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IMPLEMENTATION OF MODERN TECHNOLOGIES TO ALLEVIATE SOIL SICKNESS IN URBAN GREEN AREAS

Introduction. *Urban perennial plantations are exposed to numerous anthropogenic pollutants, recreational load, etc. As a result, the physical and chemical properties of the soil deteriorate, the development of useful soil microflora is inhibited, the phytosanitary properties of soil ecosystems worsen, the intensity of mineralization processes and availability of macro- and micronutrients for plants drops down, and the concentration of toxic substances increases, which leads to soil sickness.*

Problem Statement. *Today, in Ukraine, the causes and features of soil sickness manifestation in urban ecosystems have been virtually unexplored, and there has been no environmentally sound approach to overcoming negative consequences of this phenomenon.*

Purpose. *To implement environmentally sound technology for overcoming soil sickness in urban green areas through the integrated use of the natural silicon containing mineral analcite and a synthetic analog of allelochemical (salicylic acid).*

Materials and Methods. *The experimental sites have been established in the most polluted and anthropogenically disturbed green areas of the Obolon District in Kyiv. The content of micro- and macro-elements, the main ecological-trophic groups of microorganisms have been evaluated, the directions of microbiological processes have been assessed with the use of mineralization and immobilization coefficients. Plant vitality has been determined by the degree of foliar injury, crown defoliation, photosynthetic pigment content, and activity of enzymatic antioxidants in leaves. Soil allelopathic activity has been determined by the bioassay technique.*

Results. *Physical, chemical, and biological processes related to soil-sickness in urban areas have been studied and approaches to control these processes have been determined. The innovative technology to alleviate soil sickness in urban green areas has been tested.*

Conclusions. *The advantage of the proposed technology is a complex synecological approach that provides optimization of agrophysical, agrochemical, and biological characteristics of soil (optimal pH level, balanced content of mineral nutrients, elimination of toxicity), enhances the adaptive potential of cultivated plants to negative biotic and abiotic factors including phytopathogens.*

Keywords: urban ecosystems, perennial plantings, soil sickness, silicon-containing minerals, salicylic acid, microbiocenosis, and adaptive potential.

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Perennial plantations are an integral part of modern urban planning and creating a living environment for the population and fauna. They enrich the atmosphere with oxygen, absorb carbon dioxide, emit phytoncides, and affect the formation of the microclimate: increase humidity and assure protection from wind, high and low temperature, and solar radiation. In large densely populated cities, such as Kyiv, greenery is exposed to significant anthropogenic pressure, so the natural mechanisms of self-regulation and self-renewal are disrupted. This leads to imbalance of coenotic and trophic relationships, inhibition of agronomically useful microflora and microfauna, impairs resistance of plantations to any stressors, including phytopathogens and pests, causes disruption of normal soil formation, accumulation of phytotoxins of both biotic (toxic secretions of plants and microorganisms) and abiotic (toxic metals, pesticides) origin, with the formation of soil fatigue (i.e. depletion of positive resources, accumulation of toxic substances and phytopathogens) and reduced viability and stability of phytocenoses as consequence [1, 2]. Under such conditions, the phytocenoses are not able to perform their purpose and to provide sustainable environment conditions with appropriate phytosanitary standards for human habitation.

The analysis of the literature has allowed us to identify three scientifically sound approaches to overcoming the soil fatigue of urban soils:

- Phytoremediation by means of species and cultivars of plants, which are resistant to anthropogenic load and toxic concentrations of pollutants;
- Chemical remediation and detoxification of urban soils; and
- Microbiological reclamation of soils [3—5].

Today, the most well-known measures to improve the condition of urban soils are the introduction of organic ameliorants (biohumus, compost, and green manure), organic (washing the soil with solution of ethylenediaminetetraacetic acid (EDTA)) or mineral antidotes (liming, plastering). Soil enrichment with microelements that are antagonists of these toxicants is used to reduce the penetration of toxic elements into the plant body [3—5].

These techniques require significant financial costs or time inputs to achieve a favorable effect. In addition, the effect of their use largely depends on environmental factors and soil conditions. In particular, a high content of toxic compounds (heavy metals, xenobiotics) prevents the development of microbes, ameliorants, and sensitive phytosanitary plants. Therefore, it is important to find new efficient and environment friendly methods for overcoming soil fatigue in perennial urban plantations.

In recent years research has proven the prospects for the use of silicon-containing minerals as one of the system-forming factors of the soil ecosystem. Today, scientific, material, and financial resources are directed primarily towards the development of resource-saving technologies to improve soil condition. In this regard, research aiming at elucidating the role of silicon-containing preparations in the functioning of phytocenoses and at developing various materials based on them, which are promising for the introduction of different soil and climatic zones in green construction, is of paramount importance.

To reduce soil fatigue and soil toxicity, increase its fertility, it has been proposed to use mixes that contain a balanced ratio of salicylic acid (synthetic analog of natural growth regulator and immunomodulator) and silicon-containing minerals. On the one hand, biologically active forms of silicon (analcime) increase the adaptive potential of plants to toxic compounds and phytopathogenic microorganisms and, on the other hand, significantly improve the soil condition [6, 7]. Due to its high sorption capacity, analcime immobilizes ions of toxic substances in the soil solution and stabilizes the biological activity of salicylic acid [8]. Another component of the mix, salicylic acid, is a biostimulator of growth, productivity, and systemic resistance of plants to abiotic and biotic stressors [9]. In addition, salicylic acid in the soil solution can form chelate complexes with toxic metal ions, thereby reducing their bioavailability to plants and agronomically beneficial microorganisms [10]. Salicylic acid also stimulates the development and preservation of biodiversity of the microbiocenosis that includes species with antagonistic properties with respect to phytopathogens [10]. Combined with analcime salicylic acid enhances the active involvement of silicon in the structural and functional organization of the soil ecosystem. In turn, silicon synergistically enhances the growth-stimulating and immunomodulatory activity of this compound.

The purpose of this research is testing and introducing a new ecologically sound technology for overcoming soil fatigue in urban plantations due to the integrated use of natural silicon-containing mineral analcime and synthetic analog of allelochemical (salicylic acid). To achieve this purpose the following tasks have been performed:

- Studying the physicochemical and biological processes occurring under the influence of soil fatigue and anthropogenic factors in perennial plantations of the Obolonsky District of Kyiv;
- Determining the optimal doses of silicon-containing preparations, given the biological aspects of plant development, agrophysical and agrochemical properties of soils, climatic conditions of a particular region;
- Testing the offered technology on research sites in plantations of perennial plants of the Obolonsky District of Kyiv;
- Developing recommendations for overcoming soil fatigue in urban plantations of different functional directions.

Data from the inventory of green areas of Obolonsky District have shown that the green areas along roads (including S. Bandera Avenue, Marshal Tymoshenko Street, etc.) and some recreational areas (including Natalka Park, where irrigation water contains toxic levels of iron) are in the most critical condition because of being polluted with vehicle emissions and secondary salinization.

Six sites in the most polluted and anthropogenically disturbed areas of green plantations of Obolonsky District have been experimentally studied (Table 1).

The experiments have studied the effect of analcime and salicylic acid mix (1: 0.001, at an application rate of 400 kg/ha) on the functional state of plants and the information resource component of the soil ecosystem under conditions of a significant anthropogenic load. To do this, samples of the rhizosphere soil were taken at a depth of 0—20 cm before the introduction of silicon-containing mix (on May 28, 2019) and 3.5 months after its application (on September 16, 2019). For the second sampling, the perennial plants grown in the soil fertilized with the mix and the plants of the same species, which grew side by side, but without the use of the mix (the reference sample) have been visually assessed.

Table 1. **Description of Sites**

Site No.	Location	Dominating plants	Type of anthropogenic load
1	Roadside of S. Bandera Avenue	European ash (*Fraxinus excelsior*)	Vehicle emissions, salinization
2	*Natalka* Park	European birch (*Betula pendula*)	Increased content of iron in irrigation water, rust-colored stems of trees
3	*Natalka* Park	Feather-fern (*Spireae japonica*)	Increased content of iron in irrigation water
4	*Natalka* Park	Saucer magnolia *Magnolia soulangeana*	Increased content of iron in irrigation water
5	Traffic divider opposite to the District Public Administration building, Marshal Tymoshenko St.	Norway maple (*Acer platanoides*)	Vehicle emissions, salinization
6	Traffic divider opposite to the District Public Administration building, Marshal Tymoshenko St.	European privet (*Ligustrum vulgare*)	Vehicle emissions, salinization

The degree of foliar injuries (scorch) from phytotoxic effect has been assessed visually with the use of the gas resistance scale by N.P. Krasinsky [11].

0 — no noticeable injury on the leaves;

1 — very weak injury (1—10 % of the leaf surface is scorched);

2 — weak injury (11—20 % of the leaf surface is scorched);

3 — medium injury (21—40 % of the leaf surface is scorched);

4 — severe injury (41—80 % of the leaf surface is scorched);

5 — very severe injury (> 81 % of the leaf surface is scorched).

The degree of defoliation of the crown of trees and shrubs has been assessed visually for the 5 classes:

0 — no defoliation (0—10 %);

1 — weak defoliation (11—25 %);

2 — medium (26—60 %);

3 — strong (61—99 %);

4 — wizened trees (100 %).

The defoliation is measured with 5—10 % accuracy for the entire crown (as an indicator of the whole set of manmade factors) [12].

The leaf samples are taken to determine the content of photosynthetic pigments and catalase activity. Photosynthetic pigments are extracted from fresh leaves with dimethyl sulfoxide. The quantitative content is measured with the use of a spectrophotometer *SPECORD* 200 (*Analytik Jena*, Germany) [13]. The catalase activity is determined by the method of O.N. Bach and O.I. Oparin [14].

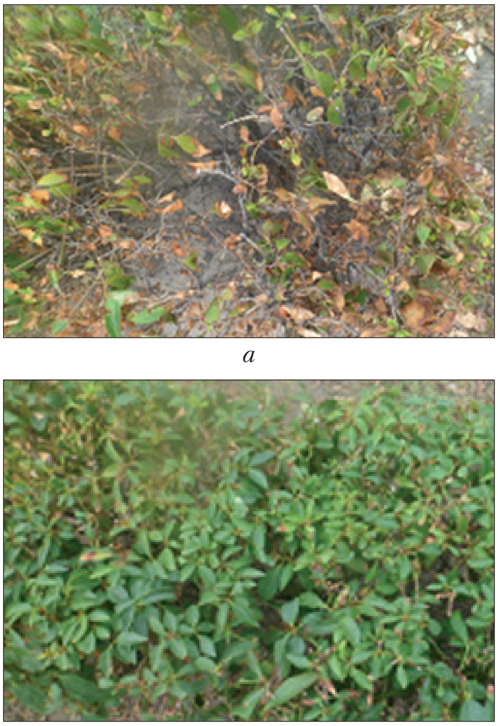
Soil phytotoxicity analysis is made by direct bioassaying. The growth responses of the roots of amaranth (*Amaranthus cruentus L.*) and winter wheat (*Triticum aestheticum L.*, *Smuglianka* variety) are used as a test-object according to the Neubauer-Schneider method [15, 16]. The Grodzinsky method is used while studying the quantitative parameters of phenolic allelochemicals in the soil [17].

The microbiological activity of the soil samples has been analyzed by sowing soil suspensions in appropriate dilutions on agar nutrient media, according to conventional methods [18]. The micromycetes on Czapek medium, actinomycetes on starch-ammonia agar (SAA), ammonifiers on meat-peptone agar (MPA), and bacteria that consume mainly mineral compounds of nitrogen on SAA have been counted. The number of microorganisms has been determined in colony-forming units (CFU) by the number of colonies that germinate while soil suspensions are sown on agar media. The direction of microbiological processes in the soil has been studied by K.I. Andreyuk and co-authors [20]. The rate of transformation of soil organic matter has been calculated by V.D. Mukha [21].

The content of nutrients in soil samples has been analyzed according to the Rinkis method [22] on a plasma-induced spectrophotometer *ISAR 6300 DUO* (*Thermo Scientific*, USA). 1 n HCl is used for extraction of macro- and microelements in the soil.

The experimental results have been statistically processed by the methods of one-dimensional statistics and analysis of variance, with the use of *Microsoft Office Excel* 2007 and *Statistics* 10.0. The data given in tables and diagrams are arithmetic means; the vertical bars on the graphs mean the least significant difference (LSD).

The visual assessment of the condition of green plantations 3.5 months after the application of the mix and of the reference plants (the same species that grew side by side, without the use of the mix) has shown a significantly better condition of the plants in the experimental sites. The generalizing indicator of the condition of green plantations is the crown defoliation that integrally characterizes the impact of unfavorable factors on plants [23]. According to [12], defoliation (loss of photosynthetic (assimilation) organs) is officially recognized as a pan-European indicator of sustainable forestry, which estimates the condition and viability of wood stands. The highest degree of leaf surface scorch, drydown, and loss of leaves, which indicates a significant level of aerotechnogenic pollution has been recorded in the areas located along the motorways S. Bandera Avenue (section No. 1) and Marshal Tymoshenko



a

b

Fig. 1. Visual foliar injuries of European privet leaves: *a* — the reference sample (without the use of any amendments); *b* — in the case of the plants treated with silicon-containing mix; September 2019

Street (sections Nos. 5—6) (Table 2, Fig. 1). In the *Natalka* Park (sections Nos. 2—4), the degree of defoliation is much lower, as this area is located at a sufficient distance from the sources of emission. In addition, the favorable location of the Dnieper Bay has a positive effect on the greenery, which contributes to the formation of a microclimate with lower air temperature and sunlight intensity in summertime.

Visual observation has shown that the reference plants are significantly more affected by various groups of phytopathogens as compared with the same species that grew in the soil fertilized with silicon-containing mixes. This has testified to the stimulation of systemic resistance of cultivated plants by the components of the studied mixes. These differences are especially noticeable in the plantings of *Natalka* Park and the traffic divider along Marshal Tymoshenko Street.

The analysis of the content of photosynthetic pigments (chlorophyll *a*, *b* and carotenoids) in the leaves of experimental plants grown in the experimental sites has shown that in the case of application of silicon-containing mix there is an increase in the biosynthesis of chlorophyll *a* and *b* (Fig. 2). This effect is especially noticeable on the sections of the highway along S. Bandera Avenue (European ash (*Fraxinus excelsior*)), in the *Natalka* Park (feather-fern (*Spireae japonica*)) and on the traffic divider along Marshal Tymoshenko Street (Norway maple (*Acer platanoides*)). The obtained dependence is important because these perennials are sensitive to aerotechnogenic pollution.

The analysis of catalase activity in the leaves of the studied perennials has shown that almost all experimental plants, except for birch (site No. 2) and privet (site No. 5), respond to the introduction of the mix by reducing the activity of this enzyme (Fig. 3). For the birch plants, there is no significant effect of the mix on the activity of catalase in the leaves, whereas in the case of privet, the activity of this enzyme increases. On the one hand, catalase is a marker of stress and, on the

Table 2. **Degree of Defoliation and Foliar Injuries Induced by Technogenic Factors in Edificator Plants on the Studied Areas of Green Plantations in Obolonsky District of Kyiv**

Site No.	Dominating plants	Defoliation degree		Degree of leaf surface damaged by burns	
		test	reference	test	reference
1	European ash (*Fraxinus excelsior*)	3	1	4	2
2	European birch (*Betula pendula*)	0	0	0	0
3	Feather-fern (*Spireae japonica*)	0	0	0	0
4	Saucer magnolia *Magnolia soulangeana*	1	0	2	1
5	Norway maple (*Acer platanoides*)	2	0	4	1
6	European privet (*Ligustrum vulgare*)	1	0	2	1

other hand, it characterizes the ability of the protective enzymatic antioxidant system to detoxify free radicals formed as a result of oxidative stress. Therefore, a decrease in the activity of this enzyme in European ash plants (site No. 1), feather-fern (site No. 3), saucer magnolia (site No. 4), and Norway maple (site No. 5), given improved photosynthetic performance, means a decrease in overall stress state. The increase in the catalase activity in the privets, provided that the content of chlorophyll *a* and *b* and carotenoids significantly increases, indicates the activation of protective antioxidant systems that are responsible for the systemic resistance of plants to adverse environment factors.

The analysis of phytotoxicity of rhizosphere soil on the growth of amaranth roots by direct assaying has shown that the first sampling (before the application of silicon-containing mix) in the root layer of the soil contains a significant amount of phytotoxins. The highest concentration of phytotoxic substances is recorded in the soil taken from site No.4 (*Natalka* Park), where the inhibition of seed germination and root growth of the test plants reached 60 %. The lowest phytotoxic effect is observed for the rhizosphere soil samples taken from sites Nos. 5 and 6 (the traffic divider along Marshal Tymoshenko Street), where the inhibition of amaranth root growth is 33—35 %, with the seed germination being on a par with the reference samples (Fig. 4).

A similar pattern has been observed in the analysis of the results of soil phytotoxicity bioassaying based on the growth reactions of wheat (the Neubauer-Schneider method). Prior to the application of the silicon-containing mix into the soil, the growth of both shoots and roots of wheat seedlings grown on the soil collected from the experimental sites is markedly inhibited as compared with the reference samples (grown on sand + sterilized tap water) (Fig. 5). The length of the root system reacts most sensitively to the presence of anthropogenic pollutants in the soil. The least sensitive marker is the number of lateral roots.

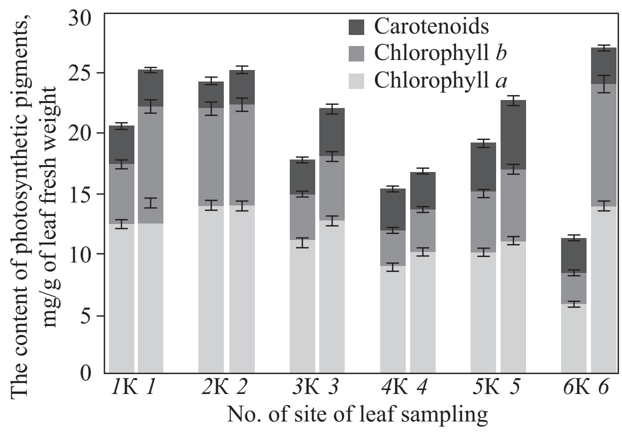


Fig. 2. The content of photosynthetic pigments in the leaves of perennial plants in the case of the use of silicon-containing mix and in the plants that grow side by side without the introduction of the mix (reference plants (K)). Vertical bars: LSD (the least significant difference): *1* — European ash; *2* — European birch; *3* — feather-fern; *4* — saucer magnolia; *5* — European privet; *6* — Norway maple.
Here and further: vertical bars: LSD (the least significant difference)

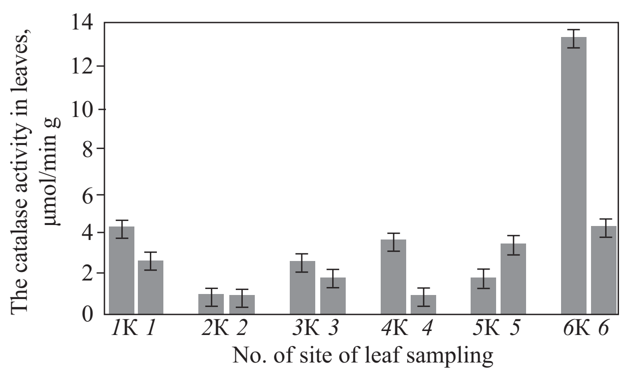


Fig. 3. The catalase activity in the leaves of perennial plants treated with silicon-containing mix and in the plants that grow side by side without the application of the mix (reference plants (K)). Vertical bars: LSD (the least significant difference): *1* — European ash; *2* — European birch; *3* — feather-fern; *4* — saucer magnolia; *5* — European privet; *6* — Norway maple

Three and half months after the mix application, the soil phytotoxicity with respect to wheat seedlings decreases significantly. This effect is especially noticeable in the growth processes of shoots of wheat seedlings, which improves by 14—30 % in the presence of silicon.

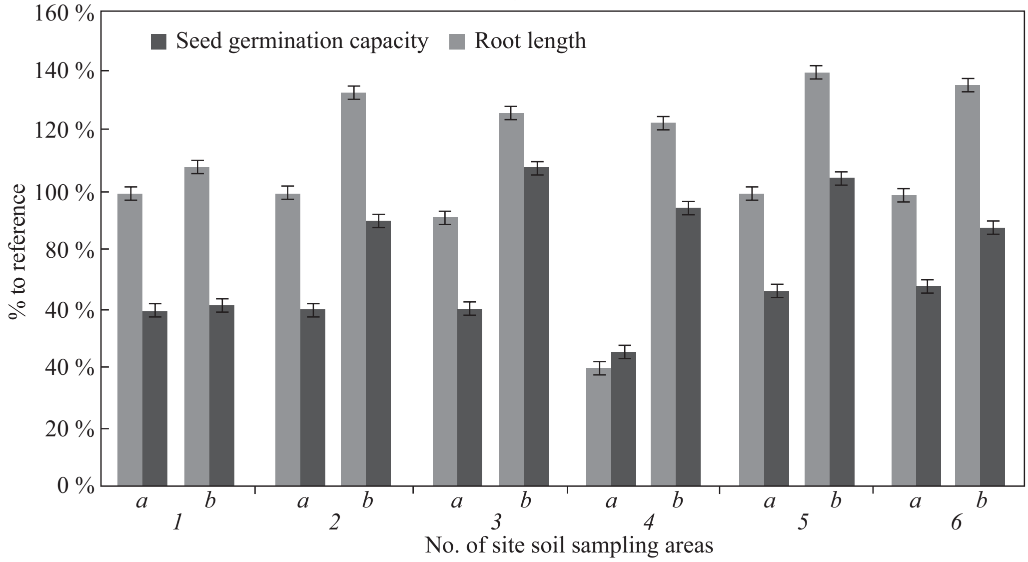


Fig. 4. Assessment of the allelopathic activity of the rhizosphere soil of the studied sites of Obolonsky District of Kyiv.
Bioassay: growth of amaranth roots: *a* — the samples before introduction of the mix; *b* — the samples in 3.5 months after the application of the mix

The analysis of the content of free phenolics in the soil solution has shown that the application of the studied mix contributes to the growth of this indicator in all experimental sites (Fig. 6). Obviously, the observed increase is explained by the presence of salicylic acid as mix component. However, the total concentration of phenolic compounds in the soil solution does not reach the phytotoxic level (> 1000 μM).

In sites Nos. 2—4 (*Natalka* Park) under conditions of regular watering, the content of phenolic compounds is minimal, as a result of the transformation of salicylic acid by soil microbiota that under conditions of regular watering and lower aerotechnogenic load develops better than that along the motorways (sites No. 1 and Nos. 5—6). The highest concentration of free phenolic compounds in the soil solution is reported in sites Nos. 5 and 6, which indicates an unsatisfactory biological capacity of root soil and a low activity of soil microorganisms capable of biotransformation of this group of allelopathically active substances.

Thus, in the case of soil drought and significant aerotechnogenic load, there are created conditions that promote the accumulation of phytotoxic allelochemicals in the rhizosphere soil of the studied species of perennial plants in Obolonsky District of Kyiv and adversely affect their growth in the metropolis. The use of silicon-containing mix significantly improves the biological activity of the soil, as well as morphological and physiological-biochemical indicators of the living condition of both woody and herbaceous plant species.

The soil condition can be assessed with the use of the characteristics of the microbial coenosis, the number and ratio between taxonomic and ecological trophic groups of microorganisms. In particular, soil microorganisms as components of the heterotrophic consortium take an active part in the primary processes of decomposition of organic residues, especially those that are hard to hydrolyze (fiber and lignin), as well as in the synthesis of specific metabolites, antibiotics, and toxins.

Fungi play an important role in the nitrogen cycle, primarily in the processes of ammonification, since they create conditions for the development of other microorganisms. In the course of

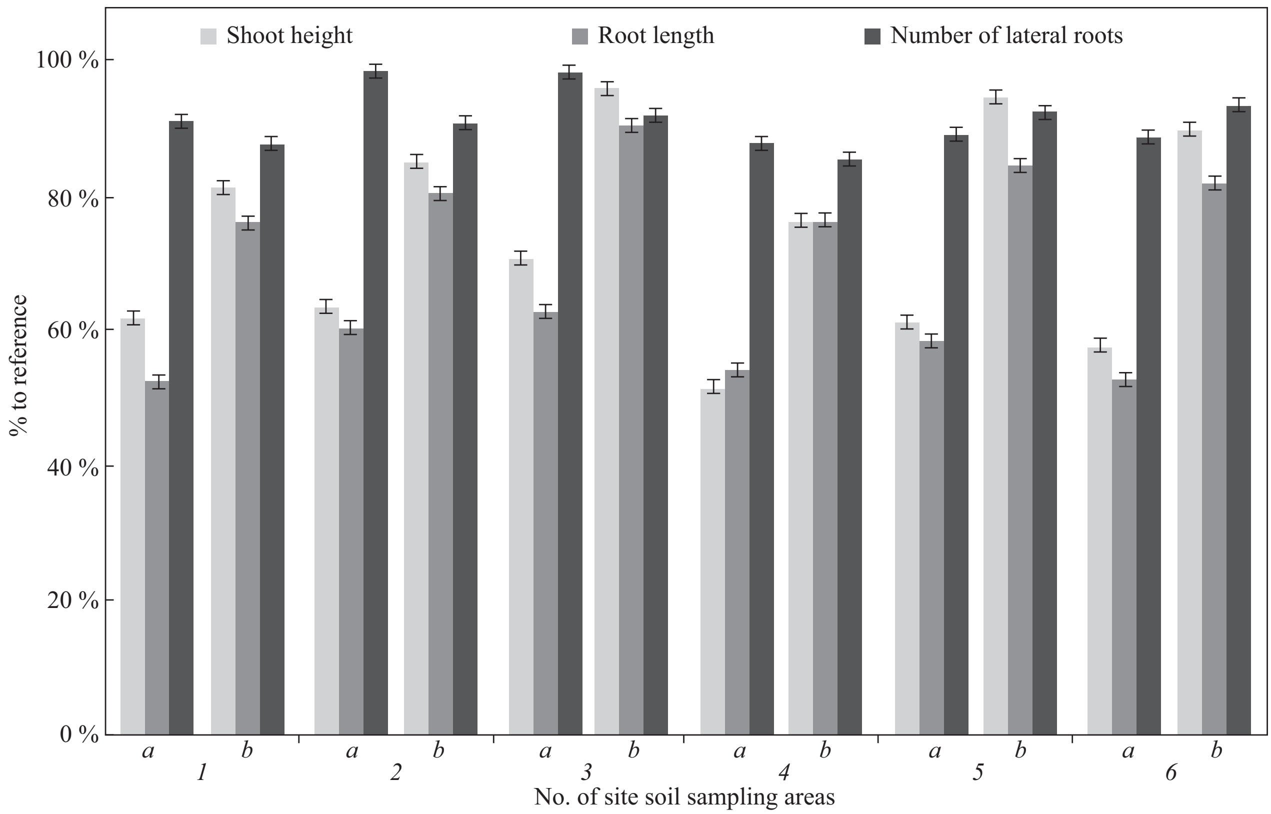


Fig. 5. Growth responses of wheat germ to allelochemicals of the rrhizosphere soil of the experimental sites of Obolonsky District of Kyiv: *a* — the soil samples before application of the mix; *b* —the samples in 3.5 months after the application of the mix

the research, it has been established that before the application of the silicon-containing mix, the highest indicators of the number of micromycetes are observed in sites Nos. 5—6 and 1, while in the soils of sites Nos. 2—4 there are much less these microorganisms. In the first three sites, a significant amount of melanin-containing strains has been recorded.

After the introduction of the silicon-containing mix in all sites, except for site No. 4, there is reported a decrease in the number of micromycetes. It is known that fungi are indicators of ecosystem stability, so the resulting dependence indicates a disturbance of the soil structure and environment pollution. The lowest indicators of the number of micromycetes are observed in the soil samples from sites Nos. 5—6 (23.6—26.4 thousand CFU) and No. 1 (25.4 thousand CFU). In the soil samples of sites Nos. 2—4 (which were watered) there are more fungi (34.4—41.0 thousand CFU). This effect of the silicon-containing mix may be considered as a positive effect, since an excessive number of micromycetes may indicate the accumulation of toxic metabolites.

Actinomycetes are one of the most common groups of soil microorganisms capable of surviving in adverse living conditions. They are characterized by a high physiological activity, and therefore can grow on various substrates, participate in the destruction of sparingly soluble organic matter at later stages of their mineralization, which are inaccessible to fungi and cellulose-destroying microorganisms, and produce antibiotics and phytotoxic compounds.

The largest number of actinomycetes is observed in samples Nos. 5—6 (1.3 million CFU) and

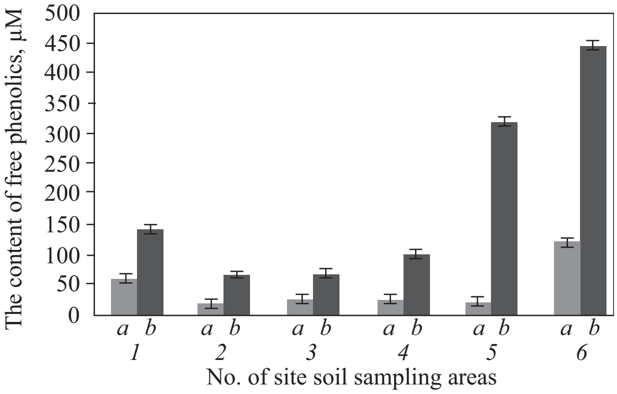


Fig. 6. The content of free phenolics in the soil solution of experimental sites of Obolonsky District of Kyiv: *a* — the samples before application of the mix; *b* — the soil samples in 3.5 months after application of the mix

in No. 1 (1.0 million CFU). The application of silicon-containing mix increases the number of microorganisms of fungi in all samples, except for the soil from sites Nos. 5—6.

Ammonifying microorganisms destroy organic compounds that enter the soil with root exudations or plant debris. The highest number of ammonifiers is found in sites Nos. 6 and 1 (7.0 and 6.8 million CFU, respectively). The application of the mix contributes to the development of this group of microorganisms, as their number increases in all experimental sites, except for site No. 6.

The microorganisms that are able to consume mainly mineral nitrogen play an important role in the nitrogen balance of the soil. A characteristic feature of the development of this group of microorganisms is the fact that their number increases 1.1—2.6 times in the soils of all experimental sites after the application of silicon-containing mix.

In general, 3.5 months after the application of the silicon-containing mix, there are reported significant changes in the structure of the microbiocenosis of the experimental soils, as the number of ammonifiers, actinomycetes, and microorganisms that consume mineral nitrogen goes up. The most significant changes are observed in site No. 1 (ammonifiers increase 2.9 times, microorganisms-immobilizers of mineral nitrogen grow 1.4 times, and actinomycetes rise 1.25 times). Increased development of these groups of microorganisms is recorded in soil samples of *Natalka* Park (sites 2—4). At the same time, the number of micromycetes, especially in soil samples Nos. 5—6 and No. 1, decreases (3.1—3.5 and 1.8—2.4 times, respectively).

The ratio of individual indicators of the number of trophic groups of microorganisms allows calculating the coefficients of mineralization & immobilization and transformation of organic matter, which indicate the intensity of the processes of mineralization and destruction of organic matter. The highest values of mineralization & immobilization coefficient (2.4 and 2.7) are observed in *Natalka* Park where the sites were irrigated with water having a high iron content. In site No. 1, after the application of silicon-containing mix, the mineralization coefficient decreases. This fact indicates more favorable conditions for the synthesis of humic compounds, which is also confirmed by a high rate of transformation of plant residues.

According to the observations of many researchers, urban soils are characterized by high pH, density, concentration of carbonates and iron oxides [24, 25]. Typically, in these soils, the carbon content increases because of organic pollutants, which results in significant changes in the biogeochemical cycles of C and N [26, 27]. In turn, under conditions of increased soil density, there are reported a disturbance of the water regime, a reduction in the mobility of nutrients, and significant changes in the quantitative and qualitative composition of the microbiocenosis. In urban ecosystems, it is difficult to trace the processes of soil evolution because of different chemical composition of pollutants that may be of both organic and inorganic origin and are characterized by multi-vector action. In particular, the content of carbon in soils decreases as a result of anthropogenic pressure, its supply is reduced as dead leaves are cleaned and because of chemical pollution. And vice versa, organic matter is accumulated in the soil as a result of effect of organic pollutants, slower mineralization of plant residues under the influence of heavy metal pollution, higher plant growth productivity at elevated temperature and high concentration of CO_2 in the air. In accordance with the peculiarities of the structural and functional organization of urban biogeocenoses, leading U.S. researchers have defined the concept of soil evolution of metropolis ecosystems [28]. The classification of soils by stages of evolution includes the two stages: the strong destructive effect at the beginning of construction works, which leads to a disturbance of the soil profile, including the humus horizon, and the artificial formation of soil cover by adding natural organic materials. This complicates the systematization of metropolis soils as a result of the disturbance of their agrophysical, agrochemical, and biological properties under anthropogenic influence.

The studies have revealed significant differences in the indicators of humus in the experimental sites. The reaction of the soil solution ranges from slightly alkaline to slightly acidic. Before to the application of the silicon-containing mix, the carbon content is higher because of labile forms of humus, which is consistent with the data of microbiological analysis of the soil samples. In September, there is a stabilization of soil processes, which manifests itself both in reducing humus labile forms and in shifting the soil solution reaction towards reducing alkalinity.

The optimization of the soil ecosystem is evidenced by the growing number of melanin-containing micromycetes that act as biotransformers of both organic and inorganic compounds. In turn, the growth of stable forms of humus leads to remedying the soil structure, decreasing its density, and activating the microbiological processes. It should be noted that aerogenic pollutants have a fairly diverse composition that includes both inorganic and organic compounds. According to American experts, the degree of contamination of urban soils with aeral heavy metals-biophiles correlates with their contamination by organic pollutants [29]. The most indicative are carbon, copper, and lead. Similar results have been obtained by German researchers who have found that the largest amount of carbon (36%) in urban soils is concentrated in the sand fraction and 18% is contained in the silt fraction, while in the natural untransformed soils,

Table 3. **The Content of Heavy Metals in the Soils of the Experimental Sites of Obolonsky District of the Kyiv City**

Site	Element, ppm									
	Al	Ba	Cd	Cr	Cu	Fe	Pb	Sr	V	Zn
May										
1	6119.0	61.8	1.1	15.7	83.1	5933.0	581.4	12.5	14.4	189.6
2	3084.0	28.3	0.4	4.1	10.6	2817.5	21.6	7.1	16.8	31.2
3	6831.5	38.4	0.9	83.6	21.7	3926.0	29.2	10.1	51.2	67.2
4	4530.0	37.1	0.6	8.2	15.0	4108.0	19.4	16.3	18.1	30.6
5	6097.0	55.1	1.0	42.2	51.2	4527.0	49.5	11.1	81.3	112.3
6	11351.5	63.3	1.3	113.5	72.2	6233.0	45.9	15.4	75.8	99.5
September										
1	5711.0	54.6	0.6	12.4	53.8	5005.0	29.9	9.8	11.5	115.7
2	2718.0	22.6	0.1	3.4	4.9	2182.0	7.6	5.8	4.4	12.1
3	6140.5	32.9	0.5	60.2	10.5	3325.0	11.6	8.6	9.9	36.1
4	4021.5	30.1	0.3	6.1	5.8	3574.0	7.6	14.3	10.5	12.0
5	5761.0	47.3	0.6	30.8	96.8	4259.0	26.4	9.2	11.7	68.6
6	9235.0	56.9	0.7	25.6	35.7	5626.0	22.6	11.2	16.3	59.4
LSD	*2.2*	*1.7*	*0.1*	*0.8*	*1.2*	*2.9*	*1.3*	*1.2*	*1.2*	*1.4*

*LSD means the least significant difference; P = 0.05.

only 5% is concentrated in sand versus 60% in silt [30]. An increase in air temperature in cities because of the influx of temperature from asphalt pavement, houses, and industrial enterprises creates a background “heat island”. This explains the increased carbon content in urban soils. On the other hand, a high concentration of CO_2 both in the air and in the ground surface stimulates the plant growing processes. Certain changes also occur with the distribution of nitrogen that enters the soil and together with dust particles enriched with Ca^{2+} and Mg^{2+} contributes to its alkalization. At the same time, the activation of nitrification processes leads to a decrease in CH_4 emissions from urban ground ecosystems [31]. In turn, the carbon cycle depends on the concentration of heavy metals in the soil, the level of which determines the quantitative parameters of microorganisms that destroy plant residues. The results of experiments have shown that the introduction of silicon compounds not only reduces the mobility of heavy metals, in particular, Cu, Pb, Cd, Zn, and Cr, but also stimulates the development of microbiota (Table 3).

Table 4. **The Content of Biogenic Elements in the Soils of the Experimental sites of Obolonsky District of the Kyiv City**

Site	Element, ppm					
	N	P	K	Ca	Mg	Mn
			May			
1	33.6	395.7	376.1	2081.5	663.3	222.2
2	15.1	118.3	124.8	1076.5	288.4	159.8
3	27.3	136.4	229.1	1919.5	526.7	146.8
4	28.9	209.2	158.9	4174.0	595.8	136.9
5	31.4	227.5	354.2	1868.5	646.9	181.9
6	42.7	455.9	599.8	2080.5	923.4	243.8
			September			
1	215.4	734.5	671.4	4975.0	815.2	95.7
2	146.1	295.3	198.9	4257.0	794.7	89.4
3	197.2	313.9	470.6	4811.5	822.9	55.2
4	201.6	481.5	236.0	5127.0	851.3	77.3
5	224.8	593.2	659.5	4926.0	810.9	99.6
6	235.8	943.4	1006.2	5009.5	837.4	101.8
LSD	*1.7*	*2.5*	*2.3*	*4.1*	*3.6*	*2.3*

*LSD means the least significant difference; $P = 0.05$.

The most significant fluctuations in the concentration of heavy metals in the soil of the experimental site are found in the samples of site No.2 that was watered. Their content in the soil is almost twice lower for most elements, the concentrations of which are measured. In this case, the concentration of Sr and V remains almost the same in all experimental sites. Lawns, especially roadsides, have a higher capacity for accumulation of heavy metals.

The presence and a high content of chromium and cadmium in the soil of site No. 6 require a more detailed study. They may be associated with the enrichment of urban soils with organic material, in particular, with lowland peat.

The balance of the components of the soil ecosystem is evidenced by 1.7 — 2.6 times increase in the content of mineral nutrients in the case of the use of silicon-containing mix (Table 4). In general, the data on the distribution of nutrients in the soil of the experimental sites are consistent with the indicators of carbon distribution

Thus, a preliminary assessment of the condition of greenery in the studied areas of Obolonsky District of Kyiv has shown that most perennials are in a depressed state: they have visible signs of damage (scorched leaves, crown defoliation, phytopathogens). Soil drought and significant aerotechnogenic load have contributed to the accumulation of phytotoxic allelochemicals in the rhizosphere soil of the studied green plantations. This further aggravates the conditions of their growth.

The application of the experimental silicon-containing mix contributes to improving the living condition of the edificators of the studied green plantations. In particular, the introduction of the mix stimulates the biosynthesis of photosynthetic pigments and the activity of protective antioxidant systems in the plants. The presence of silicon-containing mix significantly improves the biological activity of the soil: reduces its phytotoxicity, contributes to the accumulation of biologically active substances with growth-stimulating activity. The structure of the microbiocenosis of the experimental soils significantly changes in 3.5 months after the application of the silicon-containing mix. The characteristic feature is increasing number of melanin-containing micromycetes, ammonifiers, actinomycetes, and microorganisms consuming the mineral nitrogen. At the same time, there is reported in a decrease in the number of micromycetes with phytopathogenic properties and producers of phytotoxic allelochemicals. The application of silicon-containing mix helps to reduce the mineralization coefficient, which indicates more favorable conditions for the synthesis of humic compounds. This is also confirmed by intensified transformation of plant residues after the application of the studied mix. In addition, the optimization of the soil ecosystem is evidenced by the growing number of melanin-containing micromycetes that act as biotransformers of both organic and inorganic compounds. In turn, the accumulation of stable forms of humus improves the soil structure by reducing its density and activating the microbiological processes. The application of silicon-containing mix helps to increase the content of mineral nutrients 1.7 — 2.6 times and to reduce the mobility of toxic metals in the soil solution

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ВПРОВАДЖЕННЯ СУЧАСНИХ ТЕХНОЛОГІЙ ПОДОЛАННЯ ҐРУНТОВТОМИ У МІСЬКИХ НАСАДЖЕННЯХ

Вступ. Міські багаторічні насадження піддаються впливу численних антропогенних забруднювачів, рекреаційного навантаження тощо. Як наслідок — погіршуються фізичні та хімічні властивості ґрунту, фітосанітарні властивості ґрунтової екосистеми, пригнічується розвиток корисної ґрунтової мікрофлори, знижується інтенсивність мінералізаційних процесів та доступність макро- та мікроелементів, зростає концентрація токсичних сполук, що призводить до ґрунтовтоми.

Проблематика. На сьогодні в Україні причини та особливості прояву ґрунтовтоми в урбанізованих екосистемах є практично недослідженими, а екологічно обґрунтованих підходів щодо подолання цього явища не розроблено.

Мета. Впровадити екологічно обґрунтовану технологію подолання ґрунтовтоми у міських насадженнях за рахунок комплексного використання природного кремнієвмісного мінералу анальциму та синтетичного аналогу алелопатично активної сполуки (саліцилової кислоти).

Матеріали й методи. Дослідні ділянки закладено в найбільш забруднених та антропогенно порушених зонах зелених насаджень Оболонського району Києва. Визначали вміст мікро- та макроелементів, оцінювали основні еколого-трофічні групи мікроорганізмів, спрямованість мікробіологічних процесів за коефіцієнтами мінералізації та іммобілізації. Життєвий стан рослин оцінювали за ступенем пошкодження листків, дефоліації крони, вмістом фотосинтетичних пігментів, активністю ферментативних антиоксидантів в листках. Алелопатичну активність ґрунту визначено методом біологічних проб.

Результати. Досліджено фізико-хімічні і біологічні процеси, пов'язані з ґрунтовтомою, під міськими насадженнями та визначено підходи до управління цими процесами. Апробовано нову технологію подолання ґрунтовтоми у міських насадженнях.

Висновки. Перевагою запропонованої технології є комплексний синекологічний підхід, який передбачає оптимізацію агрофізичних, агрохімічних, біологічних характеристик ґрунту, підвищення адаптивного потенціалу культурних рослин до негативних абіотичних і біотичних чинників, фітопатогенів.

Ключові слова: урбоекосистеми, багаторічні насадження, ґрунтовтома, кремнієвмісні мінерали, саліцилова кислота, мікробіоценоз, адаптивний потенціал.