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SOIL BIOLOGY

Parameters of Microbial Respiration in Soils of the Impact Zone of a Mineral Fertilizer Factory

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Abstract—The carbon content in the microbial biomass and the microbial production of CO_2 (the biological component of soil respiration) were determined in the upper layer (0–10 cm) of soils in the impact zone of the OJSC Voskresensk Mineral Fertilizers, one of the largest factories manufacturing mineral fertilizers in Russia. Statistical characteristics and schematic distribution of the biological parameters in the soil cover of the impact zone were analyzed. The degree of disturbance of microbial communities in the studied objects varied from weak to medium. The maximum value (0.44) was observed on the sampling plot 4 km away from the factory and 0.5 km away from the place of waste (phosphogypsum) storage. Significantly lower carbon content in the microbial biomass and its specific respiration were recorded in the agrosoddy-podzolic soil as compared with the alluvial soil sampled at the same distance from the plant. The effects of potential soil pollutants (fluorine, sulfur, cadmium, and stable strontium) on the characteristics of soil microbial communities were described with reliable regression equations.

Keywords: ecology of impact regions, soil pollution, soil respiration, microbial biomass, stable strontium, heavy metals, sulfur, fluorine, Cutanic Albeluvisols (Abruptic), Gleyic Fluvisols (Eutric)

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INTRODUCTION

Biological parameters of soil state are used for solving the fundamental and applied problems of soil science and ecology. Judging by publication s, there is increased interest in the development of new and improvement of the existing methodological approaches to the assessment of biological state of soil [1, 6, 8, 24]. Additionally, mathematical models are developed reflecting the relationships between biological parameters and the chemical composition of soil, which changes under the influence of anthropogenic factors [4, 18, 20]. The study of the budget of microbial carbon in ecosystems subjected to heavy anthropogenic stress, including those in the impact zone of chemical fertilizer factories, deserves close attention [11, 27].

Biological activity of soil depends significantly on the soil type, its physicochemical characteristics, type of vegetation, and cultural state (for soils of agricultural lands) [19, 23, 25]. Physicochemical features of natural soddy-podzolic soils (acid reaction, low humus content, and weak aggregations of the humus-accumulative horizon) determine the low level of their biological activity. Bringing the soddy-podzolic soils under cultivation using the complex of land treatment measures (liming, fertilizers, etc.) sharply changes the life conditions for the microorganisms, and this results in the changes of the quantity and composition of microbial cenosis and intensification of the biochemical processes, including the intensity of soil respiration [15].

The respiration intensity is a labile characteristic, but it is closely associated with the total biological activity. Some researchers consider soil respiration intensity to be an informative parameter of the changes in the rates of processes in the seasonal dynamics related to changes in weather conditions, soil pollution, etc. [9, 13].

Different parameters of soil respiration are included in the State-sponsored programs of soil monitoring in Germany [26]. Laboratory methods for measuring the substrate-induced respiration (SIR) are standardized by iSO 14240-1, and the methods for determining the basal respiration (BR) and microbial metabolic quotient (QR) were standardized by ISO/DiS 16072 in 2002. Threshold values of microbial metabolic quotient for arable soils of different particle-size composition were established for the part of Germany (Lower Saxony) and whole territory of Switzerland.

The content of carbon in the microbial biomass (C_{mic}) is the constituent and the indicator of the state of soil organic carbon. This parameter is sensitive to land-use systems and intensity of agriculture. The C_{mic}/C_{org} ratio is an important parameter of organic matter quality. It can also serve in some cases as an indicator of organic carbon availability for soil microorganisms: the greater is its value, the greater amount of organic matter is fixed in microbial biomass. Unlike the value of absolute content of carbon in microbial biomass, the relative index C_{mic}/C_{org} reflects, first of all, the availability of soil organic carbon to microorganisms and the degree of its consumption by them. The C_{mic}/C_{org} ratio is expedient to use for comparing the availability to microorganisms of organic soil carbon in the soils with different humus content.

Specific respiration rate of microbial biomass (qCO_2) is calculated as the ratio of the rate of basal respiration to the C_{mic} concentration, and it is an important indicator of the efficiency of substrate utilization.

Some researchers calculate the relative coefficient of microbial respiration, also called metabolic quotient or stress index *QR*, as the ratio between BR and SIR. Index *QR* is the non-dimensional value. Its physical meaning is analogous to the essence of qCO_2 index. Using *QR* instead of qCO_2 decreases the methodical error, because in this case additional calculation of C_{mic} is not required. Calculation of C_{mic} can be performed with different methods, and it is difficult to choose one advantageous among them today [28].

We accept a hypothesis in this study that *QR* values can be ranked to assess soil resistance to technogenic effects (Table 1). The lower the *QR* value is, the fewer disturbances are revealed in the number and composition of soil biota. Optimal values of *QR* fell within the range 0.1 to 0.2 (0.3).

The effect of season (time of sampling) on SIR value was significantly lower than other possible methodical errors [2]. This factor will not be accounted in further analysis of the long-term data obtained in this region within the scope of this study. The SIR values are maximal in summer and early fall, and this fact decreases the absolute error of the method, so these seasons are considered to be most favorable for sampling.

The goal of this work was to assess the changes in microbial emission of CO_2 (“soil respiration”) and some other parameters characterizing the state of microbial biomass in different soil types along the gradient of the distance from the plant manufacturing complex mineral fertilizers. The study pursued the following tasks: determining the regularities of statistical and spatial distribution of organic carbon content and basal and substrate-induced respiration; calculating the relative and absolute concentrations of microbial biomass carbon; specific respiration of microbial biomass, and coefficient of microbial respiration (stress index); revealing the relationship between concentrations of potential pollutants in soil and characteristics of the state of microbial biomass; evaluating the expediency of using the characteristics of microbial biomass state as integrated index of the level of technogenic impact on soil cover.

Table 1. Coefficient of microbial respiration and degree of disturbance of microbial community stability [3]

Value of coefficient of microbial respiration *QR*	Degree of disturbance of the microbial community stability
0.1–0.2	Absent
0.2–0.3	Weak
0.3–0.5	Medium
0.5–1.0	Strong
>1.0	Disastrous

OBJECTS AND METHODS

The study was carried out in the impact territory of the chemical plant, which is one of the four largest Russian factories producing mineral fertilizers, fodder additives, and phosphoric and sulfuric acids. The chemical plant has currently the capacity to manufacture 700–800 thousand tons of ammonia-phosphoric fertilizer, 150–250 thousand tons of ammonia, 250–350 thousand tons of phosphoric acid, and 1000–1100 thousand tons of sulfuric acid per year. The apatite concentrate from the Khibiny mines in the Kola Peninsula is the feedstock for the production of phosphorus-containing fertilizers. According the expert evaluations [14], such industry can have adverse effects on the environmental objects. Cadmium and fluorine in the phosphogypsum obtained in the course of processing the Khibiny apatite concentrate are the most dangerous for soil. Lead and stable strontium are potentially dangerous elements. If potential pollutants are scattered and fall out on nearby territories, it can result in a serious disturbance of the environmental functions of soil in the immediate vicinity of the plant and have adverse effects on the microbial community in the soil within several kilometers radius of the source of pollution.

According to the goal of our study, we outlined the zone of impact pollution with a radius equal to 6.5 km. The boundaries of the impact zone go along the forest in the northwest, northeast, and east and along the agricultural lands in southeast and southwest. Phosphogypsum refuse banks are the additional sources of soil cover pollution. There are two phosphogypsum refuse banks in the studied territory: inactive object disposal facility 1, situated 0.9 km to the southeast of the plant, and active disposal facility 2, which is 4 km to the northwest of the plant. Disposal facility 1 is recently afforested, and wastes were stored there from 1968 to 1997; the area of this bank is about 38 ha. Wastes have been stored in the refuse bank 2 from 1976 to the present day. The area of this bank is about 40 ha, and its height increases every year and has already reached 50 m.

The part of the territory in which soil sampling was carried out (southwestern transects of agro-soddy-

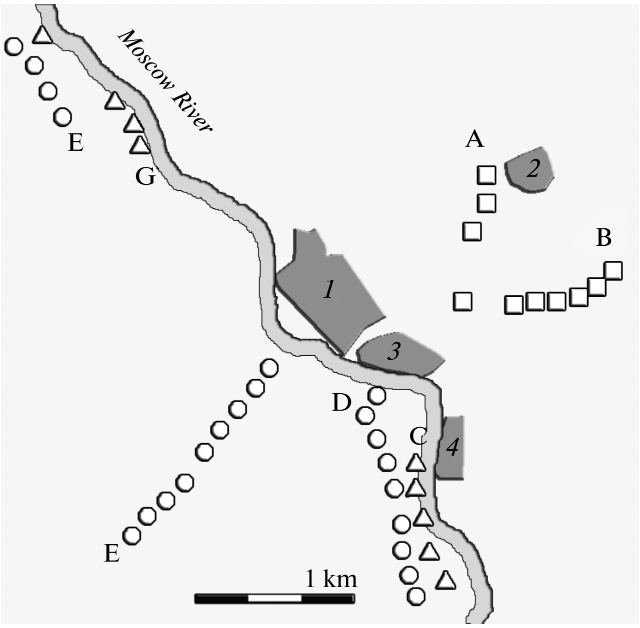

Fig. 1. Sketch map of sampling territory. Industrial objects: *1*, mineral fertilizers plant; *2*, disposal facility 1; *3*, disposal facility 2; *4*, cement plant. Transects of sampling, soils (here and hereinafter): A, northeastern, soddy-podzolic; B, eastern, soddy-podzolic; C, southeastern, alluvial; D, southeastern, agro-soddy-podzolic; E, southwestern, agro-soddy-podzolic; F, northwestern, agro-soddy-podzolic; G, northwestern, alluvial.

podzolic and alluvial soils), was situated in the sanitary protection zone of the cement plant and was subjected to aerotechnogenic emission of cement dust. Soil samples were taken from 4 to 17 July 2012 at the distance of 1.0 to 6.5 km from the chemical plant manufacturing mineral fertilizers and situated 100 km to the southeast of Moscow.

Studied object was presented by the upper soil layer (0–10 cm) in the impact zone of the plant. Sampling plots (SP) were established following five directions (seven soil transects) from the plant boundary with minimal intervals of 0.5 km (Fig. 1). The soil cover was composed of three soil types [12]:

—agro-soddy-podzolic medium arable low humus medium loamy soil on glaciofluvial loams (Cutanic Albeluvisols (Abruptic)) (profile formula: P–EL–BEL–BT–C): 22 SP (to the southeast, 9 to the southwest, and 4 to the northwest of the plant);

—soddy-podzolic typical shallow deeply bleached medium humus soil on glaciofluvial loams (Cutanic Albeluvisols (Abruptic)) (profile formula: AY–AYe–EL–BEL–BT–C): 10 SP (3 to the northeast and 7 to the east of the plant);

—alluvial gray-humus (soddy) surface gleyic medium humus heavy loamy soil on alluvial deposits (Gleyic Fluvisols (Eutric)) (profile formula: AY–AY–AYg–G1––G2): 9SP (5 to the southwest and 4 to the northwest of the plant on the right bank of Moscow River).

Weather conditions in the period of sampling were maximally favorable for soil biota: warm and sometimes hot weather (25–30°C in the daytime and 19–22°C at night) with abundant rainfall at night (up to 93 mm).

The samples after sample taking were stored in the refrigerator under the temperature 4–6°C for two months. The samples were incubated in desiccator under the temperature 22°C for 7 days before measuring the carbon dioxide emission. Basal respiration and SIR were determined in September 2012 in the Faculty of Soil Science, Moscow State University. Other chemical and physical characters of soils were determined in the period from October 2012 to May 2013 in the same place and in the JSC Center for Certification and Environmental Monitoring of Moscow.

To evaluate BR, the weighed portion of soil (2 g) was placed into air-locked 15 mL flask, and distilled water was added to 60% of maximum water capacity. Soil sample was incubated under the temperature 22°C during 24 h, when air aliquot was taken from the flask with syringe without breaking the air-tightness; precise time was recorded, and the sample was analyzed using a gas chromatograph [22].

To evaluate SIR, similar weighed portion of soil in flask was enriched with glucose solution (10 mg/g of soil) and incubated under the temperature 22°C during 3 hours. Analysis was performed similarly to the previous experiment [21]. The rate of BR and SIR was measured in micrograms C–CO_2 per gram of dry soil per hour.

Currently, none of the existing methods measures the content of microbial carbon directly, but only estimates it by means of empiric equations. We used the computational method by Anderson in this work. Carbon of microbial biomass was calculated by the formula:

$$C_{\mathrm{mic}}\ (\mu\mathrm{g\ C/g\ of\ soil}) = \mathrm{SIR}\ (\mu\mathrm{L\ CO_2/(g\ of\ dry\ soil)})\ 40.04 + 0.37\ (r = 0.96)\ [17].$$

Specific respiration of microbial biomass was found as the ratio of the rate of basal respiration to the microbial biomass:

$$\mathrm{BR}/C_{\mathrm{mic}} = q\mathrm{CO_2}\ ((\mu\mathrm{g\ C{-}CO_2/mg\ }C_{\mathrm{mic}}\ \mathrm{h})).$$

All agrochemical characteristics of the soil state and methods of its determination are presented in Table 2. One average composite sample was analyzed from every SP. Analyses were performed in triplicate. Regression analysis was carried out in Statistica 6.0 program.

RESULTS AND DISCUSSION

The main values of descriptive statistics of biological parameters (without accounting for the soil type) are presented in Table 3. Maximal values in BR and SIR samples exceeded the average values no more

Table 2. Method of determination chemical elements and parameters of agrochemical state of soil

Parameter	Measuring method	Parameter	Measuring method
C_{org}	GOST 26213-91	Cd_{tot}	Atomic absorption spectrophotometry
pH	GOST 26423-85	Pb_{tot}	
		Zn_{tot}	
P_{mobile}	GOST 26207-9	Cu_{tot}	
K_{mobile}		Cd_{mobile}	
$NO_{3_{H_2O}}$	GOST 26951-86	Pb_{mobile}	
S_{tot}	Inductively coupled plasma mass spectrometry	Zn_{mobile}	
Ca_{tot}		Cu_{mobile}	
Sr_{tot}		F_{H_2O}	Ionometric
		F_{tot} (5 M HCl)	
S_{mobile}	GOST 26490-85	Cl_{H_2O}	GOST 26425-85
Ca_{mobile}	GOST 26487-85	Hydrolytic acidity	GOST 26212-91
Mg_{mobile}		CEC	GOST 17.4.4.01-84

Table 3. Descriptive statistics of biological parameters (without accounting for the soil type)

Parameter	Background value	Mean	Error of mean	Median	Minimum	Maximum	Variation coefficient
BR, $C{-}CO_2$ /(g h)	2.52	2.21	0.21	2.14	0.28	4.98	0.61
SIR, $C{-}CO_2$ /(g h)	12.19	9.54	0.73	8.61	2.05	22.37	0.49
C_{org}, g/100 g of dry soil	1.78	1.51	0.09	1.35	0.91	3.81	0.38
C_{mic}, μg C/g of soil	911	713	54	644	154	1673	0.49
C_{mic}/C_{org}	0.051	0.05	0.004	0.04	0.01	0.13	0.49
qCO_2, μg $C{-}CO_2$ /(mg Cmic h)	2.76	3.27	0.25	3.22	0.45	6.64	0.49
QR	0.21	0.24	0.02	0.24	0.03	0.50	0.49

than by 2.0–2.5 times. Maximal BR value (4.98 $C{-}CO_2/(g\ h)$) was recorded in the north-western transect of soddy-podzolic soil 4.0 km from the plant and 0.5 km from the disposal facility 1. Maximal SIR values were observed in the north-western transect of alluvial soils (14.74–22.37 $C{-}CO_2/(g\ h)$). Low and statistically significant values of BR were found in arable soils in the southeast at the distance up to 3 km from the industrial estate of chemical plant, 0.47 $C{-}CO_2/(g\ h)$ with average value for the transect 1.26 $C{-}CO_2/(g\ h)$. Similar values of BR were typical for all arable soils to the southwest of the plant (average value for the transect 0.60 $C{-}CO_2/(g\ h)$, minimal value 0.28, and maximal value 0.88 $C{-}CO_2/(g\ h)$). Low BR in this transect could be attributed to the violation or nonobservance the scientifically proven agricultural technologies, as well as to the domination of southwestern winds in summer [16].

Two transects of sampling were established in parallel to each other on alluvial and agro-soddy-podzolic soils to the southeast of the plant. Lower values of C_{mic} and qCO_2 and greater values of *QR* were found in agro-soddy-podzolic soil in comparison with alluvial soils situated at the same distance from the plant. Microbial community of agricultural soils was more subjected to stress than the community of alluvial soils under similar technogenic impact.

Concentrations of C_{mic} varied from 500 to 1050 μg C/g of soil at the distance 3.0–5.5 km from the plant. As one moved from the plant and approached the disposal facility 1, concentration of C_{mic} in the north-eastern transect of soddy-podzolic soil was not subjected to statistically significant changes, though the qCO_2 value increased significantly—from 4.45 to 5.93 μg $C{-}CO_2/(mg\ C_{mic}\ h)$—and *QR* value increased from 0.33 to 0.44. Stress state of soil microbial community 4.0 km from the plant and 0.5 km from the disposal facility 1 could be classified as medium, whereas the remaining territory could be classified as the territory with weak disturbance.

The portion C_{mic}/C_{org} averaged 4–6% depending on soil type. Maximal portion of microbial carbon pool in organic carbon was found in continuous-cultivated agro-soddy-podzolic soil of the northwestern

Table 4. Parameters of BR and C_{mic} in different ecosystems in the districts of Moscow oblast (the data for Podol'sk and Serpukhov districts are given by [5]), minimum–maximum/mean

Ecosystem or soil type, SP number (Voskresensk/Podol'sk/ Serpukhov raions)	Raion		
	Voskresensk (2012)	Podol'sk (2007)	Serpukhov (2007)
	BR, C–CO_2/(g h		
Tilled field (22/4/13)	0.28–4.31/1.29	0.06–0.74/0.39	0.06–0.42/0.18
Soddy-podzolic (10/34/133)	1.64–4.98/3.38	0.34–3.25/1.02	0.19–2.43/0.79
Alluvial meadow (9/3/24)	2.10–3.98/3.11	0.06–0.17/0.12	0.06–0.86/0.27
	C_{mic}, μg C/g of soil		
Tilled field (22/4/13)	28–1382/792	43–318/155	72–252/150
Soddy-podzolic (10/34/133)	154–1416/599	173–1394/564	58–1319/393
Alluvial meadow (9/3/24)	356–1683/884	43–166/95	53–820/215

Table 5. Comparison of spatial and temporal dynamics of basal respiration values near the working phosphogypsum refuse bank

Zone	2005 data [10]		2012 data	
	BR, μm CO_2/(g h)	variation coefficient	BR, μm CO_2/(g h)	variation coefficient
Background	4.14 ± 0.93	12.8	No data	
Buffer	3.18 ± 0.74	20.1	1.26 ± 0.16	31.3
Impact	2.32 ± 0.62	22.4	No data	

transect 6.5 km from the plant at the boundary of the studied zone, and only control samples were taken farther.

No strong or disastrous disturbance of microbial community, characterized by *QR* value, was found.

All distributions, excluding C_{org} value, can be classified as heterogeneous according to the coefficient of variation value. Maximal coefficient of variation was found for BR parameters and the minimal one for C_{org}. The results of comparison of variation coefficients for the same modal class suggest that the totality of studied territories was more homogeneous by SIR values than by BR. Statistical distribution of SIR parameters was more stable than the analogous distribution of BR values. Distribution of C_{org} was statistically more homogeneous than the distribution of C_{mic}, and this fact attests to the heterogeneity of spatial distribution of microbial biomass in the upper soil layer.

The results of comparison of obtained data with the results of a similar study in Moscow oblast are presented in Table 4. Podol'sk and Serpukhov districts are basically characterized by more favorable environmental situation than Voskresensk district. Significant differences in BR and C_{mic} levels could be explained by the bias of estimates because of small sample sizes. Owing to high spatial variations of the parameters of soil respiration over the studied territories, this fact has a serious influence on the determination of mean values.

The study of the dynamics of soil respiration in the disposal facility 1 deserves special attention. Earlier, the study based upon similar methodical procedures was carried out on natural soils in the period from September 2005 until August 2006. The samples were taken in five-fold. The comparison of the results is presented in Table 5.

Maximal variability of respiration intensity parameter was found in the impact zone of refuse banks, and this characterized it as the plot maximally subjected to the stress effects of technogenic factors. Smaller values of BR and higher coefficient of variation, when comparing the parameters of respiration in buffer zones to the east (the data of 2006) and southwest (the data of 2012) of disposal facility 1, were probably explained by domination of southwestern winds in summer in the studied region.

Spatial distribution of C_{mic} and qCO_2 values by transects in the impact territory of chemical plant is presented in Fig. 2. Maximal concentration of C_{mic} was recorded to the northwest of the plant (Fig. 2, F, G). Maximal C_{mic}/C_{org} ratio recorded on this transect attested to the fixation of significant portion of organic matter in the microbial biomass.

Agro-soddy-podzolic soil on the southwestern transect were characterized by medium concentrations of C_{mic} and low values of qCO_2 (Fig. 2, E). The current situation can be the result of the absence of measures for expanded reproduction of soil fertility in the course of farming and relatively low involvement of the microbial community in the process of organic matter transformation.

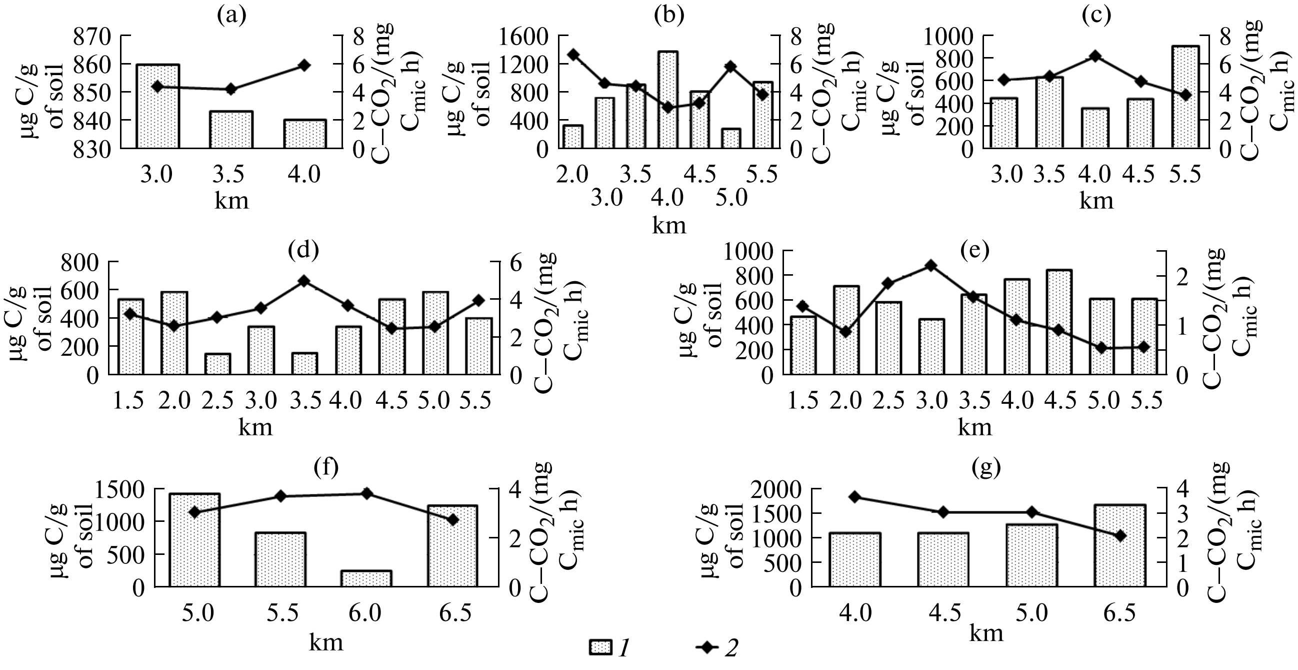

Fig. 2. Carbon of microbial biomass and specific soil respiration. (a–g) Transects with the distance from industrial area of mineral fertilizer plant.

Low and average concentrations of C_{mic} and average and high values of qCO_2 were observed on southeastern transects, and this suggested a high level of microbial stress and possible instability of microbial community functioning (Fig. 2, C, D).

Maximal values of qCO_2 with average and high C_{mic} contents were found in soddy-podzolic soils of eastern and northeastern transects. These transects were subjected not only to gas-dust emissions, but also to dust emission of waste during transportation on the road to the place of stocking and accumulation, and from the phosphogypsum refuse bank properly (Fig. 2, A, B).

Regression analysis. The distribution of the parameters of biological activity corresponded to the normal one: SIR, C_{mic}/C_{org}, qCO_2, and QR at $P \leq 0.05$; BR and C_{mic} at $P \leq 0.01$. Resulting standardized equations were calculated using the method of stepwise regression with forward selection (Table 6). All independent variables included in equations had normal distributions. Characteristics of the contents of total Ca and mobile forms of Ca and Mg were excluded from regression equations for having high values of multicollinearity with factor variables of pH of water and salt extracts. Regression equations were calculated for the whole amount of data because of insufficient volumes of the samples from the transects. The significance levels for determination coefficients of every factor were taken as $P \leq 0.05$.

Regression analysis as the method of mathematical simulation of natural processes does not establish the causal relationships between the studied characters in an explicit form, but it promotes revealing these relationships using other available information.

The greater the amount of technogenesis products in the soil is, the greater is the stress under which microbial community exists in this territory. Concentration of mobile cadmium makes the maximal absolute contribution to QR value. The increase of concentration of mobile cadmium to 0.5 mg/kg, when concentrations of all other pollutants are recorded at the background level, can result in the disturbance of stability of microbial community, which can be classified as strong. Mobile forms of biophilous phosphorus and sulfur are potential pollutants of the plant, because their concentrations in soils of the studied object exceeded standard optimal values for zonal soils. Average concentration of mobile phosphor was 169.5 mg/kg of soil; 40% of all SP were characterized by high concentrations of this element (150.0–250.0 mg/kg of soil), and 14% of all SP were characterized by very high concentrations (>250.0 mg/kg). The average concentration of mobile sulfur (22.2 mg/kg) exceeded by 1.4 times the values of local background that is equal to the recommended optimal concentration (16.0 mg/kg). The concentrations of mobile sulfur exceeded the background value by 4.5 times and more on 10% of all SP. High concentrations of biophilous elements could have direct and indirect inhibiting effects on the functioning of soil microbial community.

The increase of C_{org} content in the soil decreased the values of QR coefficient and could contribute to

Table 6. Regression equations for the parameters of soil biological activity

Regression equation and corrected multiple correlation coefficient (R^2)	Determination coefficient for every factor (R^2)
$QR = 0.0003\mathrm{P_2O_{5\,mobile}} + 0.8\mathrm{Cd_{mobile}} + 0.002\mathrm{S_{mobile}} - 0.09\mathrm{Corg} + 0.011\mathrm{Zn_{mobile}}$ ($R^2 = 0.56$)	$\mathrm{P_2O_{5\,mobile}}$ – 0.14
	$\mathrm{Cd_{mobile}}$ – 0.09
	$\mathrm{S_{mobile}}$ – 0.08
	$\mathrm{C_{org}}$ – 0.04
	$\mathrm{Zn_{mobile}}$ – 0.02
$\mathrm{BR} = 0.09\mathrm{Zn_{tot}} + 0.003\mathrm{P_2O_{5\,mobile}} - 9.3\mathrm{Cd_{mobile}} + 0.02\mathrm{S_{mobile}}$ ($R^2 = 0.68$)	$\mathrm{Zn_{tot}}$ – 0.26
	$\mathrm{P_2O_{5\,mobile}}$ – 0.07
	$\mathrm{S_{mobile}}$ – 0.07
	$\mathrm{Cd_{mobile}}$ – 0.05
$\mathrm{C_{mic}/C_{org}} = 0.20 - 0.02\mathrm{pH} - 0.0007\mathrm{F_{tot}}$ ($R^2 = 0.50$)	pH – 0.25
	$\mathrm{F_{tot}}$ – 0.05
$\mathrm{SIR} = 48.67 + 3.7\mathrm{C_{org}} - 6.16\mathrm{pH} - 0.66\,\mathrm{F_{H_2O}}$ ($R^2 = 0.54$)	$\mathrm{C_{org}}$ – 0.16
	pH – 0.12
	$\mathrm{F_{H_2O}}$ – 0.04

the decrease of integrated adverse effect of potential pollutants on the microbial community.

The rate of BR depended on the concentrations of potential pollutants, which could get to the surface of soil during manufacturing of mineral fertilizers. High concentrations of mobile forms of phosphorus, sulfur, and zinc could increase the rate of carbon cycle in the soil, and this could be also attributed to the fact that these elements are highly biophilous. The increase of concentration of mobile cadmium results in the decrease of BR rate, slowing of organic matter turnover, and decrease of the organic matter utilization by microorganisms.

Actual acidity of soil plays an important part in the process of microbial carbon fixation in the soil. The negative contribution of independent variable pH to the values of resulting variables $\mathrm{C_{mic}/C_{org}}$ and SIR can be explained by mutual influence of emissions of cement and chemical plants situated in the studied region. Acid precipitations resulting from the production of mineral fertilizers interact with the cement dust settled on the soil surface and enter into neutralization reaction. It was found that all soil types studied had more alkaline reaction (average value of pH of water extract was 6.5) than the background soils of Moscow region, where the average value ranged from 5.0 to 6.0.

The technogenic alkalization of the soil cover decreased relative to the portion of microbial carbon in organic carbon and could hinder the process of microbial cenosis functioning. The $\mathrm{C_{mic}/C_{org}}$ ratio decreased linearly, as pH value and concentration of total fluorine increased. The 0.5 unit increase of the value of water extract pH in the range of values from 5.4 to 7.3 resulted in 1% decrease of $\mathrm{C_{mic}/C_{org}}$ ratio. Evaluating the effect on $\mathrm{C_{mic}/C_{org}}$ ratio, the 0.5 unit increase of pH of water extract was equivalent to the increase of total fluorine content by 14.3 mg/kg of soil.

The rate of SIR decreased as technogenic alkalization of the soil cover and concentrations of water-soluble fluorides increased. The activity of soil microbial biomass increased as the content of organic carbon in soil increased. To compensate the decrease of SIR value because of the 0.5 unit increase of pH of water extract, it is necessary to increase the absolute content of organic carbon in soil by 0.83%, and it is necessary to increase the absolute content of organic carbon in soil by 0.18% to compensate the increase of concentration of water-soluble fluorine by 1 mg/kg.

The above regression equations have certain limits of applicability. The relationships, which are here considered as those with straight-line correlation, can actually be the part of complex nonlinear functional links [7]. The obtained regression models are true exclusively for the studied object and time of study. The character itself of obtained equations suggests the fact that the territory is subjected to multifactorial and multidirectional effects, and the total adverse effect on soil microbial community is not great. It is not improbable that simultaneous pollution of the soil cover with the emissions of chemical and cement plants result in the interaction of potential pollutants in the upper layer. Integrated results could be smaller than the expected or the forecasted ones in the case of single effect and pollution.

CONCLUSIONS

Parameters of the state of soil microbial community in the impact territory of the plant producing phosphorus-containing mineral fertilizers were within a normal range. The disturbance of the stability of the microbial community in the studied object varied in the used range of gradations from weak to medium.

Soil microbial community in the northeastern transect 0.5 km long from the working phosphogypsum refuse bank was characterized by minimal quantity of carbon of microbial biomass and high specific respiration, and this fact attested to the increased (relative to surrounding territory) stress of microbial community. This could be connected with the secondary soil pollution induced by the dust emission of pollutants from the object of refuse disposal.

Stable functioning of natural-territorial complex in the studied object could be caused by the integrated mutual influence of acid and alkaline soil pollutants. Multifactorial and multidirectional character of technogenic effect on the studied object is reflected in the structure of obtained regression equations.

The data on basal respiration and concentrations of microbial biomass carbon well correlate with concentrations of potential soil pollutants in the contaminated zone and can be used for integrated bioindication of the state of soil ecosystems. Obtained results can be taken into account when defining more exactly the boundaries of sanitary protection and recreation zones and carrying out soil-ecological monitoring in the impact territory of chemical plants. The feasibility of using the parameters of microbial biomass state as indicators of the effects of the products of technogenesis intensity on microbial community is obvious.

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