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Specific character of soil "blooming" in agricultural and urbanized territories

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Specious content and quantity characteristics of microorganiams which lead to soil "blooming" in natural, anthropogenic, and urbanized ecosystems are shown in the article. In natural ecosystems algae and cyanobacteria communities develop in gradual succession stages, from unicellular green algae and Xanthophyta, filamentous green algae and non-heterocyst cyanobacteria to heterocyst cyanobacteria. Agricultural soil "blooming" has some peculiarities, irrespective of the place, season, soil type, dominating groupings. Among the "blooming" dominants cyanobacteria and green algae of the geni *Cylindrospermum, Nostoc, Anabaena, Klebsormidium* etc prevail. In agro-coenoses there is a direct connection between doses and terms of fertilizer treatment and the stage of development of the surface growth. Urban soils suffer from more intensive and diverse impact, as compared with agricultural and natural ecosystems soils. The specious content of phototrphs shows that in late summer surface biofilms represent many-species communities with different species of cyanobacteria and diatoms dominating. Cell density in "blooming" films is very high, it varies from 18 to 47 million cells per cm^2. Various city pollutants provide diversity of phototrophic groups.

Keywords: soil "blooming", soil algae, cyanobacteria, micromycetes, bioindication.

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Специфика "цветения" почвы в сельскохозяйственных и урбанизированных экосистемах

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Проведено изучение видового состава и количественных характеристик организмов, формирующих «цветение» почвы в природных, агрогенных и урбанизированных экосистемах. В природных экосистемах развитие сообществ водорослей и цианобактерий проходит последовательные сукцессионные стадии от одноклеточных зелёных и жёлто-зелёных водорослей, нитчатых зелёных водорослей и безгетероцистных цианобактерий и заканчивается развитием гетероцистных цианобактерий. «Цветение» пахотных почв имеет ряд особенностей, независимо от места возникновения, сезона, типа почвы, доминирующих группировок. Среди доминантов «цветения» наиболее часто встречаются цианобактерии и зелёные водоросли р.р. *Cylindrospermum, Nostoc, Anabaena, Klebsormidium* и др. В агроценозах прослеживается чёткая связь между дозами и сроками вносимых удобрений и уровнем развития наземных разрастаний. Городские почвы подвергаются более интенсивным и разнообразным нагрузкам, чем сельскохозяйственные и почвы природных экосистем. Определение видового состава фототрофов показало, что в конце лета наземные биоплёнки представляют собой многовидовые сообщества с доминированием различных видов цианобактерий и диатомовых водорослей. Плотность клеток в пленках «цветения» чрезвычайно велика и колеблется в разных зонах города от 18 до 47 млн клеток /см^2. Многообразие городских поллютантов даёт пёструю картину развития фототрофных группировок.

Ключевые слова: «цветение» почв, почвенные водоросли, цианобактерии, микромицеты, биоиндикация.

A certain form of microorganisms (MO) in the form of "biofilms" (BF) has been paid special attention to lately. BF are classified as spatially and metabolically structured MO communities which are included into an extracellular polymeric matrix and they are placed on the borderline of phase division [1, 2].

BF research has shown that the so-called "quorum sensing" is characteristic of natural populations, it provides bacteria intercellular communication by means of chemical signals [3]. MO collective behavior is provided by chemical specialization both with a direct regulative influence, with definite concentration dependence, and with an indirect mediated signal through the genetic apparatus. BF requires inter-population interrelations both on the physical and chemical levels [4]. Interrelation between prokaryotic and eukaryotic organisms is possible here. The structure of such BF includes intercellular matrix which is an integration component in providing survival and normal functioning of the populations represented by polymorphic many-celled systems [5]. The research has shown that one of advantages of multi-specious biofilms consists in the fact that protection effect increases for all the partners in them [6–8].

Long-term natural BF include many-specious BF which cause "soil blooming". There are detail descriptions of soil-surface BF and crusts on the soil surface in different parts of the world: in the USA [9, 10], Europe [11–14], Africa [15, 16], Asia [17, 18]. Some researchers analyze the samples of cyanobacterial crusts from 5 continents, they do not only determine the cyanobacterial components, but also analyze the strategy of their survival [19]. It is highlighted that cyanobacteria (CB) which dominate in such BF are high-caloric and they contain proteins and carbohydrates of high quality. Thus their high nutritive value and turnover rate can quite well support secondary producers BF-eaters.

In arid and semi-arid zones algae microbe crusts play a very important role in original soil formation [20] and in the process of binding soil aggregates [21]. Studying soil structure sustainability with CB-crusts by means of quick humifying we have stated that in such soils aggregates are more sustainable, as compared with those lacking crust.

Soil phototrophic microbe complex is represented by algae and CB that inhabit both deep and surface layers of soil. Photosynthesis is the main differential feature of terrestrial surface phototrophic microbe communities (PMC) distinguishing them from all other microbe communities. Thus there are ecological niches distinguished according to the quantity and quality of light. The phenomenon of mass algae and CB reproduction on terrestrial surface is called soil "blooming". The role played by this phenomenon in different climatic zones has been numerously considered [22].

"Blooming" is caused not only by a complex of favourable ecological conditions that stimulate mass reproduction. There is also a critical cell number (soil clots), the so-called 'invasion outlets' through which cell migration takes place from down to the surface that is free of higher plants.

Places of mass phototroph reproduction become the centres of high bio-activity due to the fact that 1–89% photosynthesis by-products are excreted into the environment in the form of exometabolites. As a result, a special zone of high organic substances concentration is formed around cells and cell complexes.

Phototroph cells, as well as their excreta, serve as a food substrate for other organisms and they have a bio-chemical influence on these organisms. As a result, there appears a net of trophic and allelopathic relations with saprotrophs and biotrophs. In certain cases there can appear a morphologically united system of PMC that can function as multicellular organisms (cyanobacterial mats). This system associates cyanobacteria, algae and different groups of heterotrophic bacteria. PMC texture is not constant. The character of relations between different phototroph groups changes according to density, age, physiological state and ecological conditions.

The analysis of works in Algology shows that soil "blooming" has some characteristic features that are not dependent on the place of origin, season, soil type and dominations groups [22, 23].

1. Mass reproduction on the surface is characteristic of few species: the structure of the surface communities described is formed by phototrophic microorganisms that account for from 5 to 27.

2. The number of species forming the surface algocoenoses is far less than the species pool in soil. Due to the impact of ecological and anthropogenic factors only from 10 to 50% of deep layers species are able to vegetate and propagate on the terrestrial surface. There is a general ecological rule on PMC level: floristic capacity of ecotops is always higher than that of phytocoenoses formed in these ecotops.

3. Different species play different roles in "blooming". There are phototroph populations

Table 1

Structure of surface phototrophic microbe communities (%) at brining in increasing dozes of Nitrogen in conditions of 11-year experimental field

Variant	Common Nitrogen, %	Algae			Cyanobacteria	
		unicellular green	thread green	diatom	unheterocystic	heterocystic
N0	0.125	18.8	14.8	3.7	56.5	6.2
N60	0.127	32.2	35.2	4.2	24.7	3.7
N120	0.129	28.9	62.4	2.0	6.7	0
N180	0.131	18.8	78.8	2.4	0	0

that are capable of growing in geometric progression, what causes this population's domination in the community. Among the dominants the most common are thread forms – cyanoabcteria and green algae: genera *Cylindrospermum, Nostoc, Anabaena, Phormidium, Oscillatoria, Klebsormidium* etc.

The aim of this work is to compare the specific features of soil "blooming" phototroph complexes in agricultural and urbanized territories and to find the possibility of using the indices of alga-cenoses organization for the purpose of soil state bio-diagnostics.

The research has been carried out in Kirov region that is situated in the North-East of the European part of Russia. In the samples of "blooming" soil the phototrophs' species content was determined (direct microscoping, cup cultures with fouling glass, water cultures) [24]. Using the method of direct microscoping we calculated the quantity and biomass of phototrophs' cells and the length of fungi mycelium [25].

Plough soil "blooming". Season successions in PMS plough lands are characterized by group change that is determined by the season dynamics of biogenic elements in soil, mainly by Nitrogen dynamics, which is determined by biogenic elements extraction from soil by a higher plant. The regular yearly change of groups is as follows: unicellular green and yellow-green algae (end spring) – thread green algae (end spring – beginning of summer) – non-heterocystic cyanobacteria (beginning summer – midsummer) – heterocystic cyanobacteria (end summer – autumn). Together with season succession there takes place full realization of soil species potential.

The order of season successions is broken in case that certain biogenic elements support competitiveness of some group. So, growing Nitrogen concentrations from 60 to 180 kg/hectare, at their long-term application in the same soil, cause development of PMC with different structure characteristics (Table 1).

Autogenic succession content consists not only in change of composition and quantity of phototrophs that constitute this PMC, but also in change of character of relations between the partners. At first species and groups develop independently. Then, as a result of propagation, physical proximity of individuals takes place and this causes connected development of the population. The more the number of physical and metabolic contacts grows, the more competition increases, so that ecological niches differentiation takes place and phototroph groups get distributed according to geometric series pattern. Certainly the end succession stage is connected with sudden share growth of the leading group, which causes decrease of specious diversity and lessens community sustainability (Table 2).

PMC is also much dependent on soil biotrophs – Protozoa, ticks, nematodes, Enchytrae-

Table 2

Stages of algae-cyanobacterial soil "blooming" succession

Stages	Relations character between the partners	Evaluation criteria
I	Connected populations development: non-heterocystic – heterocystic Cyanobacteria; green algae – Cyanobacteria	Coefficient of associability r_4 : r_4 = 0.670–0.782 r_4 = 0.542–0.680
II	Competition increase, ecological niches differentiation	Model of community structure geometric distribution. Degree of niche takeover K = 65%
III	Strengthening of the leading dominant's role, decrease of species diversity, decrease of community stability	Shennon index change (D): 0.1795–0.0205–0.0164–0.0046

Table 3

Changes in thread green algae quantity under the influence of Nitrogen fertilizers in stationary conditions

Nitrogen dozes, kg/hectare of active substance	0	60	120	180
Number of cells, thousand/sm^2	60	117	552	731

Table 4

Influence of different fertilizers on biomass (mg/cm^2) of surface phototrophic community

Variant	Without fertilizers	Manure	Peat + Manure
Biomass	0.246	0.550	1.114

Table 5

Influence of increasing Nitrogen dozes on phototrophic population structure (%) in surface growths

Variant	Algae		Cyanobacteria
	green	diatom	
N0	44.9	3.1	52.0
N50	65.7	7.6	26.7
N100	64.8	7.9	27.3
N150	78.8	8.8	12.4
N200	81.6	6.5	3.9
N250	84.0	16.0	0

idae, earth warms [25]. Selectivity in consuming and digesting phototrophs by invertebrates causes elimination of some species and stimulates propagation of other species that are not eaten out or stay viable in excrements. Due to animal migration there appear new “blooming” centres with phototrophs species combinations different from a parent PMC.

The next factor influencing PMC organization is combination and dynamics of biogenic elements in soil [25].

Thus the following control mechanisms represent the survival triad of rather ephemeral PMC communities:

1) physico-chemical regulation through biogenic elements circulation;

2) self-regulation through phototroph interrelations;

3) “pasture” regulation through eating out phototrophs by invertebrates.

Phototrophs’ ecological properties were formed in conditions of their different supply with mineral elements. As a result, there appeared species that require Nitrogen and ash elements. Input of extra amount of biogenic elements violates balanced development of PMC that appeared in soil in conditions of nutrients lack. Trophic preferences of phototrophs different groups cause leadership of different groups under the influence of different fertilizers. Fluctuations of cell quantity (Table 3) and biomass (Table 4) mark original PMC changes.

Growth of concentration of accessible Nitrogen forms in soil lessens cyanobacteria competitiveness. And in normal season succession conditions cyanobacteria are characterized by absolute dominating in “blooming” films in temperate zone in the end of summer and in autumn. The longer the fertilizers are used, the more stable the changes in phototrophic organisms cenopopulations are: the share of cyanobacteria shrinks, the share of green algae quickly grows.

Finally there takes place a cardinal change of PMC structure with the loss of some definite ecologically important groups (Table 5).

Floristic PMC degradation can reach extreme limits if mineral fertilizers have been used differentiatedly for many years. The 30-year-old experimental field shows this degradation the most acutely. In conditions of one-side input of mineral nitrogen fertilizers surface communities have completely degenerated to a phototroph complex on the level of 3-species unicellular algae.

Thus working in experimental fields for many years shows that using mineral fertilizers in the same soil continuously for a long time leads to development of PMC with different structural characteristics. Structural-group analysis of soil “blooming” communities shows that in agro-systems there appear transformed communities connected with dominating positions of groups with contrast biological properties that depend on the system agro-methods. So soil biological well-being can be estimated with the use of indicator scale of phototroph group analysis. Absence of cyanobacteria in soil in the end of the vegetation season shows that soil state is in crisis. PMC unification at unicellular green algae level indicates that the soil is toxic which causes disastrous decrease of higher plants' yield.

Agrogenic influence changes the character of "blooming" so much that evolution of surface PMC takes place with edaphogenic changes of phototrophs groups' specter, as well as of soil fertility closely connected with the dynamics of biogenic elements. As a result, the character of adaptation strategies and population criteria of transformed phototrophic communities allow using soil "blooming" for the purpose of soil state diagnostics, ranging from biological well-being to ecological catastrophe.

City soil "blooming". City soils are influenced much stronger and more variously as compared with agricultural soils and natural ecosystems soils. At the same time their ecological function is as important as that of other soils. City soils absorb, convert and neutralize different wastes and contaminants. But soil saturation with contaminants has a certain limit that allows soil functioning. Exceeding this limit causes soil pathology [26].

Different pollutants such as heavy metals, organic waste, synthetic compounds, salts, plastics, etc. get into city soils from different sources. Their degree of toxicity varies wide-rangingly depending on their chemical structure, amount and quality of humus, aeration, acid regime, contaminants' microbe decomposition speed, etc. Thus microbiota life in city soils is distinguished by a big chance of stress situations and broad range of pollutants. So that it is not possible to find out how microphototrophs' development depends on a certain pollutant. Nevertheless, well-distinguished "blooming" spots in different city zones catch an eye of the observer.

Types of zoning city soils and districts vary. According the classification [27], according to morphological soil profile structure, the following groups of city soils are distinguished: natural undamaged (forest-parks and forests); natural damaged (the undamaged part of natural soil profile and anthropogenically damaged surface levels); artificial – urbanozems (technogenic soils).

The following city areas are distinguished according to their function: industrial (where different industrial objects are situated); residential (where houses, offices, cultural, educational establishments, etc. are situated) and park (green area around a city used for mass recreation, sport, etc.). Within cities parks form a recreation area. Functional city areas are crossed by a system of transport ways [28].

Interest to microbiological monitoring of city areas has increased lately [29, 30]. In particular, there takes place a drastic increase of pathogenic organisms causing opportunistic infections of bacterial and fungi micro-flora. There are separate investigations of city soils algoflora diversity [31] and special microbe groups such as biofilms of *Nostoc commune* [32]. Still "blooming" films cenoses of city soils have not been investigated yet.

This work deals with soil "blooming" of definite areas of the city of Kirov. Kirov is a big industrial city with population of 500 000 people. It has a developed infrastructure that includes all the above-mentioned areas. Natural soil surface of the territories near Kirov consists mainly of sod-podzol loam and sand loam soils.

Phototroph species investigation showed that in the end of summer (the time of the most intensive soil "blooming") surface bio-films can be represented by poly-species communities where different species of CB and diatom algae predominate (Table 6). The communities with the most diverse set of species develop in urbanozems (sawdust with sand) around HPP and in the park area (29 and 24 species accordingly), the communities with the least diverse set of species develop in the yards of houses (residential area) and along the roads (12 and 13 species accordingly).

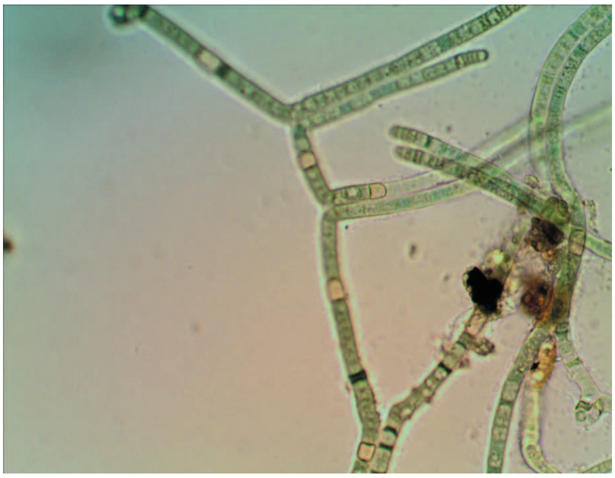
There are definite dominants of the communities in "blooming" films of different areas (Table 7). It is evident, that non-heterocystic CB prevail in all the areas, with the exception of the industrial one, in naturally damaged and non-damaged soils. Nitrogen-fixing heterocyst

Table 6

The number of phototrophic species in city soil "blooming" fields

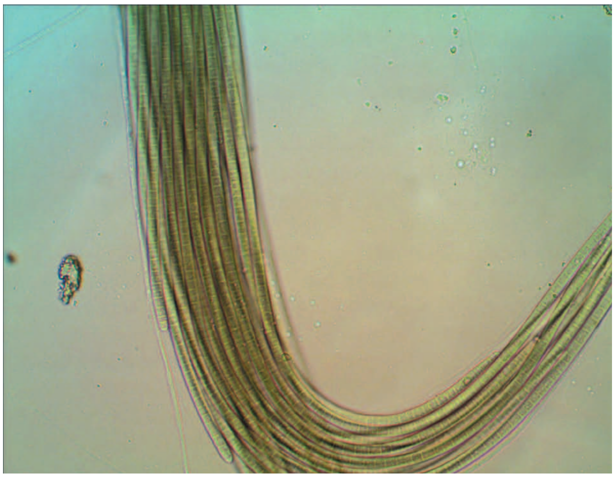
Investigation area	Cyanophyta	Bacillariophyta	Chlorophyta	Total sum of species
Industrial	19	2	8	29
Residential	5	5	2	12
Park	15	7	2	24
Transport	9	3	1	13

Fischerella muscicola

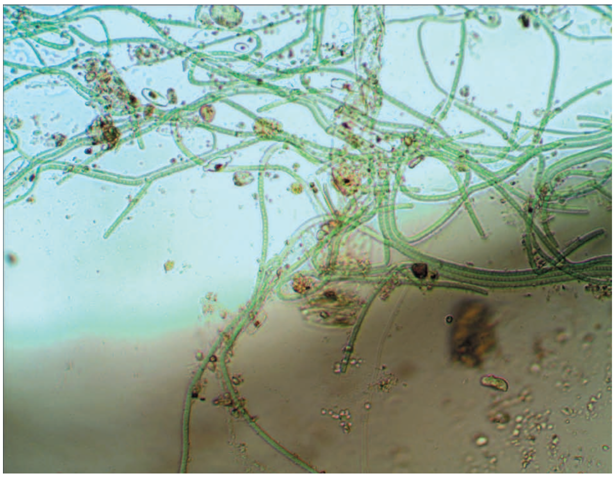


Scytonema ocellatum

Tolypothrix tenuis



Microcoleus vaginatus

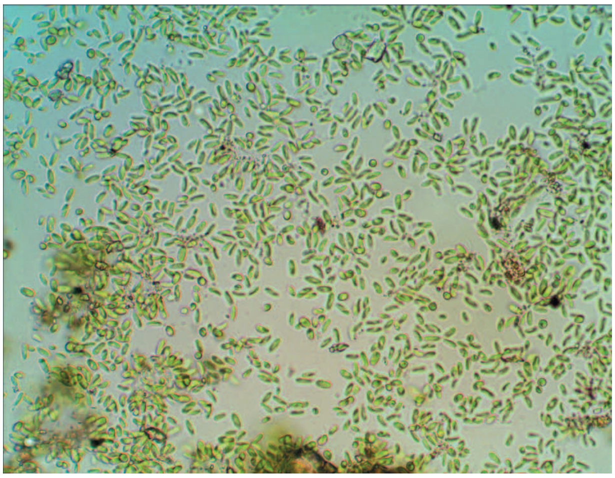


Plectonema boryanum

Nostoc punctiforme

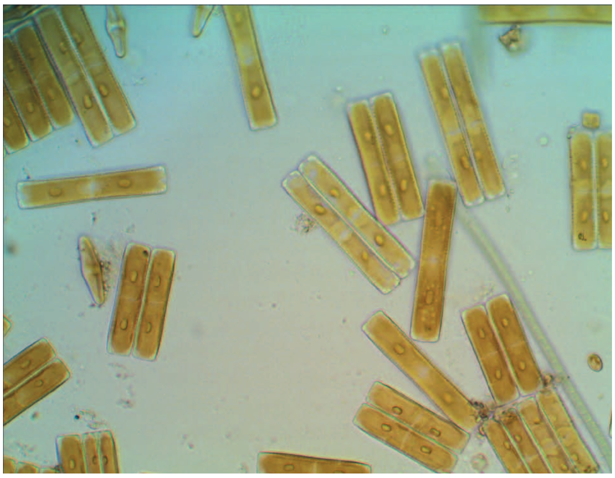
Phormidium boryanum

Klebsormidium nitens

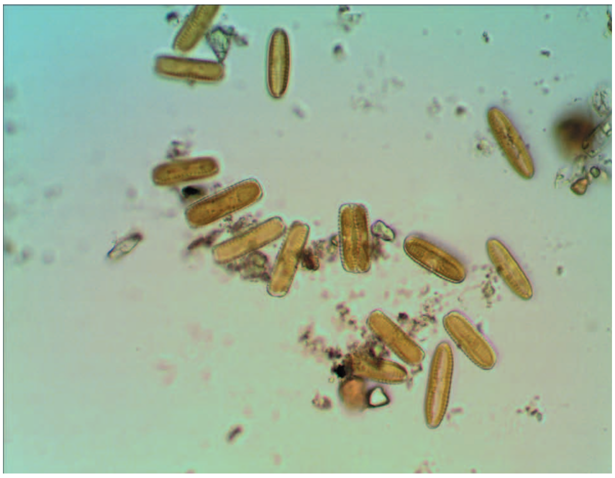


Pseudococcomyxa simplex

Heterococcus viridis



Hantzschia amphioxys



Pinnularia borealis

Table 7

"Blooming" films dominants

Investigation area	Dominant species
Industrial	*Nostoc muscorum, N. paludosum, Trichromus variabilis, Phormidium autumnale, Nitzschia palea*
Residential	*Phormidium uncinatum, Ph. aerugineo-coeruleum, Ph. autumnale, Ph. boryanum, Nitzschia palea, Hantzshia amphyoxys.*
Park	*Phormidium formosum,Ph. breve, Trichromus variabilis, Leptolyngbya augustissima, Nitzschia palea.*
Transport	*Phormidium aerugineo-coeruleum, Ph. ambiguum, Ph. boryanum, Hantzschia amphioxys, Luticola mutica v. mutica.*

Table 8

Algea and cyanobacteria cell number indices in "blooming" soils in different city areas (thousand/cm^2)

Investigation area	Green algae	Diatoms	Cyanobacteria		All
			non-heterocystic	heterocystic	
Industrial	1265±40	515±20	5850±150	18600±1000	26300
Residential	446±42	2050±57	17978±781	0	20474
Park	0	540±30	10660±500	7070±213	18270
Transport	200±10	610±20	43360±900	3500±210	46860

Table 9

Phototrophs' population structure in "blooming" soils (%)

Investigation area	Phototrophs		Cyanobacteria	
	algae	cyanobacteria	non-heterocystic	heterocystic
Industrial	6.8	93.2	23.9	76.1
Residential	12.2	87.8	100	0
Park	2.9	97.1	60.1	39.9
Transport	1.7	98.3	92.5	7.5

Table 10

Micromycets populations' features in conditions of city soil "blooming"

Investigation area	Mycelium length, m/cm^2	Population structure, %	
		colourless	coloured
Industrial	14.4±2.1	31.7	68.3
Residential	26.6±3.0	57.9	42.1
Park	21.8±2.2	44.0	56.0
Transport	34.8±1.6	23.6	76.4

CD predominate only in urbanozems (sawdust with sand) (Table 7).

Qualitative parameters of surface cyanobacteria growths show that "blooming" fields density is very big and that it varies in different city areas from 18 to 47 million/cm^2 (Table 8).

Different phototrophs' groups participate in forming surface growths' structure differently (Table 9). The fact of non-heterocystic CB dominating is the most conspicuous (from 60 to 100% in CB populations' structure) in all the cases with soil, with the exception of urbanozem. In urbanozem there are different conditions of phototrophic development and sawdust with sand forming the substrate around HPP probably do not accumulate as many pollutants as soils, and it is these pollutants that drive out nitrogen-fixing CB species form surface communities.

Apart from phototrophs, micromycets are also a constant significant component of bio-films. They have forms with colourless and coloured (melanized) mycelium. Fungi mycelium length in "blooming" films and their population structure vary wide-rangeingly (table 10).

Prevailing of micromycets with melanized mycelium shows that the ecological state of the places under analysis is problematic. It is known that fungi melanin synthesis is caused not only

Table 11

Quantitative indices of city soil "blooming" biofilms

Investigation area	Biomass mg/cm²			Population structure, %		CB thread length + mycelium, m/cm²
	phototrophs	fungi	all	phototrophs	fungi	
Industrial	4.165	0.143	4.308	96.7	3.3	110.2
Residential	3.749	0.210	3.959	94.7	5.3	80.5
Park	2.594	0.085	2.679	96.8	3.2	75.0
Transport	4.692	0.136	4.828	97.2	2.8	48.9

by the excessive insolation but also by adaptation to pollutants' accumulation in the environment [30, 33]. Thus the results presented in Table 10 show that a considerably high contamination level is characteristic of the industrial area (68.3% fungi with coloured myceliem in the population structure) and of the transport area (76.4% melanized mycromycets).

Phototrophs' reaction is discrepant. Although CB, but not algae, prevail in all city ecotops in "blooming" films (in phototrophs' population structure CB account for 87.8–98.3%), the level of CB development, as well as the share of their heterocystic and non-heterocystic forms differ in different areas very much (Table 11). Thus in transport and residential area soils non-heterocystic CB absolutely predominate (92.5 and 100%, accordingly). In park area non-heterocystic and heterocystic CB are represented almost in equal measures (60.1% – non-heterocystic, 39.9% – heterocystic CB). But in the industrial area in the substrate consisting of sawdust and sand nitrogen-fixing heterocystic CB account for 76.1% of the population structure, and non-heterocystic ones – for 23.9%. Probably, a long-term influence of city pollutants, which get also into park and residential areas with air, contributes to prevailing of CB populations with non-heterocystic forms, and high sensitivity of nitrogen-fixing cyanobacteria's nitrogenase enzyme can block their propagation. At the same time anazotic urbanozem is being occasionally renewed near HPP so that there is not enough time for it to absorb and accumulate pollutants enough to oppress nitrogen-fixing CB development.

On the whole, soil or substrate "blooming" in urbanized territories can be considered as a positive fact. Firstly, mass phototrophs propagation causes quick soil saturation with labile organic substance quickly renewed due to the high speed of algobiomass circulation. Secondly, presence of thread CB and fungi mycelium in biofilms makes the substrate stronger due to its anti-erosion functions. The total length of threads and mycelium can reach scores of meters per 1 cm² of the surface (Table 11).

Thus it seems that it is not possible to judge on the city soil state by phototrophs' growth peculiarities in "blooming" films. Nevertheless mycromycetes populations, in particular, melanized forms prevailing in the structure, can serve as a reliable criterion that indicates a high degree of contamination. At the same time "blooming" analysis of urbanized soils shows that certain species of non-heterocystic Cyanobacteria that can serve as bioagents-remediators in the future prove to be the most resistant to city pollutants. Microphototrop species which participate in soil "blooming" are show in pic. Of them only in natural biofilms of the suburban zone of the city we found *Fischerella muscicola* and *Scytonema ocellatum*.

Conclusion

The analysis of the data on plough and city soils "blooming" shows that there are features of similarity (the indices of phototrophs' cell number, biomass, species potential realization) as well as specific features consisting in the fact that diversity of city pollutants varies the development of phototrophic groups, and in agrocoenoses there is a close connection between the dozes and input time of fertilizers and the development level of surface growths.

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