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Technology of creating soils of natural zones in "Zaryadye Park" in Moscow

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Abstract. When creating "Zaryadye Park" in the center of Moscow, the tasks of creating soil constructions and artificial plantations were solved. The task was to form landscape-analogs of all natural zones of the European territory of Russia from tundra to subtropics in one small park in the center of Moscow. Based on the climatic conditions of the city, the selected range of plants, recreational load and the regime of visiting the park, a certain structure of soil cover was suggested, which is formed on the roof of underground constructions. The creation of fertile substrate and vegetation cover lasted from October 2016 till June 2017. 2 months after the planting had been completed, the first determination of soil properties in various types of forest stands was carried out.

1. Introduction

"Zaryadye Park" is the central and youngest park in Moscow. The park was created in 2015-2017 in the place of the demolished building of the hotel "Russia" on an area of 10 hectares. In accordance with the project of the park proposed by landscape architect Mary Margaret Jones and architect Charles Renfro the placement of the following zones is provided: tundra, forest zone, meadows and steppes. The forest zone is divided into 4 subzones - coniferous forests (separate planting of pines and spruce), birch groves, deciduous forests and floodplain forests [1]. When creating a complexly organized structure of soil and vegetation cover, it was necessary to comply with a number of requirements, based on the concept of the park:

1. Creating conditions for successful growth and development of plants from different climatic zones (from USDA 3 to 8) in the conditions of the center of Moscow, which belongs to the USDA zone 5 [2].
2. Solving the problem of growing natural plants in a polluted atmosphere of the city center.
3. Following the concept of a barrier-free environment proposed by architects, when visitors of the park have the opportunity to move freely around the grass cover.
4. Short deadlines of creation. Less than 1 year passed from the planting of the first plants to the opening of the park, the plants did not have time to take root and grow stronger.

The selection of the range of plants was based on the principle of vegetation zonality in Russia. The projected plants should be representative for each of the created natural zones of the European part of Russia and have high decorative characteristics. The main objectives of this work were: (1) developing the structure of the soil cover of the park, which, in fact, is a complexly organized soil construction, (2) developing a technology of forming soil constructions in accordance with a predetermined range of plants.

2. Objects and Methods

"Zaryadie Park" is located in the central part of Moscow, inside the Boulevard Ring and is bounded by streets: Varvarka, Kitaigorodsky Passage, Moskvoretskaya Embankment and Moskvoretskaya Street. The total area of the park is about 10 hectares, of which about 5 hectares are occupied by greenery.

When developing soil constructions, it is necessary to comply with a number of regulatory documents operating in Moscow [3-6].

According to the construction features of the underground structures of "Zaryadye Park", there were no restrictions on the thickness of the soil layer. The underlying layer of soil cover, located directly on the roofs and surfaces of the underground structures and utilities, was compacted sand. In those areas of the park, where there were no underground structures, the native soil (*WRB: Urbic Anthrosol*) is located.

All trees in the park are marked and mapped. In July 2017, at the end of the work on creation of the park, there have been a selective determination of soil physical properties at the monitoring sites of the following areas: with spruce plantings (Spruce forest , area between trees No. 365-366-374-375), birch stands (Birch forest, the area between trees No. 278-279-280 and 150-152-151-177) and the planting of pines (Pine forest, the area between trees No. 210-211-212).

Soil textural classes were estimated in the field by simple field tests and feeling the constituents of the soil [7]. Also, water content, bulk density, penetration resistance were measured by generally accepted methods. The bulk density of the soil was determined by core sampling method when a cylindrical sampler with known volume is hammered or pressed into the soil [8]. The density determinations were carried out three times with three replications during the studied period: in April - in the upper horizons under the tree crown and between trees, at the end of May - after filling the soil in the place between tree crowns and in the soil profile in the Spruce forest, in July - the profile density distribution in all 3 investigated sites (Birch, Spruce and Pine forests). Water content of the soil was determined by thermogravimetric method in three replications [9]. Penetration resistance values were obtained by pocket penetrometer method [10].

3. Results and Discussion

In accordance with the regulatory documents the requirements for soils for urban landscaping are very broad. When developing a technology for creating a fertile soil layer a narrower range of regulations was chosen. It was based on the environmental requirements of plants in different areas of the park. For the formation of the fertile soil layer in all zones except the "tundra", prefabricated soils with specified agrochemical properties and particle size distribution were used. The only area where the agrochemical properties of the soil initially could not meet the requirements for soil, imported into the territory of Moscow, was the Tundra site.

3.1. Technology of laying of a fertile soil layer

The following technology of laying of a fertile soil layer was suggested.

In accordance with the requirements of plants, the proposed thickness of the fertile layer for areas with tree stands was 1 m, for areas with shrubs and herbaceous vegetation, 50 cm [11].

The thickness of the first layer added on top of the leveling sand was 15–20 cm. When laying the fertile soil layer on its surface, cultivation was carried out to form a 10–15 cm thick soil-sand layer. Thus, the creation of sharp boundaries between the sand pad and the fertile soil layer, obstructing free vertical water flow, was prevented. In those cases where a layer of rubble was added on top of the leveling layer (landscape-analogs of steppe and tundra), cultivation was not carried out.

Further, the created transitional horizon was compacted to 1.3-1.4 g cm^{-3}. According to the developed recommendations, compaction should be carried out in dry weather and on dry soil. But in this case the requirement for laying the soil layer was not observed: compaction was carried out regardless of the

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weather and often on wet soil. The placement of the soil was carried out in layers of 20 cm with the accompanying of its compaction to 1.2-1.3 g cm^{-3}. For the upper soil layer, a bulk density of 1.1-1.2 g cm^{-3} was recommended.

After the completion of the backfill, it was suggested to cover the soil surface with black non-woven material to prevent the weed seeds present in the soil from germination. In this state the soil should be 2-3 months in conditions of regular watering (1 time in 2 weeks) with a norm of 100 mm. In addition to maintaining soil moisture, this procedure is aimed to optimize the bulk density and porosity of the soil.

An important issue when using these artificially created soil substrates is the enrichment of their mesofauna providing the decomposition of plant residues, loosening and mixing of the soil. The introduction of earthworms was recommended. In the process of work only one species was introducted to all sites – *Eisenia fetida*.

Requirements for soil constructions were developed considering the characteristics of plant communities and underground structures.

On the plots under the forest (tree-shrub) vegetation it is recommended to form a fertile layer with a thickness of 1 m on a sandy base and 0.2 m on urban soil with full replacement of the soil in the planting pit. Under the steppe, meadow, coastal vegetation and under lawns it is recommended to create the thickness of the fertile layer equal to 0.5 m on the sand and 0.2 m on the urban soil.

Special recommendations were developed for creating soil cover within each plant zone.

Tundra. This is the most difficult part of the park in the conditions of Moscow. Zonal and urban soils of the city are drastically different from tundra soils. To create a landscape-analog, it is necessary to prepare a specific substrate, which according to its characteristics and effect on plants, would approach tundra soils.

The project can be divided into 2 different zones for plants that will mimic tundra vegetation: a zone of high moisture (under willows, marsh vegetation) and a zone with good drainage and moisture deficit (under stonecrop, stonegrass, and other plants growing on rocks).

For the zone of excessive moistening, it was recommended to place a clay layer in the lower part of the soil profile as an impermeable horizon, simulating a natural waterproof layer - permafrost. It was suggested to use a bentonite clay with a thickness of 5 cm, then a substrate of 0.2 m thick (for low herbal plants) and 0.4 m thick (for woody vegetation)) is placed on its surface. The composition of the substrate is: high-moor peat 70%, coarse sand - 30%. The content of organic matter (Corg) was 30-50%, phosphorus and potassium content - 100-150 mg kg^{-1}, pH (KCl) 2.5-4.

Under stonecrops and other groundcover plants which cannot withstand excessive moisture it is recommended to create a soil layer as follows: a 0.4 m layer of granite rubble (fraction 20–40 mm) is added onto a planned surface with a slope of at least 2^{o}, geotextile is laid and a 10 cm layer of rubble or pebbles, in which plants are planted in special seats, is added. A fertile substrate of the following composition is added to the planting seat: silt loam - 40%, coarse sand - 30%, high-moor peat - 30%. The content of organic carbon in the substrate should be 10-20%, phosphorus and potassium content - 100-200 150 mg kg^{-1} of the substrate, pH (KCl) - 4.5-5.5.

It is necessary to mark the site depending on the type of planted vegetation, then form a fertile layer for trees and shrubs, then fill up the rest with rubble and prepare a fertile layer for planting groundcover plants.

Spruce forest. The thickness of the soil layer is recommended to be 1 m. Its soil textural class is silt loam, organic matter content is from 6 to 10%, phosphorus and potassium content is 150-300 mg kg^{-1} of soil, pH (KCl) is 5.0-6.0.

Pine forest. The thickness of the soil layer is also 1 m. The soil textural class is analogous to the soil of a spruce forest with the addition of coarse sand, 25%. Agrochemical parameters are similar to spruce.

Deciduous forest and birch forest. All parameters except acidity are similar to spruce, pH (KCl) is 5.5-6.5.

Floodplain forest. The thickness of the soil layer for shrub and grass vegetation is 0.5 m. For tree crops, it is recommended to completely replace the soil in the planting pit to a depth of 1 m. Composition of the soil substrate: 40% of silt loam, 30% of coarse sand, 30% of lowland peat. The content of organic matter is 10-20%, phosphorus and potassium content 200-300 mg kg^{-1} of the substrate, pH (KCl) is 5.5-6.5.

When planting moisture-loving plants (Bilberry, marigold, etc.) it is recommended to lay a 5 cm thick layer of bentonite clay at the bottom of the planting pit (to a depth of 0.5 m) to create a local water-proof and increase soil moisture.

Dry meadow. The thickness of the silt loamy soil layer is 0.5 m. The agrochemical parameters are similar to birch forest, except for pH (KCl) equal to 6.0-6.5. For this site, additional introduction of earthworms of *Aporrectodea caliginosa* and *Aporrectodea rosea* species in the amount of 5 ind m^{-2} of each species is recommended.

Steppe. The thickness of the soil layer is 0.8 m, of which 0.3 m is a layer of limestone rubble of 20-40 mm, on top of it is 0.5m layer of soil substrate of silt loamy composition with 10% of limestone rubble of 10-20 mm (to enrich the soil with calcium and increase the pH). The content of organic matter is 10–15%, phosphorus and potassium content are 200–400 mg kg^{-1} of soil, pH (KCl) is 6.5–7.2. For the steppe, it is also recommended adding more earthworms of the species *Aporrectodea caliginosa* and *Aporrectodea rosea* in the amount of 5 ind m^{-2}.

3.2. Investigation of the soil cover of "Zaryadye Park"

Researches of the actually obtained soil profiles on the territory of individual expositions were carried out in July 2017.

It was found that in May and June, during the final leveling of the territory and the marking of the tracks, the filling of the soil to the zero marks was carried out.

As a result, in Spruce, Pine and Birch forests, the thickness of the fertile layer approached the specified value - 1 m. In all soil profiles a transitional horizon between fertile soil and sandy dumping was found. The presence of this horizon reduces the stagnation of moisture and the formation of air obstruction at the boundaries of layers with contrasting physical properties. In the pine forest the mixing of the layers was not carried out so thoroughly. This led to the formation of numerous thin sandy layers. Even more variegated picture developed in the transitional horizon of pine forest (table 1), consisting of thin layers of sand and soil. Its thickness in this variant was only 15 cm because of close location of the roof of the building. However, the morphological signs of over moistening in the lower part of the soil layer were not found. This is due to the presence of a pronounced slope of this territory. Thus, the entry of large volumes of moisture leads to the formation of lateral (surface and subsurface) water flows and their discharge into the drainage flow.

Table 1. Depth and soil textural classes of soil layers in Birch, Spruce and Pine forests.

Layers	Birch forest		Spruce forest		Pine forest	
Added soil	0-25(28)	Loam	0-20(26)	Clay loam	0-22(28)	Loam
Basic soil	25-60	Loam	20-85	Clay loam	22-60 60-80	Silt loam Clay loam
Mixture of soil and sand	65-105	Sandy loam	85-130	Clay loam(with sandy interlayers)	80-95	Clay loam(with sandy interlayers)
Underlying sand	>105	Sand	>130	Sand	>95	Sand

The determination of soil textural class by the field method showed that the soils of all the studied sites are loamy: from silt to clay loam (table 1), with a predominance of a loamy composition. In general, the soil cover has very similar indicators for this characteristic. According to the obtained data, the Pine forest has the most heterogeneous soil textural class composition. The soils under the Spruce forest are represented by heavier soil texture composition.

Table 2. Bulk density and water content between tree crowns (1) and in root balls of trees (2) (27.04.2017).

	Variant	Water content, %	Bulk density, g/cm^3	Bulk density medium, g/cm^3
Birch forest	1	19.7	1.66	1.67
		20.5	1.68	
		20.5	1.67	
	2	24.9	1.44	1.45
		27.1	1.33	
		22.0	1.57	
Spruce forest	1	27.7	1.50	1.52
		24.8	1.55	
		25.5	1.51	
	2	29.2	1.36	1.42
		27.1	1.47	
		28.9	1.43	
Pine forest	1	25.4	1.49	1.52
		23.5	1.57	
		26.9	1.49	
	2	20.8	1.38	1.46
		17.4	1.51	
		17.5	1.51	
Linden forest		40.4	1.12	1.08
		42.4	1.07	
		42.9	1.04	
Old birch forest	planting crown	28.6	1.39	1.35
		28.1	1.37	
		29.2	1.28	
	old tree	32.7	1.30	1.34
		22.4	1.35	
		23.1	1.36	

The bulk density of the soil characterizes the possibilities for creating the optimum ratio of moisture and air in the pore space of the soil. In addition, this characteristic reflects the possibility of penetration of root systems in the soil. The range of optimal values of the bulk density is determined by the particle size distribution: with an increase of the sand content, the absolute values of the optimum density and their range increase [9]. The bulk density was determined three times over the study period: in April - in the topsoil under the tree crown and between trees, at the end of May - after adding soil in the space between tree crowns and in the soil profile in Spruce forest, in July - the bulk density profile distribution in all 3 researched sites (Birch, Pine and Spruce forests).

Obtained results of the bulk density and soil water content at the end of April showed that the upper soil horizons in the space between tree crowns of the areas with artificial plantings turned out to be over compacted (table 2), which is due to the constant arrivals of construction equipment and the movement of workers on wet soil.

Especially strong over compaction was observed in the soil of Birch forest. According to the classification of A.G Bondarev soil horizons were unsatisfactory on this basis after the planting in the spring of 2017 [12]. In root balls of plants, density values are lower, but the value range is higher, i.e. the spatial heterogeneity of the root balls of plants is more pronounced. It is noteworthy that the density of root balls of pines is higher, which is probably due to the lighter soil texture inside the root ball.

In the study period the soil moisture was not high (table 1). It is noteworthy that in Birch and Spruce forests the soil water content under the trees was higher than between their crowns, in contrast to the pine-tree, in which the root balls of the trees were more drained.

In July the bulk density profile distributions were investigated. In all cases the surface layer was over-compacted, the density decreased at a depth of 10–40 cm. There was a gradual increase in values with depth, and a naturally sharp increase in values when transited to the underlying sand in accordance with the soil textural class (figure 1). Note that in the spruce forest, the differentiation of the profile was preserved with a significant increase in the values in the surface layer.

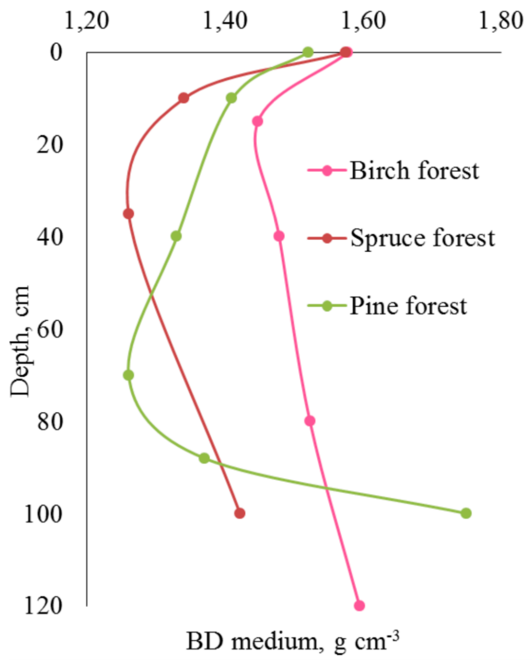

Figure 1. Profile distribution of bulk density at study points (22.07.2017).

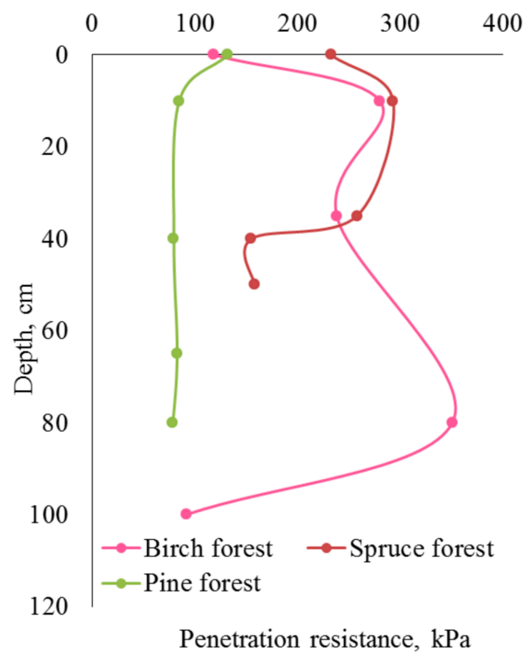

Figure 2. Profile distribution of penetration resistance at study points (22.07.2017).

In Pine and Spruce forests, the middle part of the profile has bulk density values close to optimal, and in Birch forest, the entire profile is over-compacted. According to our observations soil compaction of this area increased because of the laying of communications.

Average density of the soil surface was researched. The soil surface of the birch forest at the beginning of the growing season in April was extremely over compacted – the median values were 1.67 g cm^{-3} (table 3), with the very small value range in the space between tree crowns.

After adding the soil, the density of the soil approached the optimum and its variation became higher. But after two months it again reached critical values, which is primarily due to the anthropogenic load on the territory and constant atmospheric moisture. The most stable values of density in Spruce forest, and gradual compaction during the studied period was observed in the soil of Pine forest, which is due to the high activity of the construction works.

Table 3. Dynamics of median and scatter values of bulk density of topsoil in the studied period.

	Birch forest		Spruce forest		Pine forest	
	Median	Value range	Median	Value range	Median	Value range
April 27	**1.67**	0.02	1.51	0.05	1.49	0.08
May 31	1.37	**0.13**	1.53	0.08	1.53	0.08
July 22	1.54	0.11	1.56	0.05	**1.62**	0.06

Thus, the determination of soil density revealed a problematic situation in the upper horizon of all sites, which can be eliminated both by carrying out mechanical tillage, sowing grassy plants, the effect of soil fauna and natural processes of decompression in winter. Over compaction in the middle part of the profile requires the development of special measures to reduce and eliminate this factor. Such properties of the underlying layer as its density and evenness of the boundary are very important. According to the results of our study, the Birch forest can be a very problematic area because laying of the top layer was made on the over compacted soil with a very low water permeability in the absence of a subsurface slope. The pine forest, despite the detected compaction, has a pronounced subsurface relief, and there were ruts from the influence of the technique, creating a kind of "corrugation" of this surface in the direction of the slope. This leads to an increase in water consumption for irrigation, the danger of over-wetting of the lower parts of the slope due to the formation of lateral flows of water. In the Spruce forest, the most favorable situation, despite the slightly increased values of the density and water content of the upper layer, which are easily removable.

Penetration resistance of the soil was measured simultaneously with the determination of the bulk density. This characteristic reflects the resistance of the soil to the free penetration of the root systems of plants into the soil. Despite the variation of its values in the profile of all the studied soils, the penetration resistance did not exceed the critical 3 MPa, which indicates the optimality of its values for all the soils (figure 2).

4. Conclusions

Generally, the recommendations on the construction of the fertile soil layer have been implemented. The absence of sharp transitions in soil textural class and density between the soil layers allows us to hope that over time the artificial layer will work as a natural soil.

Recommendations on the technology of creating a fertile layer were made at the rate of laying artificial soil in the summer period of 2016. However, the transfer of the beginning of work on the formation of soil cover in the fall and the performance of the main work in the cold wet period - from October 2016 to the beginning of June 2017 led to over moistening of the soil. Under these conditions, soils are particularly sensitive to mechanical stress, which has led to subsoil and surface compaction, on the one hand. And, on the other hand, to the formation of differentiation and layering of the profile with an extremely high degree of mosaic and spatial heterogeneity of the soil cover. This creates conditions for the formation of local waterlogged areas at different depths of soil cover.

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