Transformation of structural organization of model soil constructions with different structure in conditions of Moscow

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Abstract. Three variants of model soil constructions were created. Variant 1 (control) is made from Aarable horizon (0-18cm); variant 2 (layered construction) is represented by Aarable horizon (0-6cm), lowland peat (6-12cm), sand (12-18cm); variant 3 is a mixture of Aarable horizon, peat and sand in the same mass proportion as in the layered variant (0-18cm). Water retention capacity of Aarable horizon increased in all variants regardless of the location in the profile. Number of macropores increased and number of mezopores decreased in Aarable horizon of control and layered variants. The greatest number of moisture-saving pores is observed in the peat-containing layers of variants 2 and 3 as a result of 4-year functioning. The lowest content is in the control in all layers.

1. Introduction
Nowadays, more and more attention is paid to issues of optimal using and functioning of soil for plant growing, its behavior under different anthropogenic pressures. The behavior and functioning of soils in different conditions (dry and wet) is due to its structure (spatial distribution of aggregates and pores) [1]. Simultaneously, initial structure affects the distribution of moisture in soil [2]. Thus, the interrelation of spatial characteristics of soils and their functional (hydrophysical properties) is very important and difficult to study. Especially, the transformation of these characteristics into correlations with each other is insufficiently explored. Therefore, there are more and more works, which are devoted to this particular problems, in recent years [3-8].

Water retention curve, which is relationship between the capillary-sorption pressure of moisture and soil moisture, is one of the most informative characteristic of structural and functional organization of soils [9]. This characteristic curve shows the ratio of pores of different sizes and, simultaneously, the mobility of the soil moisture and its accessibility for plants. It is possible to make a forecast of the movement of water and solutes along the pores based on data experimentally obtained, using mathematical modeling and water retention curve.

Soil-hydrological constants, moisture values of which correspond to a certain pressure, are reference points on the water retention curve [10]. This provides a possibility to quantify pores and analyze the structure of pore space of soils [9, 11].

The moisture itself, its amount affects forming soil structure, especially when soil is being compacted [1, 2]. Therefore, the spatial organization of the solid phase of soils, which forms a
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Soil constructions with different structures, located on the territory of Soil Stationary Department of Lomonosov Moscow State University (GPS: 55°42'30.8"N 37°31'25.6"E), were investigated. Three variants of model urban soil constructions with the most equalized properties of soil layers were created by mixing them thoroughly during creation in 2012 [12]. Profiles of soil constructions are as follows: 1) variant 1 (control) - Ap horizon (0–18 cm); 2) variant 2 (layered construction) – Ap horizon (0–6 cm), eutrophic peat (6–12 cm), fine sand from a quarry (12–18 cm); 3) variant 3 (mixture) – mixture of Ap horizon, peat and sand in the same amounts proportion as in layered construction (0–18 cm). All constructions belonged to Urbic Anthrosols according to WRB international classification. All constructions were underlain by Ap horizon (18-24 cm) and located in same conditions. Observations were made from 2012 to 2016.

Samples of damaged and undisturbed structure (monoliths) were taken in 2012, 2014 and 2016. Monoliths were taken in plastic rings with diameter of 4.5 cm and height of 2 cm. Samples were sealed and placed in a refrigerator before the start of the laboratory experiment to preserve the natural moisture.

The determination of the upper part of the water retention curve was carried out by the method of desorption of moisture over saturated salt solutions, the lower part - by the tensiostatic method on soil monoliths [10] in the desiccation mode. Model of van Genuchten in RETC program was used to approximate the water retention curve based on experimental data [13]. Obtained curves were used to calculate the pore size distribution: each soil moisture pressure interval (capillary diameter) corresponds to a segment on the ordinate axis — a moisture interval located in capillaries of a certain size [10].

All determinations were carried out in triplicate; statistical data processing was performed using standard functions of MSExcel and Statistica electronic packages.

3. Results and Discussion

Water retention curves (WRC) of different soil layers are presented in figure 1. Curves of initial samples (figure 1a) have typical shape corresponding to their genetic specificity. Ap horizon - sloping shape characteristic of soils of loamy granulometric composition, sand - S-shaped curve, located below the rest, which indicates its low water-retaining capacity. Water retention curve of peat, by contrast, is located above all on the figure. A high water-holding capacity was also found for mixture, which includes peat. Although its curves are more pronounced S-shaped than peat, which is due, apparently, with a different ratio of pores of different diameters.

Water-retaining capacity of the surface Ap horizon in the variant 1 decreased by 2016: the curve moves downward compared to the initial one (figure 1b). Moisture-holding ability of Ap horizon, when it is located on the peat layer (variant 2), increased. WRC of 2016 shifted upwards relative to the curve of 2012 (figure 1c). This may be explained by the fact, that fragments of well swelling peat penetrate along large pores of the arable layer to the Ap horizon. This penetration was recorded visually during analysis of constructions. WRC acquired more pronounced S-shape in layers of peat and sand in variant 2 (figure 1e, f). It reflects an increase in freely suspended moisture and a decrease in film moisture. Simultaneously, the left part of WRC of the sandy layer shifted upwards, this indicates an increase in water sorption. WRC of all layers shifted downward in mixture (variant 3, figure 1d). It indicates a decrease in the water-retaining capacity of this option and may be due to a
decrease in the organic matter content from 6% to 3%. Note, that the largest change in water-retaining capacity and organic matter content in this variant is observed in the surface horizons, which may be caused by the increased activity of zoobiota, which is most inhabited in this particular variant of constructions.

**Figure 1.** Approximation of water retention curves by van Genuchten model: a) initial samples 2012; b) variant 1; c) variant 2; d) variant 3; e) peat (variant 2); f) sand (variant 2).
Water retention curves were approximated by equation of van Genuchten, the main parameters of which are $\theta_s$, $\theta_r$, $\alpha$ and $n$ (table 1). It is believed that the parameter $\theta_s$ is close in magnitude to the volume moisture content of complete soil saturation, although with mathematical description of the WRC overwhelmingly it has smaller values than the porosity of the soil [4]. Parameter $\alpha$ is a value inversely proportional to the pressure of air entering the soil, “bubbling pressure”, and parameter $n$ is a characteristic of the angle of inclination of WRC. T-test was compared for all parameters (with a significance level of 0.05) and showed, that parameters of samples were significantly different from each other.

Table 1. Parameters of approximation (average values).

| Year | Horizon          | $R^2$ | $\theta_s$ | $\alpha$ | $n$  |
|------|------------------|-------|------------|----------|------|
| 2012 | Initial samples  |       |            |          |      |
| Ap   | 0.993            | 50.577| 0.620      | 1.236    |
| Mixture | 0.997 | 89.179| 0.212      | 1.328    |
| Peat | 0.988            | 95.526| 1.752      | 1.219    |
| Sand | 0.994            | 34.133| 0.213      | 1.444    |
| Ap 0-6 cm | 0.998 | 40.813| 0.144      | 1.255    |
| Ap 6-12 cm | 0.996 | 44.144| 0.216      | 1.244    |
| Ap 12-18 cm | 0.997 | 44.310| 0.169      | 1.257    |
| Ap 18-24 cm | 0.997 | 38.666| 0.122      | 1.251    |
| 2016 | Variant 1        |       |            |          |      |
| Ap 0-6 cm | 0.991 | 59.423| 0.379      | 1.238    |
| Peat 6-12 cm | 0.994 | 73.668| 0.356      | 1.334    |
| Sand 12-18 cm | 0.998 | 44.695| 0.147      | 2.581    |
| Ap 18-24 cm | 0.997 | 45.997| 0.181      | 1.262    |
| 2016 | Variant 2        |       |            |          |      |
| Mixture 0-6 cm | 0.996 | 52.857| 0.453      | 1.299    |
| Mixture 6-12 cm | 0.999 | 52.244| 0.216      | 1.338    |
| Mixture 12-18 cm | 0.998 | 68.445| 0.422      | 1.275    |
| Ap 18-24 cm | 0.998 | 40.555| 0.107      | 1.283    |
| 2016 | Variant 3        |       |            |          |      |
| Mixture 0-6 cm | 0.996 | 52.857| 0.453      | 1.299    |
| Mixture 6-12 cm | 0.999 | 52.244| 0.216      | 1.338    |
| Mixture 12-18 cm | 0.998 | 68.445| 0.422      | 1.275    |
| Ap 18-24 cm | 0.998 | 40.555| 0.107      | 1.283    |

Peat and mixture contain the largest amount of water among initial horizons according to values of the parameter $\theta_s$, and sand contains the smallest one (table 1). This parameter decreased in Ap horizon of all variants as a result of 4-year functioning. The exception was Ap horizon of variant 2 (layered construction 0-6 cm). Note, that the value of parameter $\alpha$ decreased for all Ap horizons of all variants during their functioning. This means, in physical terms, an increase in the pressure of air entering the soil, which is due to the complexity of its structural organization. Indeed, a visually distinguished increase in the number of small aggregates against the background of the growth of large pores and cavities was shown in the previous work of authors [12].

Pore size distributions were calculated for numerical confirmation of the pore space transformation (table 2). By 2016 number of moisture-preserving pores in Ap horizon of control variant and mixture (variant 3) decreased compared initial variants, and an increase of moisture-conducting pores is observed. The reverse picture was found in the surface Ap horizon of layered construction. Number of moisture-conducting pores decreases with an increase in moisture-preserving and residual pores, which is due to the involvement of fragments of underlying peat in its composition. Change in the pore space is associated with an increase in the volume of macropores and a decrease in the volume of micropores in peat layer. This is consistent with the data obtained by scanning electron microscopy.
[12], which showed the appearance of large cavities and pores. Similar results were found by Casini [1], in whose work results on the formation of aggregates from microaggregates are presented, leading to an increase in the volume of intergranular pores and cavities.

Table 2. Distribution of pore size (%).

|             | Moisture-conducting, >50 µm | Moisture-preserving, 50-0.2 µm | Residual, <0.2 µm |
|-------------|------------------------------|-------------------------------|------------------|
|             | mediana                      | range                         |                  |
| Initial samples |                              |                               |                  |
| 2012 Ap     | 61.5                         | 28                            | 10.2             |
|             | 61.5-70.8                    | 17.8-28.3                     | 9-10.5           |
| Mixture     | 26.2                         | 60.1                          | 13.7             |
|             | 20.8-37.2                    | 50.1-65.3                     | 12.7-13.9        |
| Peat        | 43.8                         | 39                            | 17.2             |
|             | 42-45                        | 38.3-40.8                     | 16.7-17.2        |
| Sand        | 74.8                         | 22.8                          | 2.7              |
|             | 72.1-75.3                    | 22.2-25.2                     | 2.4-2.7          |
| Variant 1   |                              |                               |                  |
| Ap 0-6 cm   | 62.8                         | 25.1                          | 10.7             |
|             | 62.2-65.2                    | 24.3-26.5                     | 10.5-10.7        |
| Ap 6-12 cm  | 62.8                         | 26.4                          | 10.8             |
| Ap 12-18 cm | 61.6                         | 27.7                          | 10.7             |
|             | 61.6-61.6                    | 27.6-27.9                     | 10.5-10.8        |
| Ap 18-24 cm | 65.4                         | 24.1                          | 10.5             |
|             | 65.1-65.5                    | 24.4-24.5                     | 10.5-10.5        |
| 2016 Variant 2 |                              |                               |                  |
| Ap 0-6 cm   | 52.1                         | 32.8                          | 13.2             |
|             | 50.8-55.6                    | 31.5-34.4                     | 12.9-13.5        |
| Peat 6-12 cm| 47.3                         | 43.7                          | 9                |
|             | 36.1-47.3                    | 33.7-55.3                     | 7.8-10.6         |
| Sand 12-18 cm| 68.5                         | 31.5                          | 0.02             |
|             | 65.5-71.2                    | 28.8-34.5                     | 0.02-0.02        |
| Ap 18-24 cm | 60.6                         | 28.9                          | 10.5             |
|             | 60.3-61                      | 28.6-29                       | 10.4-10.7        |
| Mixture 0-6 cm | 59.2                         | 29.8                          | 7.6              |
|             | 57.5-68.5                    | 23.9-35                       | 7.5-7.6          |
| Mixture 6-12 cm | 58.1                         | 34.5                          | 7.4              |
|             | 58.1-58.2                    | 34.4-34.5                     | 7.4-7.4          |
| Variant 3   |                              |                               |                  |
| Mixture 12-18 cm | 50.1                         | 39.2                          | 10.7             |
|             | 49.2-51                      | 38.3-40.1                     | 10.7-10.7        |
| Ap 18-24 cm | 63.1                         | 10.7                          | 9.7              |
|             | 62.8-63.2                    | 10.7-10.7                     | 9.7-9.7          |
4. Conclusions
The study of the transformation of water-retaining capacity of model soil constructions in a 4-year field experiment showed increase of water-retaining capacity in Ap horizon, underlain by the peat layer, against the background of its decline in the underlying peat. There is a sharp decrease in this characteristic in the surface layers of the mixed substrate, the shape of the curves has become flatter and more similar to the curves of Ap horizon.

There was a transformation of the pore space of all variants of urban soils. The greatest change is observed in variant 2. Decrease in moisture-conducting pores from 62% to 52% against the background of an increase in the content of moisture-preserving and residual pores from 28% to 33% and from 10 to 13%, respectively, are obtained in the surface Ap horizon of layered construction. Formation of different spatial organization of the pore space took place in the peat layer, as a result of 4 years functioning: the number of residual pores decreased and the number of moisture-conducting (from 44 to 47%) and moisture-preserving (from 39 to 44%) pores increased. This was reflected in the change in functional characteristics - a decrease in the water-retaining capacity of the peat layer occurred.

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