Artificial soils for urban greening

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Abstract. This study presents new data on structural and hydraulic characteristics of artificially-layered soils and their dynamics in urban environment. Full-profile soils in large lysimeters and short-profile soils at the experimental plots of Moscow University Soil Station were studied. Short-term changes and long-term evolution of soil matrix and soil hydraulic properties are discussed.

1. Introduction
Nowadays the artificially layered soils are an integral part of anthropogenic landscape within the urban territories. Artificial soils are also applied in rural landscape management and as high value substrates for greenhouses, vegetated roofs and plants in urban containers [1]. The key problems related to properties, functioning and evolution of artificial soils are widely discussed in scientific literature. Much attention is drawn to soil structure development, aggregate formation, organic matter turnover. Interrelationships between soil texture, mineral composition, organic matter input and microbial community structure were analyzed in many recent publications [2–5].

Practical significance of investigations aimed at improving properties of artificial soils is obvious. But there also exist two fundamental aspects which one cannot ignore. First, the substrates used to create the artificial soil profile are usually quite different in their physical and chemical properties. When these substrates are united into one layered profile, the general, integral, effective transport characteristics of artificial profile such as effective hydraulic conductivity or effective thermal diffusivity highly depend on the sequence of layers in the profile which determines both fluxes of solutes and energy and the interaction between the neighboring layers. Second, the newly created soil systems are functioning under influence of well-known factors of soil genesis, such as climate, relief, plants and anthropogenic impact, which certainly leads to gradual transformation of soil properties. Artificial soils can be qualified as very young soils, and we are able to study the very first stages of their transformation which is a real challenge. Fortunately, the fast changes of soil properties start at the very beginning of the process and can be registered within the first years after artificial profile was created [6].

Our studies of artificial soils started in early 90s. The long-term investigations of full-profile artificial soils in the large lysimeters of Moscow State University Soil Station were carried since 1961; we added such research options as transformation of soil matrix, soil hydrology and soil temperature [7–9]. Plenty of laboratory experiments were carried out to study the impact of substrate properties and sequence of different layers within the artificial soil profile on the vertical movement of soil water and solutes. Since 2010 we work with different short-profile artificial soils which are functioning at the experimental sites on the territory of Moscow State University and also those located within different landscape zones of...
Zaryad’ye park in the very center of Moscow. The next research stage began in 2019; the research objects are short-profile artificial soils located in different climatic zones of the European Russia, from northern taiga to subtropics. The main research objectives are (1) to study the short-term changes in soil texture, soil chemical properties, sorption characteristics of soils, soil microstructure and architecture of soil pores; (2) to study the transformation of hydraulic and thermal soil properties, i.e. water retention, hydraulic conductivity, dynamics of soil water content and potential head, soil thermal diffusivity and soil temperature; (3) to predict hydraulic regimes of artificial soils under different scenarios.

This paper is aimed at presenting some results concerning structural and hydraulic characteristics of artificial soils located in Moscow.

2. Material and methods
The objects of our research were (1) the full-profile artificial soils in the large lysimeters of Moscow State University Soil Station created in 1961 and (2) the short-profile artificial soils on the territory of Moscow State University Soil Station created in 2010 and later (figure 1). The large lysimeters of the experimental station are open-surface cement containers with the surface area of 8 m² filled with soil material to a depth of 1.5 m; the surface of the artificially-layered soils in the lysimeters lies at the same level as the surface of natural soils on the station territory. The lysimetric waters are collected in special gauges installed in the underground gallery under the lysimeters. Our experiments were carried in two lysimeters with different construction of soil profiles. In the first lysimeter (profile 1), the morphology of the constructed soil profile imitated deep inverse tillage, upon which the material of a potentially fertile B2 horizon is placed on the soil surface, and the Ap horizon is buried.

![Figure 1. Soil profiles of studied artificially-layered soils.](image)

Thus, the first artificial soil profile is characterized with the following horizonation: B2 (0–43 cm), B1 (43–65 cm), E (65–80 cm), Ap (80–100 cm), B2 (100–120 cm), and B3 (120–150 cm). The subsequent soil cultivation resulted in the development of a plow layer in the upper part of the material of the B2 horizon (the B2p horizon). In the second lysimeter (profile 2), the morphology of the constructed soil profile imitated the ameliorative tillage technique suggested by Mosolov with B1 and E horizons being swapped for one another: Ap (0–20 cm), B1 (20–45 cm), E (45–60 cm), B2 (60–120 cm), B3 (120–150 cm). From the depth of 150 cm, 25-cm-thick sandy-gravelly layers underlay the soil columns in both lysimeters. Both artificial soils include similar horizons Ap, E, B1, B2, B3 with clear boundaries; the sequence of these horizons is the only difference between the studied variants. Moreover, the location of some horizons does not correspond to natural conditions. These quite different artificial soils are located at the same lysimetric station under similar weather conditions and were subjected to similar agricultural practices for the whole period of their functioning.

The short-profile soils were created to study the short-term changes in the properties of artificial soils when being exploited in the urban environment. All experimental plots were 0.5×0.5 m², and the depth of soil profiles was 30 cm. There were three variants of soil profile construction, but the used substrates...
were the same in all three cases. The bottom part of all soil profiles was 12 cm thick and was filled with the material of initial topsoil. The first variant of artificial soil profile was quite a homogeneous one: the upper 18 cm were filled with the same topsoil material as the lower 12 cm. Soil profile 2 included topsoil layer (0–6 cm), sedimentary peat layer (6–12 cm) and river sand layer (12–18 cm). And in the last profile 3 the upper 18-cm layer was filled with the mixture of three substrates, i.e. topsoil, peat and sand. Each variant of soil profiles was created in 6–10 replicates; all plots were thermally and hydraulically isolated from the neighboring soils and were sown with a mixture of lawn grasses.

Soil texture was determined using the pipette method with sodium pyrophosphate pretreatment [10]. Soil microstructure was studied with the method of scanning electron microscopy [11]. Sorption isotherms were investigated by desorption of water vapor over saturated salt solutions in triplicate for each sample [12].

3. Results and discussion

3.1. Transformation of solid phase characteristics in artificial soils

The artificially layered soils are characterized by changes in soil texture which are primarily due to redistribution of clayey fractions in the profile. This concerns those layers which were placed into position not typical for their genesis. Clay content in upper B2 horizon in lysimeter soil profile 1 decreased from 32 to 27% during the first twelve years of functioning; in the buried Ap horizon the content of particles less than 0.001 mm in diameter grew from 9 to 16% after 40 years of observations. Besides, the changes in amount of clayey fractions are affected by the properties of underlying layer. Thus, B1 horizon in lysimeter soil profile 2 is underlain by sandy layer E, and the decrease in clay content in B1 horizon was 10% after forty years of functioning [6]. Similar situation is observed in the short-profile layered soil created in 2012: the decrease in clay content in Ap horizon which is underlain by peat and sand was 1.4% after four years. But generally, profile texture differentiation is preserved for a very long period of time [13].

Soil sorption capacity is closely related to soil texture and also to qualitative characteristics of the surface of soil particles. Isotherms of desorption of water vapor in the initial soil samples demonstrated a distinct difference between the illuvial and eluvial horizons of the lysimeter soils and the short-profile layered soils created in 2012 (figure 2).

![Figure 2](image)

**Figure 2.** Isotherms of water desorption for lysimetric soils (I) and short-profile soils (II): (a) initial substrates; (b) full profile 1 and short profile 2; (c) full profile 2 and short profile 3.
By now the sorption capacity grew in all horizons of lysimeter soil profile 1 with the exception of Ap horizon. Isotherm for this horizon is located now lower than that for the buried E horizon. The desorption curves for samples from B horizon diverge, and this divergence depends on the location of each horizon in soil profile: the lowest sorption capacity characterizes soil samples from the surface layer, which is consistent with data on soil texture. Both in profiles 1 and 2 the lowest one is the isotherm for Ap horizon. The desorption curve for E horizon moved upwards, and now it is higher than the desorption curves for illuvial B1 and B2 horizons. B1 horizon lowered its sorption capacity towards water vapor and approaches Ap horizon. Generally, in profile 2 the initial high differentiation in sorption capacity decreased.

In the short-profile soils similar changes were observed after four years of functioning. In the layered soil profile 2 the curves of desorption isotherms for Ap horizon underlain by peat layer moved upwards, and in the peat layer an abrupt lowering of sorption characteristics occurred. Nevertheless, the peat isotherm was still the highest as compared with other curves for this short-profile soil. In the short profile 3 the upper mixed layer was characterized by lowering of water retention, and the degree of downward shift of the curves as compared to the isotherm obtained in 2012 decreases with the depth of soil sampling.

These changes in sorption properties can be explained by changes in soil texture and in the surface properties of soil particles related to formation or degradation of organic and ferro-clay films [6].

3.2. Hydraulic properties of artificial soils

The main hydraulic soil properties are hydraulic conductivity and water retention. Lysimeters are special devices to investigate vertical downward fluxes, and so the main studies on water and solutes transport in their annual cycle and in multiyear aspect are being carried on lysimeter soils. It was found out that lysimeter profile 1 with the surface B2 horizon with prismatic structure is able to form preferential water flows. Unlikely, lysimeter profile 2 had an advantage in the volumes of percolation water during lingering rains with high water contents in the profile.

Detailed investigations of annual dynamics of lysimeter percolation, water content and pressure head were fulfilled in 1997. In was found out that in the annual cycle one can distinguish different periods which correspond more or less distinctly to calendar seasons: winter period, spring snowmelt, summer and autumn periods. The spring filtration begins when the snow cover is still rather thick, but the main percolation occurs during the first day after snowmelt is complete. Thus, in profile 1 80% of the whole spring percolation occurred during the first three days, and in profile two it was 70%. Generally, spring filtration was over by the middle of April in profile 1 and by the end of the first week of May in profile 2. In summer, the percolation depends not only on the amount of precipitation, but also on their intensity. When soil is rather wet, the greatest water fluxes after rains are formed in soil profile 2. After draughts, the heavy rains result in intense percolation only in soil profile 1. In autumn, lysimeter percolation is observed long after the stable snow cover is formed and the negative air temperature is observed. Soil water content in autumn is lower than that observed in spring. Similar annual dynamics was also observed in other years. It is important to note that in the very first years after the layered profiles were created in lysimeters, the spring percolation was about 10% of the annual percolation, and by now this proportion reaches from 20 to 40% and even more. We explain this phenomenon by the process of pore space differentiation and formation of continuous moisture paths during the evolution of lysimeter soils.

Water retention of soil substrates and its changes during functioning of the substrates in the layered soil profiles were studied for the artificial short-profile soils created in 2012. For these soils the water retention curves, the pore-size distribution, and scanning electron microscopy images with magnification range from 100 to 9,000 were obtained and analyzed. It was discovered that at the very beginning of the experiment in the Ap and sandy layers the greatest number of water-conducting pores was observed, and in the horizons comprised of mixture or of peat the water-retaining pores prevailed. The number of residual pores was similar in Ap horizon and in the mixture; the greatest number of such pores was observed in peat, and the smallest one – in sand. As compared to the initial substrates, the greatest transformation by 2016 was observed in the short-profile 2.
4. Conclusion
The long-term lysimetric experiments since 1961 and the short-term studies of the artificial soils with different profile structure in 2012–2016 allowed to identify the following regularities.

The transformation of soil texture was reflected in the downward movement of thin fractions during the first years after creating the artificial soils and further stabilization of soil textural profile. Sorption properties of the substrates turned out to be more sensitive to the inclusion into profiles of artificial soils. The presence of layers in the profile resulted in lessening of humic and ferroclay coatings of grains and microaggregates in organogenic horizons (Ap horizon and peat) and lowered water sorption capacity.

The water transport characteristics of soils in lysimeters were determined by profile structure. Despite absolute similarity of the substrates used to create these soils, the volumes of annual and multiyear lysimetric percolation were different. With B horizon located at the surface, the quick water flows were formed during spring snowmelt and after heavy rains. Soil profiles with surface Ap horizon better conducted water during chronic rains. Lowering of water retention of organogenic horizons in short soil profiles was conditioned by emergence of cavities and by increasing the openworkness of soil pore space, which was registered by scanning electron microscopy method at different magnification ranges. During these processes no decrease in layer thickness occurred.

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