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DEGRADATION, REHABILITATION, AND CONSERVATION OF SOILS

Ecotoxicity of Dust from Different Functional Zones of Moscow

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Abstract—Ecotoxicity of dust was assessed for different functional zones in three Moscow districts. Ecotoxicity was estimated by the reaction of higher plants using a new approach to the implementation of biotesting method and by changes in the biomass and respiration of microorganisms in residential and transport zones as compared to recreational zones. The proposed method of assessing urban dust toxicity upon modeling dust transfer to soil-like substrates allowed us to solve the main methodological problem, i.e., the choice of control. By the example of perennial ryegrass (*Lollium perenne* L.), it was found out that annual volume of dust deposition upon a high load within a one-meter zone from the road surface does not manifest toxicity, whereas a three-year volume suppresses plants up to 27% relative to the control. No significant differences were found between the phytotoxicity of dust in different functional zones; and phytotoxicity did not correlate with any of the studied properties of dust (organic carbon content (C_{org}), pH, electrical conductivity, moisture capacity, particle-size composition). Basal respiration and carbon content in microbial biomass (C_{mic}) of dust were maximal in the recreational zones of the city (3.1–7.2 μg $C–CO_2$ g^{-1} h^{-1} and 314–435 μg g^{-1}, respectively) decreasing by 27–71% in residential and by 76–81% in the transport zones. Significant correlations of basal respiration and C_{mic} with C_{org} were observed ($r_S = 0.57$ and 0.61, respectively, $p < 0.05$, $n = 49$). High values of microbial metabolic quotient qCO_2 of dust and a small share of C_{mic} in C_{org} indicate unfavorable conditions for microorganisms.

Keywords: urban dust, dust properties, phytotesting, basal respiration, microbial biomass

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INTRODUCTION

The term “urban dust” (hereinafter referred to as “dust”) means a set of solid particles of various sizes, ranging from <1 to 100 μm [67] that are accumulated on any surface of the Earth under urban conditions [66]. The road dust accumulating on the sides of roads appears to be the most common and most studied type of urban dust.

The main sources of dust in cities include dusting of soils and rocks, motor vehicles, application of deicing materials (DIM), emissions from industrial enterprises, construction and demolition of buildings and engineering structures, as well as blossoming of plants [14, 52]. The variety of dust sources results in its complicated composition containing organic and mineral particles of natural and technogenic origin. Many substances in the urban dust exhibit proven toxicity to living organisms [17]. Motor transport plays a special role in their formation in large cities. Corrosion of vehicle bodies, abrasion of automobile pads, leaching of fences and road signs, abrasion of tires and road surfaces, incomplete combustion of automobile fuel and its leaks, the use of washer fluids and the use of DIM provide for a wide range of pollutants in road dust [40, 58, 62]. Heavy metals, oil products, soot, polycyclic aromatic hydrocarbons, and DIM are found among the dominant pollutants in dust [40, 62]. It is not surprising that urban dust can serve as an integral indicator of the urban environment quality [37]. The capacity of fine dust fractions to migrate over large distances with wind causes high risks to human health [29]. The particles <10 μm in size (PM_{10}, where PM stands for particulate matter (the term designating the mixture of solid particles and liquid droplets in the air) are most hazardous [61]. Due to their easy penetration into human respiratory organs, this group of particles causes a complex of diseases, including cancer [44].

Currently, the world is experiencing an intensive growth in research in the abiotic characteristics of dust and the sources of its formation [39, 41]. The assessment of content and distribution of potentially hazardous components in urban dust, with special focus on heavy metals, appears to be one of the most acute issues [27, 33, 38, 39, 68]. Various properties of dust in Moscow were studied at the Lomonosov Moscow State University. Physical, physicochemical and chemical properties of urban dust, including the content of pollutants, were scrutinized at the Faculty of Geography, Lomonosov Moscow State University [6, 13, 43, 64]. Particular attention is paid to the study of heavy metal and metalloid content in various dust fractions [6, 42, 65]. Microstructure, specifics of the dust influence on the formation of urban soils and their microbial composition are intensely investigated at the Faculty of Soil Science of the Moscow State University [14, 21, 22, 35, 45]. In the last three years, studies in dust pollution have been conducted in such Russian cities as Tyumen [46], Surgut [51], Chelyabinsk [47], and Sevastopol [4]; and publications have appeared on comparison of some dust pollution specifics for a group of Russian cities (Ufa, Perm, Tyumen, Chelyabinsk, Nizhnii Tagil, Magnitogorsk, Nizhnii Novgorod, Rostov-on-Don, Murmansk, and Yekaterinburg) [59].

However, the dust ecotoxicity, i.e., its ability to cause adverse effects on the functioning of biological components of ecosystems, remains almost unstudied. Biotesting methods appear to be especially promising for assessing the dust hazard for living organisms in the environment. The essence of biotesting consists in assessing toxicity of the studied environmental objects based on the response of laboratory test organisms measured by certain parameters. The key advantage of biotesting methods lies in providing the integral assessment of the test object [26, 56], taking into account the impact of all potentially hazardous substances under particular conditions.

To calculate the absolute ecotoxicity, the test parameters of studied objects are compared with those of the control, i.e., uncontaminated objects.

As proceeds from foreign publications, very few studies of dust have been performed using biotesting methods (we have found only 13 papers), with mainly aquatic organisms. Unlike soils, there are currently no generally accepted standards for biotesting dust. In many respects, this is due to methodological difficulties, the choice of control, i.e., the reference dust for comparing the suppression of the studied parameters for living organisms, being the key problem [17]. For aquatic organisms, pure water is used as a standard (the eluate method), and dust is tested in water extracts. However, for testing terrestrial ecosystems, soils, in particular, applicative (contact) methods, with testing carried out directly on a solid substrate, are shown to be more suitable for a comprehensive assessment of tested objects, due to the weak transition of many toxicants into water extracts [23]. The reference soil containing no pollutants serves as a control in this case. Taking into account the polycomponent composition of dust and the wide variety of substances contained in it with different potential for transition into water extracts, the applicative biotesting methods may be recommended for assessing ecotoxicity correctly.

Among various organisms used for biotesting soils, the higher plants are the most sensitive [18, 49]. Our own studies on ecotoxicological assessment of soils in roadside areas showed that it were higher plants that demonstrated the greatest sensitivity to transport pollution among contact biotests [53].

The present study proposes and approbates a new approach to phytotesting dust by modeling its transfer to the model substrate surface. A soil-like substrate with dust applied to its surface was used as a test object, and the same substrate without dust served as a control.

Microorganisms are known to be an integral component of ecosystems, performing a wide range of biosphere functions. Being highly adaptive, they are found almost everywhere and develop in various environments, i.e., soil, water, and the air [36]. It is of great interest to study the vital activity parameters (biomass and respiration) of dust microorganisms and to compare these parameters in different functional zones of the city with different anthropogenic loads in some Moscow districts.

The work is aimed at assessing the dust ecotoxicity on the basis of higher plant reaction by approbation of a new approach to phytotesting, as well as analyzing the dust differentiation in different functional zones by biomass and respiration of microorganisms in three Moscow districts.

OBJECTS AND METHODS

The objects of study and the sampling scheme. The urban dust collected at three key sites of ~0.5 km^2 in August 2021 was the object of study (Fig. 1). The first site was located in Khoroshevo-Mnevniki district and Shchukinskiy Park (hereinafter referred to as the Khoroshevo-Mnevniki site) in North-Western administrative district of Moscow; the second one and the third one were located in Filevskiy Park and Ramenki district, accordingly, in Western administrative district of Moscow. The number of sampling points was 15, 17 and 18 in each site, respectively. Dust was sampled in three functional zones, i.e., in the residential area (on roadway pavements of multistorey building courtyards), in the transport area (on highways), and in the recreational area (on pedestrian paths in the parks). Residential zones of all districts are represented by courtyards with multistorey buildings. Transport zones cover 2- and 4-lane roads in Filevskiy Park and Khoroshevo–Mnevniki areas, as well as 2- and 6-lane roads in Ramenki district. The recreational zone at the Khoroshevo–Mnevniki site is represented by a public garden, whereas those at Filevskiy Park and Ramenki, by parks. In each zone, dust was collected at random points 50–100 m apart.

The Khoroshevo–Mnevniki and Filevskiy Park sites are located on the second terrace of the Moskva River composed of alluvial heterogeneous sands, sandy loams and loams overlying the Don moraine or

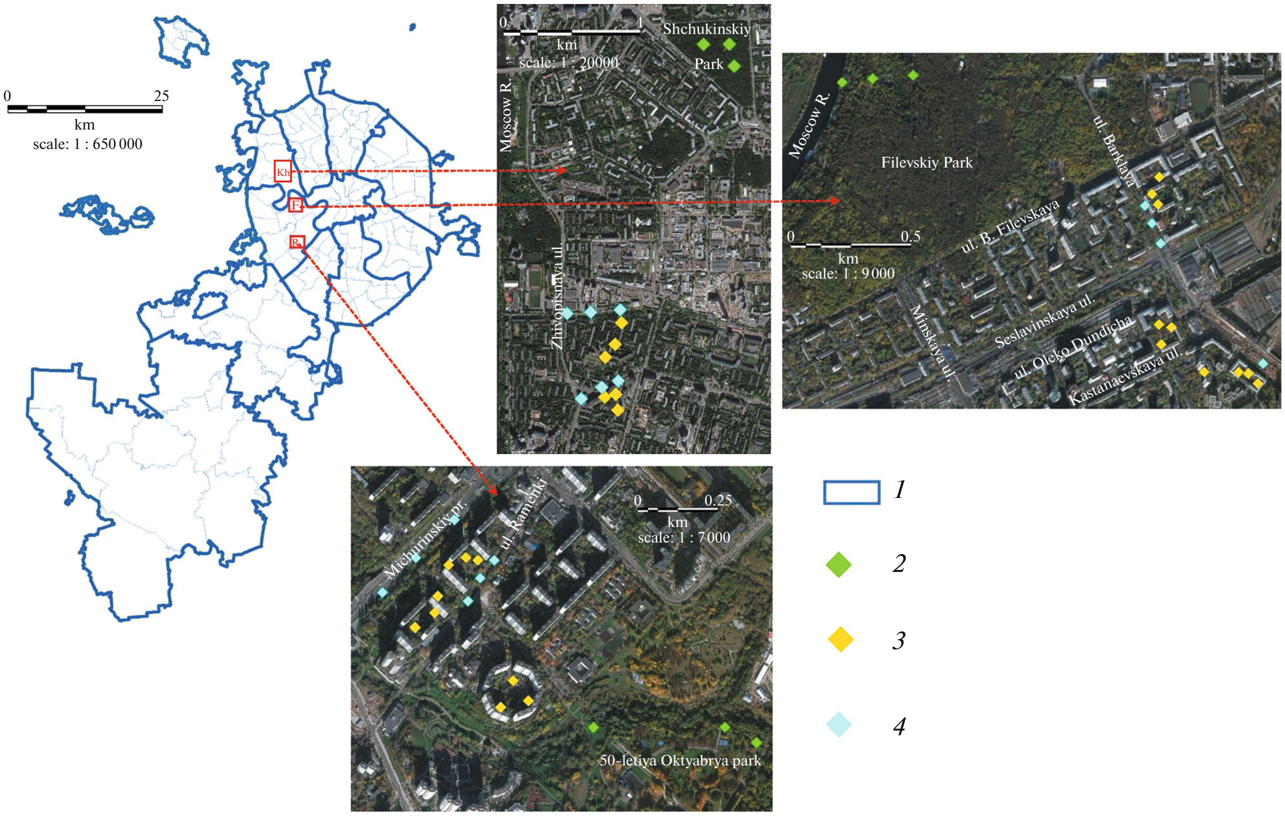

Fig. 1. Location of dust sampling sites in three districts of Moscow: (Kh) Khoroshevo–Mnevniki, (F) Filevskiy Park, (R) Ramenki; (*1*) boundaries of administrative districts, (*2*) recreational zone, (*3*) residential zone, and (*4*) transport zone.

on the overlying the moraine alluvial–glaciofluvial deposits. The Ramenki site is located on the Teplostanskaya Upland, where Quaternary deposits are represented by boulder-containing loams of the Moscow moraine [16]. Urbostratozems and technozems created upon the area improvement with adding the surface soil layer according to [20] predominate in the soil cover of residential zones and in the areas adjacent to transport zones. In recreational zones, natural urbostratified soils can occur, i.e., rzhavozems in Khoroshevo–Mnevniki, soddy-podzolic soils, and typical or gleyed soddy eluvozems in Filevskiy Park, and soddy-podzolic soils in Ramenki [57].

In the areas under consideration, the main sources of environmental pollution include the road and railway transport, thermal power plants and boiler houses. Enterprises in the "Ochakovo", "Zapadnyi Port", "Filevskiy Park", and "Oktyabrskoe Pole" industrial zones, as well as the construction work on partial repurposing or reassignment of unclaimed engineering structures may also exert a certain impact. The traffic intensity was 400–650 vehicles per hour on the studied 2–4-lane highways in the middle of a weekday; and it was 3 times higher on the 6-lane highways.

Dust samples were collected at a stable air temperature (20–25°C) and precipitation absent for at least 2 days before sampling. Sampling from asphalt-covered surfaces was performed using a plastic brush and a dustpan; in parks, surfaces were also wooden or tile-covered. Sampling points represented rectangular sites of the same 2.5 m^2 area (5 × 0.5 m) along curbs. Samples were collected from each site in the same manner until all visible dust was removed.

The quantitative distribution of dust was uneven by the functional zones of the city. The average weight of dust collected from an area of 2.5 m^2 was equal to 200, 100, and 50 g in the residential, transport, and recreational areas, respectively. Each collected sample was divided into halves and placed in separate plastic containers on site, i.e., sterile 25-mL containers for subsequent freezing in the laboratory (at –14°C) and nonsterile 200-mL containers for subsequent air-dry storage. The samples were frozen for subsequent analysis of dust respiration, whereas the air-dried samples were intended for phytotesting and the study of physical, chemical and physicochemical properties of dust.

Research methods. *Methods of the study of physical, chemical, and physicochemical properties.* The dichromate oxidizability of dust was analyzed by the Tyurin method in Nikitin's modification with a titrimetric final [19]. The values obtained from this analysis show conventionally the content of organic carbon (C_{org}) in

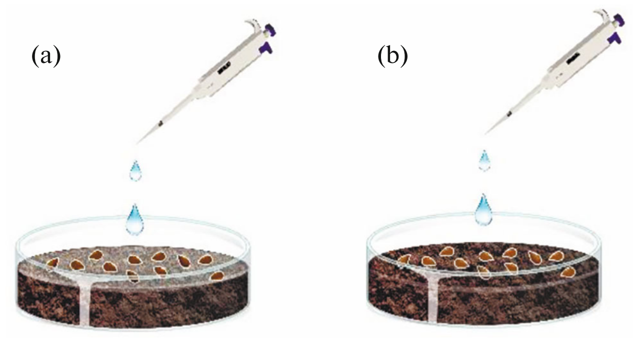

Fig. 2. Scheme of performing urban dust phytotesting: (a) test sample (layers from bottom to top: soil, dust, seeds), (b) control sample (soil, seeds).

the dust; however, partial oxidation of its other components cannot be ruled out.

The pH of the dust suspension (pH_{water}) was determined at 1 : 2.5 dust-to-water ratio with a HI 8314pH meter (Hanna Instruments, Germany) equipped with a combined electrode HI 1230 [9].

The electrical conductivity in the dust suspension (EC) was measured at 1 : 5 dust-to-water ratio with a DiST 4 WP conductometer (Hanna Instruments, Germany) [8]. The total moisture capacity (MC) of dust and soil for phytotesting was analyzed by the tube method [5].

The PM_{10} content in dust was identified by laser diffractometry using an Analysette 22 MicroTec device (Fritsch, Germany). Before instrumental analysis, the air-dried dust was sieved through a 2-mm mesh to remove large components and next treated with sodium pyrophosphate to disperse aggregates.

Phytotesting methods. Phytotesting was performed in laboratory in accordance with the international OECD [55] and US EPA [54] rules as recommended for soils and other environments. Perennial ryegrass (*Lolium perenne* L.) was chosen from the list of crops recommended for phytotesting due to its wide spreading in the Moscow lawns [24]. Ryegrass is one of the main crops sown in Moscow, as it is unpretentious and resistant both to high temperature and frost. Various studies have proved this crop sensitivity to toxicants of different classes [48, 60].

The novelty of dust phytotesting method implies the test system modification containing in this case not only dust, but dust applied to the soil surface, which is similar to the dust coming to the urban soil cover in real conditions. The “3D Universal” soil purchased from the company “Gera” (Russia) was chosen as a dust-contaminated medium, which represented a mixture of oligotrophic and eutrophic peat with the addition of river sand and fertilizer (N 250 mg/L, P_2O_5 275 mg/L, K_2O 275 mg/L, pH 5.5–7.0). In the implemented approach (Fig. 2), the control was the soil with no dust added.

To assess the dust phytotoxicity, the following set of controlled parameters of plant growth and development was selected: seedling root length, seedling stem length (aerial part of plant) and seed germination. The root length, as a rule, is the most sensitive parameter in soil phytotesting [15]. Since urban dust appears to be a new object of study, and there are no investigations of this kind yet, methodologically it was important to understand the response of each testing parameter.

Phytotesting was performed in triplicate. Four gram of air-dry soil was placed in sterile Petri dishes of 5 cm in diameter. Next, 3.9 g of dust were uniformly distributed by its surface, which approximately corresponded to a high level of dust load to the soil surface in Moscow roadside areas within a 1-meter zone from the highway, where the dust fallout is maximal. This value was obtained by recalculating the average daily dust fallout per 1 m^2 of soil and ground surface near highways in Moscow within a 1-meter zone (1.77 g/m^2 according to [2]) to the surface area of a Petri dish. Distilled water was added by drops evenly to the substrate surface in the Petri dish in the amount of 60% MC, similar to the soil testing method [12]. Calculations took into account that the moisture capacities of soil and dust differ, so the final amount of water to be added to the Petri dishes was calculated as the sum of water amount required to achieve 0.6 MC_{dust} and 0.6 MC_{soil}. Ten ryegrass seeds were placed in each Petri dish on the moistened substrate surface. The dishes with seeds were covered with lids, placed in sealed plastic bags to prevent moisture evaporation, and incubated at room temperature for 7 days. At the end of the exposure period, the germination of seeds in each cup was assessed. Then, the plant seedlings were washed from the soil and placed on paper napkins, where the length of the main root and aerial part was measured with a ruler, taking germination into account. The dust toxicity was assessed by the changes in plant growth and development parameters (root length, stem length, germination) in the test samples in relation to the control by the following equation:

$$T\,(\%) = (A - B) \times 100 / A,$$

where A is the average parameter value in the control sample, and B is the average parameter value in the tested sample.

Note that preliminary studies carried out on some samples with the addition of annual dust volume (1.3 g per Petri dish) did not reveal the dust toxicity, whereas toxicity appeared in case of increasing the dust mass to a level of its three-year load on the roadside surface. Therefore, the final phytotesting described above was carried out with the addition of dust in the amount equal to that accumulated on the soil surface in 3 years (3.9 g per Petri dish).

As the experiment was very laborious, the research was performed in 3 stages. The first stage involved the analysis of the dust ecotoxicity in one district. Taking into account experiment triplicate, the total number of seeds for the study of one dust sample was 30. On testing all samples, the growth parameters of 1710 plants were analyzed.

Methods for studying respiration and microbial biomass. The response of microorganisms was assessed by analyzing the basal respiration intensity and microbial biomass using the method of substrate-induced respiration [1].

After collection, dust samples were stored frozen (at −14°C), and they were prepared before analysis in accordance with ISO 18400-206-2018, i.e., first kept for a week in the refrigerator (at +4°C); next the weighed 2 g samples of air-dry dust were placed in 15-mL penicillin-shape flasks, moistened to 60% MC and incubated for 3 days at room temperature (22–23°C). The basal respiration was measured in 24 hours of incubation and expressed in μg $C-CO_2$/(g h). The substrate-induced respiration was analyzed in 2–3 hours of incubation on adding a glucose solution with a concentration of 10 mg/g dust. The air samples were analyzed with a Kristallux 4000 M gas chromatograph, with strictly recorded time of taking the initial and final samples. Microbial biomass carbon (C_{mic}) was calculated using the equation:

$$C_{\text{mic}}\left(\mu\text{g C/g dust}\right) = \text{SIR} \times 40.04 + 0.37 \ [28].$$

All measurements were performed in triplicate. The microbial metabolic quotient qCO_2 showing the specific respiration of microbial biomass was calculated as the ratio of basal respiration rate to microbial biomass (μg $C-CO_2$/(mg C_{mic} h)).

Data processing. The research results were statistically processed using Microsoft Excel 11 and Statistica 12 software. For normally distributed data (found from Shapiro-Wilk test), the significance of differences was assessed using the Student's *t*-test, and the Pearson correlation coefficients were calculated. For nonnormal data, nonparametric methods were used (Mann-Whitney test and Spearman correlation coefficient r_S).

RESULTS AND DISCUSSION

Physical, chemical and physicochemical properties of dust. Studying the basic properties of dust (Fig. 3) was important for understanding their differences from soil properties and further answering the question about the possible causes of dust ecotoxicity. Comparing the studied properties of urban dust and the properties of soils [10], the following specific features can be noted: dust shows lower C_{org} content and higher alkalinity as compared to soils, whereas their moisture capacity values are similar. Higher pH values of urban dust as compared to soils may be due to DIM, windshield washer fluids and leaching of concrete materials of road infrastructure (curbs, etc.). Hard surfaces of highways and pedestrian areas, where dust is accumulated, prevent leaching of these components, unlike soils, which provide free drainage.

The analysis of differences in the properties of dust in the functional zones in Moscow elucidates a number of regularities.

A clear uniform differentiation of C_{org} content in dust is observed in the residential (2.4 ± 0.5%) and transport zones (1.4 ± 0.3%) in each studied urban district (for the statistical significance level $p < 0.05$). Urban recreational zones can be identified as variable by this parameter (C_{org} ranges from 1.2 ± 0.3 to 3.0 ± 0.3%).

The values of pH vary within 7.6–8.6. It is worth noting the stability of dust pH values in the residential zones of the studied districts (varying from 8.1 ± 0.2 to 8.3 ± 0.2), whereas these values vary more significantly in transport and recreational zones. It is interesting that pH values differ statistically significantly ($p < 0.05$) between the Khoroshevo–Mnevniki district and two other districts. Since pH is constant in the residential areas of all studied districts, we may assume that lower pH in transport and recreational zones of the Khoroshevo–Mnevniki district is caused by local specifics, possibly with a lower DIM load.

The moisture capacity of dust shows close values in residential and transport zones, varying within 30–40%. Two of the three studied districts reveal higher rates (46 ± 6 and 70 ± 14%) in the recreational zones; they differ statistically significantly from other zones ($p < 0.1$).

The maximal EC values were equal to 138 μS/cm in residential and recreational zones. They were higher (up to 650 μS/cm) in the dust from transport zones in two out of three districts.

A similar content of PM_{10} particles is noted in the dust from residential and transport zones. Significant differences ($p < 0.01$) between them were found only in one of three city districts (Filevskiy Park). The content of PM_{10} particles is twice lower in the park (recreational) zones as compared to transport and residential zones ($p < 0.05$). The recreational zone in the Khoroshevo–Mnevniki district represented by a public garden was an exception. It did not differ from the transport and residential areas in PM_{10} content. The public garden surrounded by roads must experience a higher average dust load per unit area than larger parks.

Summarizing the results obtained, two differences can be formulated between the functional zones of all studied districts: (1) the C_{org} content is 2 times higher in residential zones as compared to the transport ones, (2) the dust shows the lightest texture (the reduced content of PM_{10} particles) in recreational zones consisting of large parks.

The data obtained fit the results of other research in Moscow dust [64]. Comparing our results with the dust properties in other Russian cities (Tyumen, Surgut, Chelyabinsk, Alushta, Yalta, Sevastopol), we can note similarities in such parameters as pH and EC,

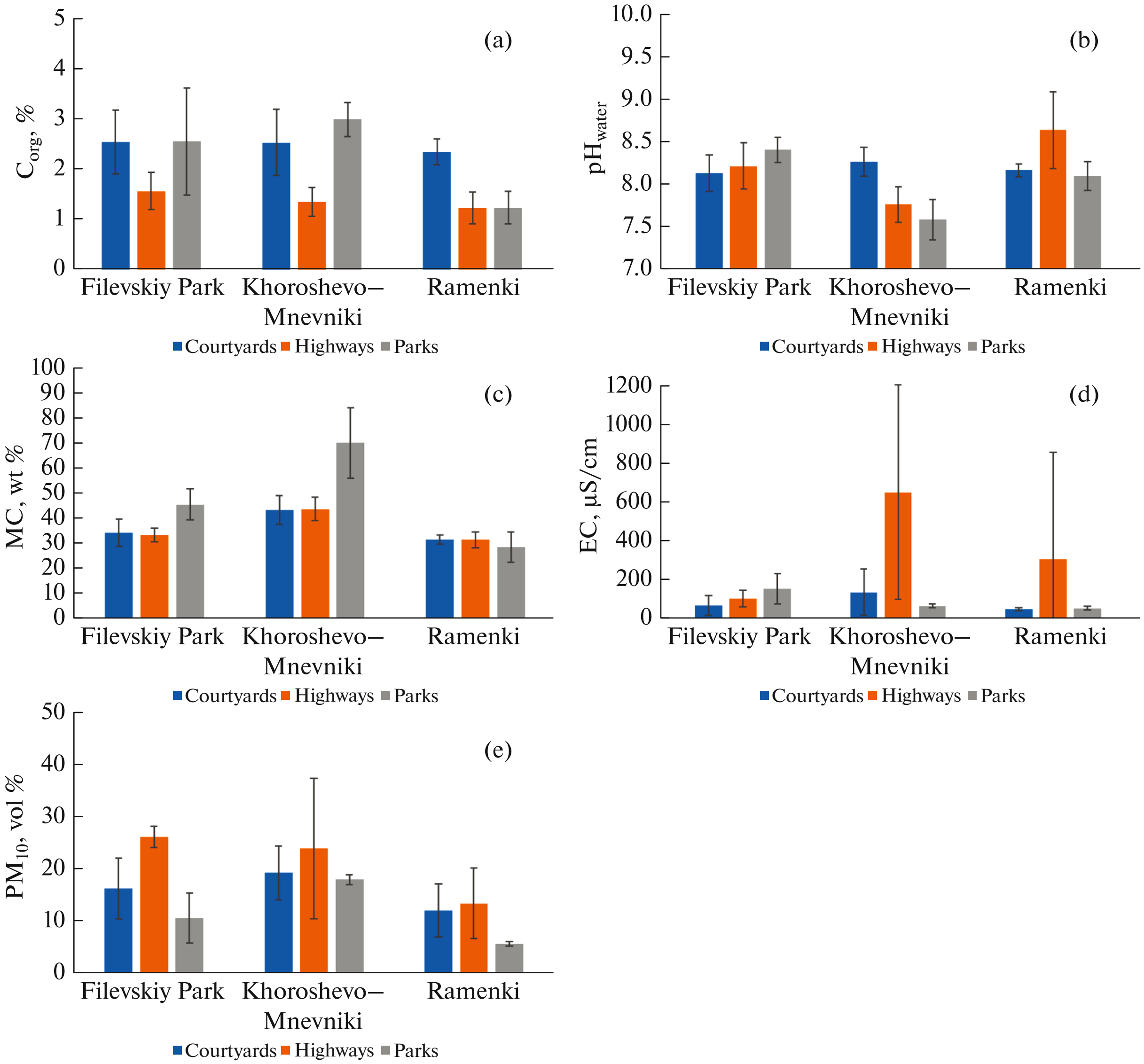

Fig. 3. Physical, chemical and physicochemical properties of dust: (a) organic carbon content, (b) pH, (c) total moisture capacity, (d) electrical conductivity, and (e) PM_{10} content.

while the difference consists in a higher content of C_{org} in the Moscow dust. By the PM_{10} content in road dust, the cities, for which data were found, can be ranked as: Sevastopol > Alushta, Moscow, Tyumen > Surgut.

Assessment of dust ecotoxicity by phytotesting. The results of phytotesting with perennial ryegrass (Fig. 4) showed that ecotoxicity assessed by a decrease in plant growth and development relative to the control varied from 2 to 27%. The root length turned out to be the most sensitive parameter that showed the highest toxicity; the stem length parameter showed close results; and the germination parameter showed the lowest values. Methodologically, it is important to note that the germination parameter is the simplest and fastest for obtaining analytical results; however, this parameter alone is not sufficient, since it underestimates the results on ecotoxicity. In this work, we took the root length as the main parameter.

According to the root length parameter, ecotoxicity values were found not to differ statistically significantly between the functional zones. Even to dust samples collected in recreational areas, plants responded the same as to those from residential and transport ones, which appeared unexpected. However, statistically significant differences in ecotoxicity were recorded between two out of three districts of the city ($p < 0.01$). This observation seems interesting for the further analysis of dust phytotoxicity in different districts of Moscow, shifting the focus from functional zones to districts as a whole. According to the root length parameter, the highest values were registered in Khoroshevo–Mnevniki (residential and recreational zones), whereas Filevskiy Park and Ramenki districts were similar to each other, showing 1.5–2 times lower values. As for the properties of dust in the Khoroshevo–Mnevniki district, in order to understand its differences from other districts (Fig. 3), we can point out the lowest pH values in residential and recreational zones as compared to Filevskiy Park and Ramenki, the highest EC values in some points of transport zones, and the highest PM_{10} content in recreational zones. As is known, the lower the pH, the greater the bioavailability of heavy metals is [32]. High EC values point to the presence of readily soluble salts, which can adversely affect plants by changing the mineral nutrition pattern [34]. The higher the PM_{10} content, the potentially higher concentration of pollutants may be found in dust [31]. For the territory of Moscow, the PM_{10} fraction in city road dust was found to contain, on average, 1.2–6.4 times more heavy metals and metalloids than non-fractioned dust as a whole [64].

Since no reliable correlations were found between the dust ecotoxicity and the dust properties (Table 1), we may assume that the higher dust ecotoxicity in the Khoroshevo–Mnevniki district may be due to a higher content of pollutants in it.

It is interesting to note that phytotoxicity of the surface layer of three-year-old urban soils in the transport zones of Moscow is equal to 20–45% [53]. These values were obtained in an area of intense dust pollution at a distance of 1–6 m from the road surface. In this study, the maximum values of dust ecotoxicity reached 27%. Thus, dust can contribute significantly to soil phytotoxicity.

As proceeds from the afore-said, dust appears to be a hazardous component of the urban ecosystem. Ecotoxicity values referred to a three-year-long load of dust to the soil cover in the areas of maximal load (i.e., in the immediate vicinity to a road surface), prove its adverse impact on plant organisms. In practice, we can state that minimizing the formation and timely removal of dust are appropriate measures aimed at improving the environmental situation in the city. In addition, the obtained data on dust phytotoxicity can be used in developing a time schedule of soil replacement along roadsides for the effective planting lawns.

Basal respiration and microbial biomass. Basal respiration correlated with the microbial carbon content; therefore, their distribution patterns were the same ($r_S = 0.81$, $p < 0.05$). Significant correlations were revealed between basal respiration and microbial biomass and the organic carbon content ($r_S = 0.57$ and 0.61, respectively, $p < 0.05$, $n = 50$). The dust in park

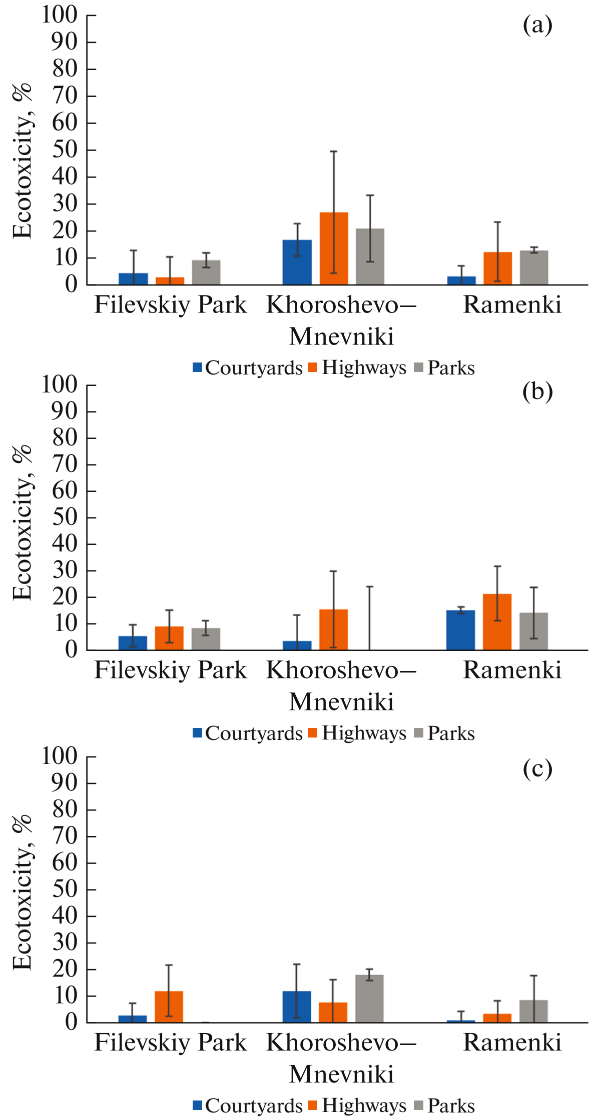

Fig. 4. Assessment of dust ecotoxicity by phytotesting using the following parameters: (a) root length, (b) stem length, and (c) seed germination.

Table 1. Correlation coefficients between dust phytotoxicity and its physicochemical properties

Toxicity parameter	C_{org}	pH	EC	MC	PM_{10}
Root length	–0.08	–0.10	0.36	0.36	0.30
Stem length	–0.31	0.47	0.39	–0.50	0.05
Seed germination	–0.01	–0.40	–0.18	0.26	0.15

Correlations were obtained for the entire array of dust samples in the amount of 50. C_{org} is content of organic carbon in dust; pH stands for dust acidity; EC (electrical conductivity) is the specific electrical conductivity of dust; MC—total moisture capacity of dust; and PM_{10} is the share of particles <10 μm in the total volume of dust particles.

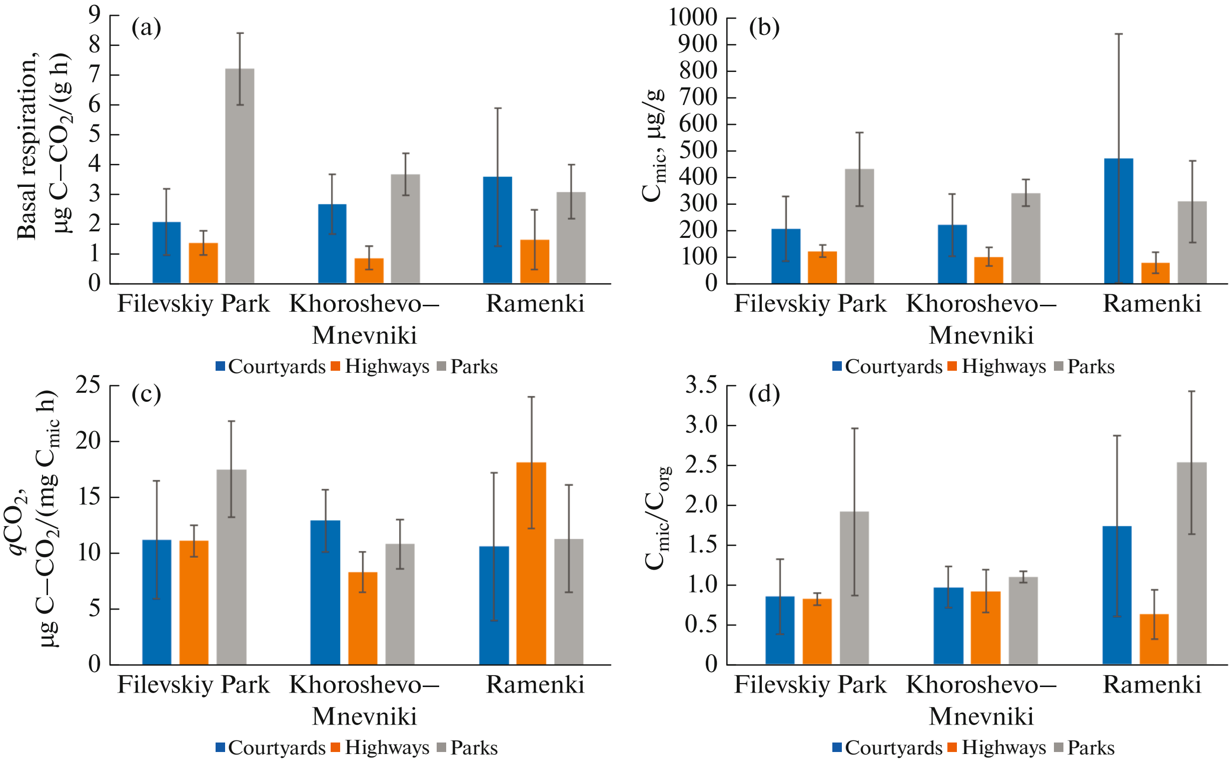

Fig. 5. Assessment of the parameters of the microbiological state of dust: (a) basal respiration, (b) microbial biomass carbon, (c) metabolic quotient qCO_2, and (d) the share of microbial carbon in the total organic carbon.

areas showed the highest intensity of basal respiration and microbial biomass volume (upon a comparable amount of organic matter). The average values constituted 3.1–7.2 μg $C–CO_2$/(g h) and 314–435 μg/g, respectively (Fig. 5). As compared to the parks, the intensity of dust basal respiration in the residential zone decreased by 27% in Khoroshevo–Mnevniki and by 71% in Filevskiy Park; whereas, in the transport zone it decreased by 76 and 81%, respectively. Low basal respiration and microbial biomass in dust from roads may be the result of salinization (registered by the elevated electrical conductivity in water extracts from dust), the highest content of PM_{10} particles and the lowest content of C_{org} as compared to other functional zones. No significant differences in the biological activity indices in transport zones have been specified between districts. In Ramenki district, where the park dust contained less C_{org} than the dust in the residential area, no decrease in basal respiration was registered for the residential area as compared to the park. In the transport zone, basal respiration was by 52% lower than in the park. The carbon content in microbial biomass was 35 and 51% lower in the dust of the residential zones of the Khoroshevo–Mnevniki and Filevskiy Park districts, respectively; it was 69–71% lower in the transport zone dust. Ramenki district showed a similar decrease in microbial biomass in the transport zone as compared to the park, i.e., 73%.

We did not find any studies of microbial respiration of dust, so we used the data of urban soil respiration. According to published data, they can vary from 0.64 ± 0.45 in Moscow [63] to 0.22–2.04 in residential areas and 0.13–1.58 μg $C–CO_2$/(g h) in industrial zones of towns in the Moscow region [11]. In our study, the values of basal respiration of dust from transport zones and partly from residential zones (Filevskiy Park) fall within these ranges, and the basal respiration appears to be higher in park dust. As proceeds from publications, the C_{mic} content in urban soils of the Moscow region varied within 300–700 and 150–300 μg/g in the residential and industrial zones, respectively [11]. The obtained C_{mic} content in dust from transport zones was a bit lower than the values known for soils; and it was comparable to them in dust from residential and park zones.

The specific microbial respiration (qCO_2) turned out to be very high in dust samples, varying on average from 8.4 to 18.2 μg $C–CO_2$/(mg C_{mic} h). At the background of a similar microbial biomass content in road dust, the highest qCO_2 was registered in Ramenki, which attests to the most stressful conditions for microorganisms functioning there. In Ramenki courtyards, on the contrary, the most balanced microbiota respiration was noted among all districts.

The specific respiration of dust microorganisms measured for all sites exceeded significantly that in urban soils. This indicates unfavorable conditions for microbiota functioning in the dust. The results obtained in [11] proved that qCO_2 did not differ significantly for the residential, recreational and industrial zones of the city and varied within the range of 0.74–6.26 μg $C–CO_2$/(mg C_{mic} h), but it was by 30–90% higher in industrial zones. Since qCO_2 values are 3–10 times higher for dust, and the higher values can be registered in dust both near roads and in parks, this testifies to stress conditions for the microbial functioning in dust in any part of the city.

The C_{mic}/C_{org} ratio indicates carbon availability; for soils, high values of this index shows the soil health. In all the studied districts, the C_{mic}/C_{org} ratio was higher in parks; and its average values ranged within 1.1–2.55. In Filevskiy Park and Khoroshevo–Mnevniki districts, the share of microbial carbon in the total organic carbon was close in the residential and transport zones and amounted to about 0.9%; while in Ramenki, the minimal content of microbial carbon in the dust from large highways indicated the worst conditions for microorganisms. The share of microbial carbon in the total organic carbon of dust was comparable to the indices for urban soils in the Moscow region. Its decrease in the most polluted transport zone also confirmed the available data on the lowest C_{mic}/C_{org} for the industrial zones of the city as compared to residential and recreational zones [11].

CONCLUSIONS

(1) Approbation of the method for assessing the urban dust ecotoxicity by modeling the dust load to urban soils showed its validity. This method may be promising for dust phytotesting, as it solves the problem of choosing control. In addition, the similar model can be used for biotesting dust on other test organisms contacting with dust in the environment.

(2) By the example of perennial ryegrass (*Lollium perenne* L.), which is one of the most common grasses in Moscow lawns, it was found that the annual dust fallout on soils in the maximally loaded areas (at a distance of one lane from the road surface) does not exhibit toxicity, while the three-year fallout volume suppresses plants by up to 27% as compared to control.

(3) No significant differences have been found between the phytotoxicity of dust from different functional zones. It did not correlate with any of the studied dust properties (organic carbon content, pH, electrical conductivity, moisture capacity, and particle size composition).

(4) Unlike plants, the microbial vital activity parameters revealed differences between urban functional zones. The basal respiration and microbial biomass of dust were maximal in the recreational zones of the city (3.1–7.2 μg $C–CO_2$/(g h) and 314–435 μg/g, respectively), decreasing by 27–71 and 76–81% in residential and transport zones of the city, respectively. Significant correlations were revealed between the basal respiration and microbial biomass and the carbon organic matter (r_S = 0.57 and 0.61, respectively, $p < 0.05$, $n = 50$).

(5) Higher values of microbial metabolic quotient qCO_2 of dust as compared to urban soils and a low share of microbial carbon in the total organic carbon content point to worse conditions for microorganisms in dust as compared to soils.

(6) Dust is a special component of the urban ecosystem, which is differentiated by the microbiota status and which exerts a toxic effect on plants. It seems appropriate and timely to draw attention to biotesting and bioindication of dust, studying its properties and pollutant content in order to understand the ecotoxicity causes.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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