-podzolic heavy loamy semi terrestrial type with the low level of cultivation. Such soils are typical for the Neva terrace plain, which is one of the soil-geomorphic subareas of the Neva Lowland.

Linear plantations are planted on sandy soils with a slightly acid or neutral reaction. They are well supplied with humus, phosphorus and potassium. Their procuring with nitrogen is above the average level. A positive factor of the soil fertility of the linear plantations is the presence of the significant amount of alkaline bases in the soil-colloidal complex. Humus content in the top soils corresponds to a very high degree of supply. Humus composition is positive due to the presence of calcium salts, humic and fulvic acids. Quantitative and qualitative parameters of humus indicate the high potential fertility of sandy loam soils.

The results of the research indicate the soil contamination by the ecotoxicants as the main reason of plants poor condition in the residential areas but not the regime of the mineral nutrition of soil. Saturation of urban soils with the sodium compounds is explained by the anthropogenic impact and using sodium chloride as a deicing agent. The presence of a large amount of sodium blocks the normal conditions of the plant root nutrition and impairs the physical, chemical and biological properties of the soil. Consequently, one of the reasons of death or depressed condition of linear plantings along the streets and highways is the high content of exchangeable sodium and chlorides in the soil. A big amount of water-soluble sodium in soils demonstrates sodium salinization of the root zone. The presence of sodium in the soil solution has a negative influence on the adsorption of nutrients by plant roots [5].

Thus, the soils of the microecological system have the maximum anthropogenic pressure, compared with the soils of the forest parks and gardens, which negatively affects on the condition of biogeocoenosis.

Conclusions. As a result of the anthropogenic impact the physical and chemical properties of soils in the green areas of St. Petersburg change. Silvicultural properties of the forest-park ecosystems are close to the forest features of the taiga zone. The soils in the park mezo ecosystem of the historical part of St. Petersburg differ in particle size distribution, agrochemical properties and degree of transformation of the soil profile. Soils of the parks of the satellite towns take an intermediate position between the forest and urban soils by the morphological structure and silvicultural properties. In the gardens of the historical part of the city the fertile soils due to the use of organic and mineral fertilizers are formed. Maximum degree of disturbance of organic-mineral horizons and their sodium chloride salinity are typical for the microecosystems of residential areas and linear plantations. Human activities and the composition of the parent rock materials have a decisive influence on the soil trophic level in the urban ecosystems. The soils of the city urban ecosystems need of the urgent measures to improve their silvicultural properties in order to increase the sustainability and survivability of green plantings.

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Состояние почв в зеленых насаждениях Санкт-Петербурга

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В настоящее время отмечаются высокие темпы урбанизации, в результате которой разрушается естественная природная среда, особенно почва. В статье приводятся результаты 25-летних исследований лесорастительных свойств почв экосистем Санкт-Петербурга различной степени урбанизации. Территория мегаполиса несколько миллионов лет назад была затоплена водами Литоринового моря. После отступления моря сформировались террасы с разным уровнем над уровнем моря. Для Санкт-Петербурга авторами предложена классификация урбоэкосистем, основанная на сходстве морфологических и экологических особенностей биотопа, дана краткая характеристика антропогенного воздействия. Почвы урбоэкосистем представлены намывным грунтом, содержат строительный мусор и древесные остатки, загрязнены тяжелыми металлами и соединениями натрия и хлора. Выделены 4 степени антропогенного воздействия на природные экосистемы мегаполиса: малонарушенные (пригородные лесопарки), средненарушенные (городские парки), сильнонарушенные (сады и скверы) и деградированные (линейные и аллейные посадки и насаждения селитебных территорий). Границами урбоэкосистем являются многочисленные водные артерии. Экологическое состояние почвенно-растительных ресурсов оценивали по комплексу

критериев: ботаническому, биохимическому, почвенному, пространственному и динамическому. Для каждой экосистемы подобраны и обследованы представительные объекты с закладкой не менее 5 почвенных разрезов в характерных местах. Из верхних горизонтов почвы брали опытные образцы, по которым в лаборатории устанавливали лесорастительные параметры корнеобитаемого слоя почвы в 5-кратной повторности. Определяли обменную и гидролитическую кислотность, сумму поглощенных оснований, степень насыщенности основаниями, содержание гумуса, подвижных азота и фосфора, обменных калия и натрия, хлоридов и физической глины, влажность, плотность почвы и уровень грунтовых вод. Полученные лесорастительные параметры корнеобитаемого слоя почвы сравнивали по выделенным урбоэкосистемам. Установлено, что почвы в урбоэкосистемах различаются по гранулометрическому составу, агрохимическим свойствам и степени трансформации почвенного профиля, нуждаются в срочных мерах по их улучшению. Предложена тактика сестайнинга природных экосистем.

Ключевые слова: урбоэкосистемы, сады, парки, лесопарки, линейные насаждения, жилые районы, физико-химические свойства почв.

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