

The influence of introduced tree species on the relationships between soil buffering capacity and ecological groups of microorganisms in urban park soils

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As a component of urban parks, soil is an essential part of urban green infrastructure; soil influences the green plantings in megacities, being affected by environmentally unfavorable factors. To reveal relationships between soil buffering capacity and ecological microbial groups of park soils, soil acid-base buffering capacity (pHBC) was determined with the Arrhenius method. We counted the soil microorganisms using differential diagnostic nutrient media with serial dilutions. Soil microbial biomass was determined by thermal rehydration. In statistical data processing, we used the methods of descriptive statistics, univariate analysis of variance, etc. We established strong positive correlations between pH values and pHBC in the acid and acid-base range, and a negative correlation between pH values and buffering capacity in the alkaline range; a strong correlation between the abundancies of amylolytic and pedotrophic soil microorganisms. We determined the effect of the three following soil sustainability-associated latent factors: Factor 1 – effect correlated with total pHBC, pHBC in the acid range and soil acidity, Factor 2 and Factor 3 – effects characterized by the direction of microbial processes and which formed a balanced system between the soil humus decomposition and the entry of plant litter. We revealed a beneficial impact of subcrown space on the abundancies of soil microorganisms. We recommend using acid and acid-base buffering capacity and microbiological characteristics as soil quality indicators. The abundance of soil microorganisms increased in the forested sites.

Keywords: introduced dendroflora; parks; soil buffering capacity; soil microbes; soil quality; urban green space; urban soil.

Introduction

The global problem of urbanization is characterized by the rapid and unmanageable growth of the urban population and urban development. Lack of green infrastructure in cities and megacities represents one of the main aspects of this global challenge (Tessema & Abebe, 2024). To overcome the problem of insufficient use of green spaces in cities, several actions can be taken, such as encouraging the use of green technologies in urban planning and construction (Gabriel et al., 2024; Muratet et al., 2024) and implementation of projects to increase the number of green areas in cities (creation of parks, squares, street plantings) (Kunakh et al., 2022), in which the woody and shrubby vegetation are essential functional elements. Current trends of globalization, being a consequence of rapid urbanization, cause steady growth of the proportion of alien species in the dendroflora of urban ecosystems; these species form the core of the species richness and dendrological diversity in some European cities (Marinšek et al., 2022). Nowadays, tree and shrubby stands in cities are increasingly receiving attention as active components for mitigation and counteraction to the consequences of global climate change (Zölch et al., 2016).

Green spaces and urban soils are interconnected through ecosystem links, which, on the one side, determine the state of tree vitality, and, on the other side, are manifested in the beneficial influence of woody vegetation on the urban soil properties (Kang et al. 2023). Microbiological processes in the soil (Finlay & Greg Thorn 2019) were highlighted as playing a key role in plant nutrition, affecting soil fertility, decomposition of plant residues, and the cycle of minerals and organic substances. Probst et al. (2023) noted that microbial interactions can vary depending on environmental conditions, such as nutrient availability and soil pH.

As an integral component of park areas in the territory of urban systems, soil, on the one hand, determines the conditions for the growth and development of green spaces in megacities (Morel et al., 2015; Didur et al., 2019); on the other hand, it is part of the green infrastructure within an urbanized territory. Therefore, the soil in the urban ecosystem undergoes environmentally unfavorable effects, such as disturbance of its profile, compaction of the root layer and restriction in the volume of the root system development, low fertility, contamination with heavy metals and other toxicants (Probst et al., 2023), pH changes, reduced diversity of soil microflora and soil invertebrates (Didur et al., 2017). Such consequences decrease soil quality and productivity (Pamba et al., 2023). In this regard, there is an urgent need for assessment of soil sustainability and quality; this is particularly relevant for urbanized territories, especially for green infrastructure of park areas.

In context of restoration and optimization of the soil ecological properties in urban ecosystems, soil buffering capacity (Bartmiński et al., 2012; Didur et al., 2019) and the direction of soil microbiological processes (Mónok et al. 2021) can serve as important indicative characteristics. Buffering is understood as the ability of the soils to resist changes in pH values under the influence of various factors. This is the so-called acid-base buffering capacity (or soil pH buffering capacity, pHBC) (Truskavetskyi, 2003; Kissel et al., 2012). Mónok et al. (2021) emphasized that the application of microbiological analysis (e. g., for soil quality assessment) is crucial because soil microbiota play a key role in numerous soil functions, such as nutrient circulation, organic matter decomposition, and biodiversity regulation. So, the clarification of interaction between components of the green infrastructure of parks (such as soil pHBC and various ecological microbial groups that determine the direction of soil microbial proces-

ses) is relevant. The goal of our study was determining the relationships between the soil pHBC as a protective mechanism for maintaining the fertility potential of edaphotope and ecological microbial groups in the soils of park green infrastructure in areas with various plantings of introduced tree species.

Material and methods

We collected material for this study in the territory of Dnipro city (Ukraine) within the one of the largest by area urban parks in the city: Taras Shevchenko Central Culture and Leisure Park (48°27'40" N, 35°04'21" E), and also within the mini-park (48°27'27" N, 35°03'55" E) located in minimal proximity (236 m southwest) to Taras Shevchenko Central Culture and Leisure Park. Dnipro city is a large housing and industrial center covering an area of 410 km². The region under study is located in the Steppe physical-geographic zone; it corresponds to the temperate continental climate zone of Central Europe and is characterized by warm, often hot summers (Lovynska et al., 2022) and the cold, wet winter.

Taras Shevchenko Central Culture and Leisure Park is a park-monument of landscape art of national significance, one of the major garden and park complexes in the city, which belongs to the objects of the nature reserve fund. Its total area is 45 hectares. According to WRB classification (IUSs Working Group WRB, 2022), the majority of the soils in the studied areas are classified as Hortic Anthrosols (Loamic, Eutric). The mini-park (Ivan Starov Square) covers an area of 14 hectares and is located near Taras Shevchenko Central Culture and Leisure Park. Soils of the mini-park are potentially suitable for the growth of woody and shrubby vegetation. According to the WRB classification, the soils of the studied areas are classified as Hortic Anthrosols (Siltic, Eutric).

To determine the pHBC values in the park's soils, we collected the soil samples from the upper layer (topsoil) of soil profile (0–20 cm) within the subcrown space of introduced deciduous and ornamental tree species (25–30 years old) in Taras Shevchenko Central Culture and Leisure Park and the mini-park. We determined the soil pHBC values by changes in pH values after adding incrementally increasing quantities of acid or base solutions to an experimental soil sample (Nelson and Su, 2010). To determine the soil pHBC, the Arrhenius method was used (Raczuk and Deska, 2012). A series of incremental amounts of either acidic (HCl 0.1 M) or alkaline component (NaOH 0.1 M) were added to air-dried soil samples (Huang et al., 2009). The ratio of the acidic component to water (or alkali to water) was 1.0 to 2.5, respectively. The pH values of the solutions were measured after the samples were resuspended for 1 hour. Based on pH measurements, pHBC values of the studied soil samples were calculated by the buffering area in the region of the acid and alkaline intervals of external influence, respectively. We used Simpson's rule (Chapra, 2012) to calculate the buffering areas. Measurements of pH values were performed using the potentiometric method with electronic digital laboratory ionomer I-160MI.

Analysis of soil microbial communities was performed using differential diagnostic nutrient media by serial dilutions of soil suspension (Patyka & Symochko, 2013). We counted the number of ammonizers on meat-peptone agar, actinomycetes and microorganisms that assimilate mi-

neral forms of nitrogen (amylolytic microorganisms) on starch-ammonia agar, oligotrophic microorganisms on hungry agar, and pedotrophic microorganisms on soil agar. Microorganism count was expressed in colony-forming units per gram of absolutely dry soil. Soil microbial biomass was determined by the thermal rehydration method (Partyka et al., 2019), based on soil rehydration with a weak solution of neutral salt (0.5 M K₂SO₄), which was centrifuged, and the content of organic matter in the supernatant was determined by dichromate oxidation followed by spectrophotometry of the extract at a wavelength of 590 nm. The soil microbial biomass was expressed in µg C/g dry wt soil. Spectrophotometry was conducted with an ULAB 102UV spectrophotometer (China).

In statistical processing we used the descriptive statistics (mean, standard deviation), ANOVA analysis, the multiple comparison method (Tukey's test) and multivariate statistical analyses (factor and cluster analyses). All differences were considered to be statistically significant at P < 0.05. The laboratory experiments were carried out in five replicates. Principal component factor analysis with Varimax rotation was applied to the exploratory factor analysis. The threshold level of the factor loading was set at >0.70.

Results

The samples of the studied soils collected from the topsoil layer were humic loamy and initially (prior to adding the acidic or alkaline components) had a conditionally neutral (site 8, site 10, site 11) and slightly alkaline reaction of the soil solution (site 1 – site 7, site 9, site 12), the difference in their averages was confirmed statistically (Table 1). In general, the acidity (pH) values varied from 6.83 ± 0.038 (mini-park soil, beneath the crown of *Gymnocladus dioica*) up to 7.90 ± 0.047 (park soil within subcrown space of *Ulmus pumila*).

After testing of the urban park soil samples (humic topsoil) with the acidic and alkaline components, we found that the buffering area in the acid range of external exposure was at a minimum in the samples taken in site 8, site 11, and at a maximum for site 1 (Table 2). The same trend persists for the total buffering area.

The dataset of buffering areas in the alkaline range has a higher statistical homogeneity compared to the dataset of the areas in acid and acid-base (total) range of external influence (Table 2). Hence, samples of urban soil collected from site 1, site 3, and site 6 have a minimal buffering area and do not differ statistically from each other, forming a homogeneous group. Samples of urban soil taken in site 8, site 10, and site 11 have a statistically larger buffering area compared to other sites and also form single statistically homogeneous group.

For the purpose of comparison of microbiological characteristics of soil samples collected within subcrown spaces of introduced trees, the soil samples were taken outside the subcrown spaces, which were conditionally considered averaged for all experimental sites (conditional control). The ANOVA results show that the presence of crown space affects the abundance of ammonifying, oligotrophic and pedotrophic soil microorganisms (Table 3). Hence, within the subcrown spaces their abundance in the soil increased compared to the soil sampled outside the subcrown spaces in the treeless experimental site.

Table 1

Results on actual acidity (pH) measurements in urban soil samples taken within the subcrown spaces of introduced tree species in the studied park areas (x ± SD, superscript letters a–d indicate significant difference at P < 0.05 by Tukey's criteria in a given column for different sample sites)

Site	Grouping of parks by area	Name of introduced tree species growing in the experimental site	Soil pH (within the subcrown space)
1	park	<i>Aesculus hippocastanum</i> L.	7.82 ± 0.103 ^a
2	park	<i>Acer saccharum</i> Marshall	7.41 ± 0.190 ^{bd}
3	park	<i>Ulmus pumila</i> L.	7.90 ± 0.047 ^a
4	park	<i>Celtis occidentalis</i> L.	7.76 ± 0.111 ^a
5	park	<i>Gleditsia triacanthos</i> L.	7.43 ± 0.095 ^{bd}
6	park	<i>Styphnolobium japonicum</i> (L.) Schott	7.32 ± 0.057 ^{bd}
7	park	<i>Fraxinus pennsylvanica</i> Marshall	7.24 ± 0.063 ^b
8	park	<i>Robinia pseudoacacia</i> L.	6.89 ± 0.066 ^c
9	mini-park	<i>Quercus rubra</i> L.	7.49 ± 0.090 ^d
10	mini-park	<i>Ailanthus altissima</i> (Mill.) Swingle	6.92 ± 0.072 ^c
11	mini-park	<i>Gymnocladus dioica</i> (L.) K.Koch	6.83 ± 0.038 ^c
12	park	<i>Acer negundo</i> L.	7.71 ± 0.066 ^a

Table 2

Buffering area of the humic topsoil (cond. cm²) territory of Taras Shevchenko Central Culture and Leisure Park and mini-park ($\bar{x} \pm SD$, different letters for each parameter indicate statistically significant difference at $P < 0.05$ by Tukey's Multiple Test)

Sampling site with tree species	Acidic	Alkaline	Acid-base (total)
Site 1 (<i>Aesculus hippocastanum</i>)	40.72 ± 0.76 ^a	12.57 ± 0.38 ^{abc}	53.29 ± 1.08 ^a
Site 2 (<i>Acer saccharum</i>)	25.74 ± 0.60 ^b	13.21 ± 1.20 ^{bc}	38.95 ± 1.04 ^b
Site 3 (<i>Ulmus pumila</i>)	39.04 ± 0.34 ^{cd}	12.05 ± 0.57 ^{ab}	51.08 ± 0.90 ^c
Site 4 (<i>Celtis occidentalis</i>)	39.16 ± 0.45 ^d	11.42 ± 0.94 ^a	50.57 ± 0.67 ^c
Site 5 (<i>Gleditsia triacanthos</i>)	32.88 ± 0.29 ^e	14.08 ± 0.54 ^c	46.96 ± 0.77 ^d
Site 6 (<i>Styphnolobium japonicum</i>)	25.87 ± 0.46 ^b	13.15 ± 0.79 ^{bc}	39.02 ± 0.77 ^b
Site 7 (<i>Fraxinus pennsylvanica</i>)	24.14 ± 0.34 ^f	12.52 ± 0.55 ^{abc}	36.66 ± 0.64 ^e
Site 8 (<i>Robinia pseudoacacia</i>)	18.23 ± 0.38 ^e	16.72 ± 0.65 ^d	34.95 ± 0.75 ^{de}
Site 9 (<i>Quercus rubra</i>)	27.84 ± 0.32 ⁱ	13.78 ± 0.64 ^c	41.62 ± 0.75 ^f
Site 10 (<i>Ailanthus altissima</i>)	22.55 ± 0.20 ^h	17.12 ± 0.68 ^d	39.67 ± 0.81 ^b
Site 11 (<i>Gymnocladus dioica</i>)	18.08 ± 0.19 ^e	16.76 ± 0.65 ^d	34.84 ± 0.51 ^e
Site 12 (<i>Acer negundo</i>)	38.25 ± 0.31 ^c	13.76 ± 0.90 ^c	52.01 ± 0.85 ^{ac}

Table 3

ANOVA results for microbiological characteristics in the humic topsoil of the studied sites in the areas of Taras Shevchenko Central Culture and Leisure Park and mini-park (superscript letters a–b indicate statistically significant difference at $P < 0.05$ by F-test for indicators taking into account the soil location relative to the tree crown)

Index	Soil sampling location	$\bar{x} \pm SD$	
	ammonifying	within subcrown space outside subcrown space	4.24 ± 1.82 ^a 2.30 ± 0.04 ^b
	Abundance of ecological-trophic groups of microorganisms (million colony-forming units in 1 g of dry soil)	amylolytic	within subcrown space outside subcrown space
oligotrophic		within subcrown space outside subcrown space	1.80 ± 0.86 ^a 0.88 ± 0.01 ^b
	pedotrophic	within subcrown space outside subcrown space	5.09 ± 3.44 ^a 1.80 ± 0.03 ^b
Microbial soil organic matter		biomass (µg C/1 g of dry soil)	within subcrown space outside subcrown space

In the course of data processing, we established the relationship between the level of actual pH and buffering areas (Fig. 1). The closest positive correlations were found between pH values and buffering area in the acid ($r = 0.93$, $P < 0.0001$) and acid-base (total) ranges of external influence ($r = 0.87$, $P < 0.0001$), respectively. A negative correlation was found between pH values and buffering area in the alkaline range of external in-

fluence ($r = -0.78$, $P < 0.0001$). There were no medium or strong correlations between the studied buffering characteristics and microbiological traits. Among the microbiological characteristics, a strong relationship was found between the abundances of amylolytic and pedotrophic microorganisms ($r = 0.70$, $P < 0.0001$).

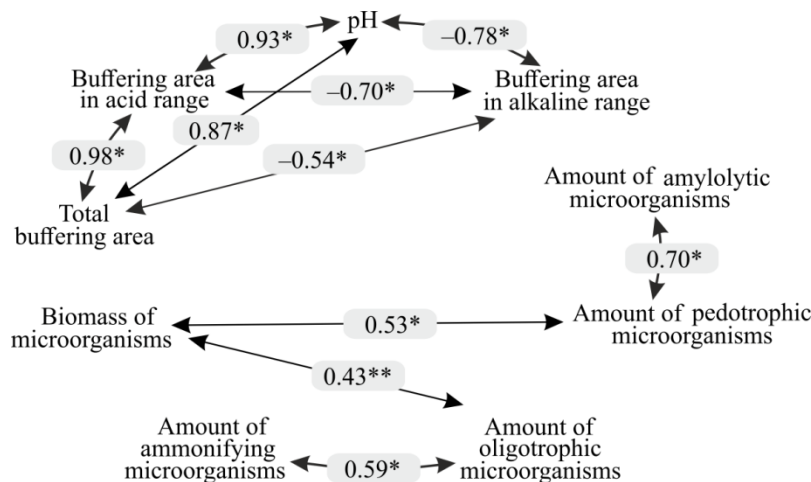


Fig. 1. Pearson correlation coefficients between actual acidity, buffering characteristics, and microbiological parameters of the studied park soils: P-value: * – 0.001–0.0001, ** – 0.0001–0.00001; correlations over 0.4 (in modulus) were found

A continuation of the analysis of the relationships between the traits studied was the identification of latent factors in the data structure, which correlated with the characteristics of buffering capacity and microbiological traits of the studied soils. An exploratory factor analysis was conducted to reduce the number of components via principal component analysis with Varimax rotation. Procedures of factor analysis found that three latent factors taken together accounted for a larger percentage of the total variance of experimental data (83.8% of the total variance). So, Factor 1 accounted for 42.1%, Factor 2: 29.8%, and Factor 3: 11.9% of the total variance of the feature set.

In the process of the correlation matrix factorization using Varimax normalization we revealed that Factor 1 is strongly and positively correlated with such pHBC traits as pHBC in the acidic range of external influences, with the pH value, with total pHBC, and negatively correlated with pHBC in the alkaline range of external influences (Table 4). Factor 2 was strongly and positively correlated with the abundance of amylolytic and pedotrophic microbiota, and Factor 3 – with the abundance of ammonifying and oligotrophic microbiota. The results obtained generally coincide with the correlation analysis.

Table 4

Matrix of factor loadings in the frame of relations between buffering and microbiological parameters of the studied park soils within subcrown spaces of introduced trees

Index	Factor 1	Factor 2	Factor 3
Total pHBC (acid-base)	0.954	0.018	0.128
Actual acidity (pH)	0.976	0.120	-0.093
Soil pHBC in the acid range of external influences	0.988	0.064	0.025
Soil pHBC in the alkaline range of external influences	-0.796	-0.212	0.356
The abundance of ammonifying microorganisms	-0.041	0.120	0.923
The abundance of amylolytic microorganisms	0.064	0.888	0.027
The abundance of oligotrophic microorganisms	-0.081	0.405	0.736
The abundance of pedotrophic microorganisms	0.202	0.936	0.198
Biomass of microorganisms	0.058	0.645	0.319

We performed a cluster analysis to combine the characteristics of acid-base soil pHBC and quantitative composition of ecological-trophic groups of the soil microbiota within the subcrown spaces in the studied park areas with a specific site of soil sampling and its marking species of introduced dendroflora. This technique allowed us to carry out the clustering, as dividing a set of objects into homogeneous classes (Fig. 2). We found out that (considering the above-mentioned traits) the soil samples taken within subcrown spaces of *Robinia pseudoacacia* (site 8) and *Gymnocladus dioica* (site 11), *Celtis occidentalis* (site 4) and *Quercus rubra* (site 9) were different maximally from the soil samples taken within subcrown spaces of *Aesculus hippocastanum* (site 1), *Acer saccharum* (site 2), *Fraxinus pennsylvanica* (site 7), *Acer negundo* (site 12), and can be divided into 2 statistically different groups.

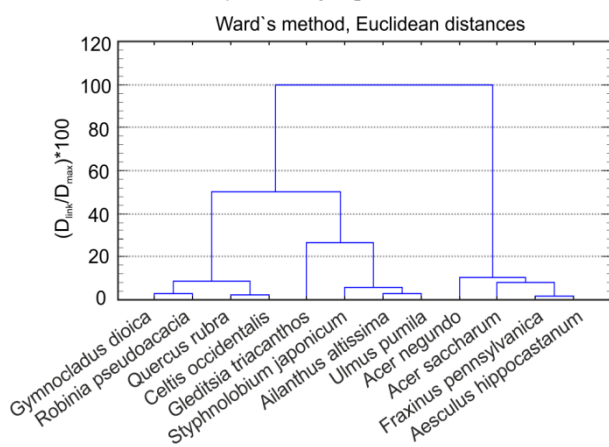


Fig. 2. Dendrogram of clustering of soil physico-chemical and microbiological traits by the marking characteristic (species of introduced dendroflora)

Discussion

Movsesian & Myslyuk (2017) considered soil pHBC as one of the indicators of soil resistance to degradation, including the man-made one. These authors have developed computer models that consider the data on the level of acid-base pHBC of urban soils and which allowed assessment of the degree of the soil degradation under the influence of various levels of man-made load. Our research has revealed the sites (site 7, 8, 11) with a relatively low level of acid-base pHBC and the sites (site 1, 3, 4, 12) with a relatively high level of acid-base pHBC (Table 2), which indicates quantitative and qualitative heterogeneity, variability of the studied soils in terms of buffering capacity. Univariate analysis of variance revealed no relationship between the pHBC level and the properties displayed by the Loamic and Siltic qualifiers ($F = 0.54$, $P > 0.05$).

Bartmiński et al. (2012) also evaluated urban soil resistance to degradation by determining the acid-base pHBC. These researchers showed that the reference soil profiles had greater resistance to acidification compared to the studied soils within Lublin city (Poland); the authors associated soil degradation that occurred within the agglomeration with the acidification phenomenon which occurred because of anthropogenic influences. In our study, park soils sampled within subcrown spaces of the trees had a higher soil pHBC to acidification than to alkalization (Table 2).

This is obviously due to the fact that the chemical composition of urban soil is dominated by such exchange cations as Ca^{2+} and Mg^{2+} in its absorption complex inherited from the calcic chernozem as a zonal soil (Yakovenko et al., 2023).

Wei et al. (2022) showed a close relationship between pH level and the soil pHBC values. The results of our study (Fig. 1) support the relationship established by these authors. During investigation of the relationship between physiological groups of microorganisms with the fertility indicators of podzolic chernozem under various fertilizer systems, Demydenko (2021) found out a direct strong correlation between exchangeable acidity and the abundance of ammonifiers, pedotrophs and micromycetes; the correlation was weakened to an average level for amylolytic and oligotrophic groups of microorganisms. In addition to other indicators, Parra-González et al. (2017) recommended calculating the soil quality index as an integral function of ΔpH , pH of soil-water extract, for its implementation in agroforestry systems of tropical fruits. So, pH value and its alterations are considered to be one of the criteria for assessing the soil quality, on the monitoring of which our own research is based. These outputs confirm the effectiveness of using such a soil indicator as pH value in soil quality diagnostics.

The composition of soil microbiota is known to be correlated with the level of man-made load, so it is widely used as a diagnostic index of ecological state of the soil (Andrejuk et al., 2001). Identification of microbiotic ecological-trophic groups in the rhizosphere allow us to find out the direction of microbiological processes occurring in the upper root-saturated layer of the studied urban soils in the green infrastructure, and to identify the relationship between buffering characteristics and microbiological traits. We determined reliably significant correlations (Figure 1) between microbial biomass and the abundance of oligotrophic microbiota, microbial biomass, and the abundance of pedotrophic microbiota, the abundance of amylolytic and pedotrophic microbiota, as well as between the abundance of oligotrophic and ammonifying microbiota.

Comin et al. (2024) elucidated the effect of woody vegetation on soil quality. Using as an example the soils of two pasture systems with rational grazing (with and without trees) and an adjacent natural forest as a reference, the researchers performed statistical factor analysis (principal components analysis) and showed that the soil of the pasture system with tree stands and forests was of higher quality compared to the other forestless system. In addition, the principal components analysis allows us to identify the relationship (similarity) of soil quality in the system with tree stands to the forest soil quality. As a result of our factor analysis, the effect of two latent factors was established that characterized the direction of microbiological processes. Thus, we assume that Factor 2 (29.8% of the total variance), which correlated with the abundances of amylolytic and pedotrophic microorganisms (Table 3), is associated with the soil dehumification processes. Factor 3 (11.9% of the dataset variance), which correlates with the abundances of oligotrophic and ammonifying microorganisms (Table 4), is probably associated with the entry of fresh organic matter into the soil. The effect of Factor 1 (42.1% of the dataset variance), which correlates with the total buffering capacity, buffer capacity in the acid range, and soil acidity (Table 4), is probably related to the specifics of the soil chemical composition of the studied soil, wherein calcium cations are the dominant ions associated with the cation exchange capacity. Our analysis of variance allowed us to establish that the abundances of ammonifying, oligotrophic and pedotrophic soil microorganisms are greater in the upper

layer of soils located within subcrown space than that in the soils of forestless areas (Table 3), which indicates an active involvement of microbiological processes in the establishment of a balance between dead plant matter entering in the soil and dehumification.

Conclusions

The soils of the studied park sites in a megalopolis forested with introduced tree species are represented by Hortic Anthrosols (Loamic, Eutric) and Hortic Anthrosols (Siltic, Eutric). We found the studied soils to have a higher buffer capacity (total pHBC and pHBC in the acidic range) to acidification than to alkalization, which indicates the greater resistance of these soils to acidic load. We revealed that the abundancies of ammonifying, oligotrophic and pedotrophic soil microorganisms were higher in the topsoil located within subcrown spaces compared to the topsoil of forestless sites. This fact indicates a favorable effect of introduced tree species on microbiological processes that is reflected in maintaining the balance between plant matter decomposition in the soil and dehumification. For the studied urban park soils influenced by introduced tree species, a weak correlation was found between pHBC in the alkaline range and the abundance of ammonifying microbiota. By the methods of multidimensional factor analysis, we revealed the effect of three latent factors that explain 83.8% of the total variance of experimental data. Buffering indicators strongly correlated with Factor I (42.1% of dataset variance), and microbiological characteristics strongly correlate with the II and III factors (29.8% and 11.9% of dataset variance, respectively). The correlated features develop a system wherein physical-chemical and microbiological indicators are interrelated, and which can be used to indicate soil processes and determine the soil sustainability in park areas.

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