ISSN 0016-7029, Geochemistry International, 2020, Vol. 58, No. 10, pp. 1135–1144. © Pleiades Publishing, Ltd., 2020.
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Biogeochemistry of Impact Regions: the Role of Edaphic and Phytocoenotic Environmental Factors

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Received March 10, 2020; revised April 4, 2020; accepted April 10, 2020

Abstract—The paper addresses the removal of chemical elements by suprasoil and subsoil phytomasses of herbaceous phytocenoses and their subsequent return to soil during decomposition of plant remnants. The obtained results allowed us to evaluate the biogeochemical cycles of essential (Zn, Cu) and toxic (Pb, Cd) elements in natural biogeocenoses of the Middle Urals. It has been shown that the intensity of such an exchange in areas subjected to variable anthropogenic impact is determined not only by the direct influence of mobile forms of chemical elements, which are contained in soils and operate as environmental pollutants, but also by a combination of edaphic (physicochemical parameters of soils), coenotic (abundance and correlation of agrobotanical groups in phytocenosis) and microbiological (level of evolution of soil microbiocenosis) conditions.

Keywords: phytomass, decomposition of plant remnants, biogeochemical cycles, heavy metals, agrobotanical groups, soil microbiocenosis

DOI: 10.1134/S0016702920100043

INTRODUCTION

Functional stability of natural biogeocenoses (bgc) is determined by the degree to which these systems are able to support the required level of exchange of matter, energy, and information inside and relative to the adjacent bgc (Ermakov, 2017). Such exchange is based on two opposite processes: creation of primary production by living matter and its subsequent decomposition. This results in soil replenishment by humus and mineral nutrients.

Organic matter is synthesized mainly at the first trophic level of bgc within herbaceous communities, while subsequent destruction and mineralization are accomplished by other structural components. Thus, the production–destruction activity of "living matter" produces cycles of chemical elements, the intensity of which depends on both factors of autogenic succession and on the degree of anthropogenic impact.

Numerous works dedicated to study of phytocenosis productivity usually consider only the former aspect of this process. Some papers address the phytomass decomposition (Andreyashkina and Peshkova, 2001; Kurachev and Baturina, 2005; Zhuikova and Zhuikova, 2010; Vorobeichik and Pishchulin, 2011, and others). Complex studies spanning both aspects of the production process are few in number (Andreyashkina and Peshkova, 2003; Zhuikova et al., 2011; Bezel' et al., 2016).

In recent years, an especially acute problem of biogeochemical exchange is associated with contribution of anthropogenic factor, including the chemical pollution of natural bgc, in the indicated processes (Ermakov, 2015, 2017; Petrunina et al., 2003; Kalabin and Moiseenko, 2011; Bezel' et al., 2015; Moiseenko, 2017; Ermakov et al., 2018, and others).

Within the framework of this problem, this study considers the removal of some chemical elements by suprasoil and subsoil phytomasses of herbaceous phytocenoses subjected to diverse anthropogenic transformations. Subsequent decomposition of plant remnants made it possible to estimate the intensity of their return in biogenic exchange.

The aim of this work is to estimate the intensity of biogeochemical cycles of some elements (Cu^{2+}, Zn^{2+}, Cd^{2+}, Pb^{2+}) in herbaceous bgc and the dependence of these processes on the edaphic and cenotic environmental factors. It was suggested that soil conditions, including level of their heavy metals (HM) pollution, could significantly affect the intensity of biogenic exchange of the studied chemical elements, thus reflecting the degradation degree of natural bgc subjected to anthropogenic impact.

Table 1. Reserves of organic matter in the blocks of herbaceous communities under a gradient of anthropogenically transformed soils, t/ha dry matter

Phytomass	Sites			
	agrozems		technozems	
	A-1 (1.0)	A-2 (3.33)	T-1 (6.19)	T-2 (22.78)
Maximum green	2.67 ± 0.16	2.49 ± 0.29	2.05 ± 0.27	2.30 ± 0.45
Total suprasoil*	4.65 ± 0.28	4.33± 0.50	3.57 ± 0.47	4.00 ± 0.78
Total subsoil**	3.22 ± 0.23	3.15 ± 0.33	1.98 ± 0.46	1.63 ± 0.33

*Calculated values of annual production of suprasoil phytomass with allowance for data by Titlyanova (1977).
**Subsoil phytomass with allowance for unidentified remains. In table, the averaged data are given for 2006 and 2009–2012. Error in arithmetic mean is given as a measure of variability. *Z* value is given in parenthesis.

METHOD

Characteristics of test areas. The studied area is the taiga geographical zone, southern taiga subzone (Tagil part of the Middle Urals, 58° N, 60° E). The intensity of biogeochemical cycles was studied in four phytocenoses, which grow on deposits and dumps of the industrial enterprises located at the background and anthropogenically transformed territories.

Based on physicochemical parameters, the soils are subdivided into two groups: agrozems and technozems. The agrozem test sites are confined to agrolandscapes with soddy-podzolic soils and moderate fertility, which are weakly and moderately saturated with bases ($V = 50–95\%$) and have low and moderate contents of mobile phosphorus and potassium compounds. The content of readily hydrolysable nitrogen in agrozem is moderate and low.

The technozem test sites are confined to anthropogenic landscapes (on industrial dumps over 45 years old). Young soils in these areas develop into burozem and lithozem types with a higher fertility, high basesaturation ($V > 95\%$), and high and very high contents of exchangeable phosphorus and potassium. The anthropogenically disturbed soils have been identified in detail earlier (Kaigorodova et al., 2013; Zhuikova et al., 2015, 2019). According to soil groups, the test areas overgrown by diverse herbaceous phytocenosis are designated as A-1, A-2 (agrozems) and T-1, T-2 (technozems). This series of test areas represent a gradient of soil HM pollution, the integral indicator of which is the integral toxic load, $Z = \Sigma(C_i/C_b)$ (rel. u.), where C_i/Cb is the ratio of element concentrations on test site to the background value. Corresponding Z values are given in Table 1.

Syntaxonomic status of communities is as follows: A-1—rankless community *Deschampsia caespitosa-Festuca pratensis* [*Arrhenatheretalia*], A-2—rankless community *Alchemilla vulgaris-Festuca pratensis* [*Arrhenatheretalia/Carici macrourae-Crepidetalia sibiricae*], T-1—rankless community *Carum carvi-Festuca pratensis* [*Arrhenatheretalia*], T-2—rankless community *Tussilago farfara-Calamagrostis arundinacea* [*Dauco-Melilotion/Agropyrion repentis*].

The considered herbaceous communities are serial communities forming on deposits and dumps. On such territories, herbaceous communities evolve toward increase of species diversity and increase of total projective plant coverage (Zhuikova et al., 2019).

Determination of suprasoil and subsoil phytomass. The primary production of herbaceous communities is measured as the amount of phytomass collected during its maximum development (Bukvareva and Aleshchenko, 2013). During vegetation seasons of 2006–2012 ten 25 × 25 cm plots spaced over 3 m from each other were outlined using random sampling method. Samples were collected by the monolith method from a depth of 25 cm (Shalyt, 1960). Plants from each area were sorted by species. After preliminarily treatment, the air-dry suprasoil and subsoil phytomasses of each species were measured (g/m^2). In total, 1370 and 1285 weighings were carried out for suprasoil and subsoil phytomasses, respectively.

The study of the actual decomposition rate of plant remnants was carried out in the same phytocenoses. Suprasoil phytomass from three agrobothanical groups (legumes, grasses, forbs) was used as exposed material in field experiment. The samples were placed into the uppermost 5-cm soil layer along transect spaced 30 cm apart. Ten samples of legumes, grasses, and forbs were subsequently placed on each transect. The samples were exposed for 12 months.

Upon expiry of the exposure time, the packets were extracted, purified from soil particles and thin roots, and dried in thermostat up to absolutely dry mass at 105°C. The decomposition rate of the exposed material was evaluated by the loss (%) of sample weight (Vorobeichik, 2007).

The decomposition rate of plant roots was determined by calculations based on data by N. V. Pereverzev (1987), taking into account that the annual decomposition rate of suprasoil phytomass was higher than that of subsoil phytomass by 1.26 times for legumes, 1.69 times for grasses, and 1.48 times for forbs. The decomposition rate of roots for group "other plants" was calculated as average value of three agrobotanical groups.

Determination of heavy metal content in soils and plants. Sampling and analysis of soils were carried out according to RD 52.18.191-89 in compliance with certified methods at the Laboratory of the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences (certificate No. ROSS RU. 0001.515630). Plant samples were collected according to requirements (*Methodical...,* 1992). Metals were extracted by 5% HNO_3 from soil and by 70% HNO_3 or HNO_3 and HCl mixture from plant samples. Concentrations of Cu^{2+}, Zn^{2+}, Cd^{2+}, and Pb^{2+} in acid extracts were measured by flame atomic absorption spectrometry using an AAS Vario 6 spectrometer (Analytik Jena AG). In total, we carried out 200 element analyses of soil, 360 of suprasoil plant organs, and 235 of subsoil plants.

Statistical processing involved calculation of arithmetic mean (M) and its error (m). Modality of selective distributions was verified using Shapiro–Wilk W-test, as well as through asymmetry (As) to asymmetry error (S_{As}) ratio and through the excess (Ex) to excess error (S_{Ex}) ratio. Zero hypothesis was discarded, if $t_{As} = \frac{As}{S_{As}} > 3$ and $t_{Ex} = \frac{Ex}{S_{Ex}} > 3$. Accepting zero hypothesis served as an assumption to use of parametric criteria. Differences between samplings and a percent of explained dispersion were estimated by one- and two-way ANOVA with calculation of F-criterion. Groups were compared by Sheffe's S-method (method of linear contrasts).

Conjugation between features was estimated using Spearman's rank correlation coefficient (R_s) as well as regression analysis (R^2). Statistical analysis was carried out with software package Statistica v. 10.0 (Stat Soft, Inc., 2012).

RESULTS AND DISCUSSION

Phytomass and content of chemical elements in plants under conditions of anthropogenic transformation of soils. Plant phytomass of natural bgc is an important source of organic matter in ecosystems and a major factor in the formation of biogeochemical processes. The suprasoil phytomass collected during its maximum development in herbaceous communities (peak standing crop) is usually taken as a measure of primary production (Titlyanova, 1979; Bukvareva and Aleshchenko, 2013). Subsoil phytomass reflects its reserves at the moment of study.

While studying the herbaceous phytocenosis, we estimated the total suprasoil and subsoil phytomass, as well as the content of some chemical elements in organs of plants of separate species from these communities (Zhuikova, 2009; Bezel' et al., 2015; 2016). This allowed us to estimate the reserves of chemical elements in the blocks of studied herbaceous bgc (Tables 1, 2).

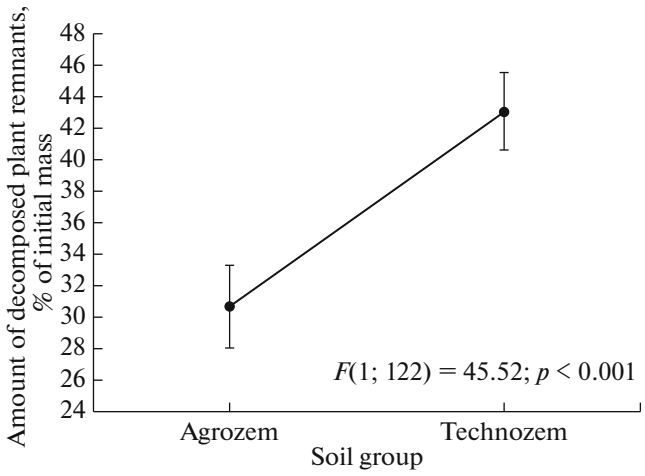

Fig. 1. Results of one-way ANOVA analysis of differences in amount of decomposed plant remnants between agrozems and technozems for year.

Decomposition of plant remnants. During the studies, the current decomposition rates of legumes, grasses, and forbs were determined at test sites with different degree of anthropogenic transformation (Table 3).

Verification of selective distributions for correspondence to the normal distribution law made it possible to accept the zero hypothesis and to apply methods of parametric statistics. The dependence of the average content of decomposed plant remnants (y) on the level of toxic load on soils of different type (x) is approximated by equation of linear regression: $y = (29.41 \pm 2.05) + (2.68 \pm 0.63)x$ ($R^2 = 0.12$; $p < 0.001$). In general, the amount of decomposed plant remnants on technozem test sites during exposure time was higher than on agrozem test sites, which is confirmed by the one-way ANOVA (Fig. 1) and Sheffe's S-method ($F = 5.08$; $df = 3$; 116; $p = 0.001$).

The intensity of HM involvement in biogenic cycle is determined by two parameters: their accumulation in phytomass and return to biogenic exchange through destruction and mineralization of plant remnants. The description of these processes is only some approximation to true circulation of chemical elements, because it ignores the decomposition of plant material of previous years. Obtained estimates should be considered only as some integral characteristics of the total state of bgc, including the measure of its anthropogenic transformation.

According to numerous data (Medvedeva et al., 2006; Uzbek, 2006; Sandanova, 2007; Netrusov and Kotova, 2009; Lisetsky, 2012; Golovatskaya and Nikonova, 2013; Käärik, 1974; *Global-Scale Similarities...*, 2007), the intensity of destruction of plant remnants is mainly determined by the chemical composition of decomposing samples, time factor, and soil conditions (composition of soil microbiocenosis, con-

Table 2. Removal of chemical elements from suprasoil and subsoil phytomasses by agrobotanical groups of herbaceous phytocenosis

Site	Agrobotanical group	Removal of ions, μg/m^2 year			
		Zn^{2+}	Cu^{2+}	Pb^{2+}	Cd^{2+}
		Suprasoil phytomass			
A-1	Legumes	2553.3 ± 145.6	411.5 ± 145.6	357.3 ± 126.5	11.1 ± 3.9
	Grasses	1711.6 ± 15.1	165.5 ± 15.1	304.0 ± 27.8	13.1 ± 1.2
	Forbs	4499.1 ± 198.9	1335.7 ± 198.9	868.3 ± 129.3	44.4 ± 6.6
A-2	Legumes	2101.9 ± 49.1	372.5 ± 49.1	368.8 ± 48.6	15.9 ± 2.1
	Grasses	1273.8 ± 38.7	224.3 ± 38.7	263.1 ± 45.4	21.7 ± 3.7
	Forbs	6347.9 ± 218.4	1451.6 ± 218.4	1891.0 ± 284.5	89.5 ±1 3.5
T-1	Legumes	5202.7 ± 188.4	542.8 ± 188.4	480.5 ± 166.8	16.4 ± 5.7
	Grasses	2664.8 ± 54.7	246.5 ± 54.7	387.5 ± 85.9	10.2 ± 2.3
	Forbs	9345.2 ± 166.7	980.4 ± 166.7	1657.5 ± 281.9	80.9 ± 13.8
T-2	Legumes	5075.3 ± 413.5	1642.4 ± 413.5	558.3 ± 140.6	40.5 ± 10.2
	Grasses	4866.9 ± 460.5	1857.0 ± 460.5	472.3 ± 117.1	33.1 ± 8.2
	Forbs	3916.6 ± 352.2	2001.2 ± 352.2	1088.8 ± 191.6	107.7± 19.0
		Subsoil phytomass			
A-1	Legumes	2426.3 ± 933.1	3274.0 ±1259.0	2616.9 ± 1006.3	56.9 ± 21.9
	Grasses	5059.3 ± 576.1	1743.9 ± 198.6	1211.8 ± 138.0	379.0 ± 43.2
	Forbs	4936.5 ± 549.9	1509.5 ± 168.1	631.8 ± 70.4	32.9 ± 3.7
	Other plants	926.9 ± 312.4	610.2 ± 205.6	197.9 ± 66.7	12.4 ± 4.2
A-2	Legumes	1097.2 ± 286.1	231.7 ± 60.4	484.4 ± 126.3	12.6 ± 3.3
	Grasses	2003.3 ± 657.4	4497.2 ± 1475.8	640.6 ± 210.2	808.4 ± 265.3
	Forbs	5812.9 ± 716.5	5513.8 ± 679.6	1815.6 ± 223.8	1321.2 ± 162.9
	Other plants	359.1 ± 74.7	2488.2 ± 517.3	1308.2 ± 272.0	199.2 ± 41.4
T-1	Legumes	2531.4 ± 731.0	1071.5 ± 309.4	551.3 ± 159.2	42.7 ± 12.3
	Grasses	3581.1 ± 835.7	1551.6 ± 362.1	314.9 ± 73.5	43.3 ± 10.1
	Forbs	7232.0 ± 1973.8	2414.0 ± 658.8	1296.9 ± 354.0	818.0 ± 223.3
	Other plants	119.5 ± 40.4	290.7 ± 98.2	935.7 ± 316.2	1584.8 ± 535.5
T-2	Legumes	4765.3 ± 1646.3	12109.6 ± 4183.5	1089.8 ± 376.5	24.4 ± 8.4
	Grasses	7614.3 ± 1698.1	20047.3 ± 4470.8	994.1 ± 221.7	30.0 ± 6.7
	Forbs	5959.1 ± 682.1	6454.5 ± 738. 8	821.7 ± 94.1	50.9 ± 5.8
	Other plants	3318.4 ± 1412.1	5722.6 ± 2435.2	272.2 ± 115.8	10.5 ± 4.5

Table lists arithmetic mean and its error (repetition of year, $n = 5$).

Table 3. Amount of decomposed plant remnants under a gradient of anthropogenic transformation of soil (% for year)

Agrobotanical groups	Agrozem		Technozem	
	A-1	A-2	T-1	T-2
L	$\frac{32.59 \pm 2.13}{10}$	$\frac{23.53 \pm 3.77}{10}$	$\frac{41.87 \pm 0.54}{3}$	$\frac{48.79 \pm 1.23}{10}$
G	$\frac{27.81 \pm 1.90}{10}$	$\frac{30.59 \pm 2.59}{10}$	$\frac{41.93 \pm 2.67}{5}$	$\frac{45.29 \pm 3.81}{8}$
F	$\frac{36.86 \pm 2.08}{8}$	$\frac{33.62 \pm 2.44}{10}$	$\frac{55.34 \pm 5.29}{3}$	$\frac{54.49 \pm 1.54}{9}$
Average	**32.10 ± 1.33**	**29.24 ± 1.87**	**48.47 ± 1.29**	**35.81 ± 2.14**

(*L*) legumes, (*G*) grasses; (*M*) forbs. Arithmetic mean, in numerator, number of samples is denominator; statistical unit – sample.

tent of organic components in soils, HM pollution, and others).

Obtained results were analyzed by two-way ("soil group" and "agrobotanical group") ANOVA with a "toxic load (Z)" as covariates of volume of decomposed plant remnants. It was demonstrated for the test sites with different edaphic conditions, including their HM pollution, that an increase of exposure time is accompanied by a significant increase of contribution of "soil group" factor from 3.55% after two months to 25.20% by the end of the first year. Thereby, the contribution of factor "agrobotanical group" shows three time decrease during this period (Fig. 2).

Thus, the initial decomposition stages (first six months) are mainly controlled by the structure and chemical composition of decomposed plant material. By the end of the first year, the decisive role goes to edaphic conditions, in our case, likely physicochemical features of soils, including their HM pollution.

Dependence of HM return on their concentrations in soils. The content of mobile HM species in soils determines both their accumulation in phytomass as well as the quantitative and qualitative composition of soil destructors (Kurachev and Baturina, 2005; Uzbek, 2006; Semenova et al., 2011; Ivashina et al., 2014).

The data from Tables 1 and 2 make it possible to estimate the content of chemical elements that are returned in biogenic cycles owing to the decomposition of suprasoil and subsoil phytomass. Figure 3 demonstrates the results of analysis of the Zn, Cu, Pb and Cd involvement in biogenic exchange by suprasoil and subsoil phytomass of herbaceous communities, their annual return during decomposition of plant remnants, as well as annual fraction of this return.

The obtained data show that the HM removal with suprasoil and subsoil phytomass clearly depends on the concentration of the corresponding chemical elements in soils, as well as the level of their return to biogeochemical cycles through destruction and subsequent mineralization of plant remnants. With 20 times increase of Zn concentration in soils, its removal with phytomass and subsequent return to biogeochemical cycle increase by only 1.5–2.0 times. At over 75 times soil pollution by copper, the removal and return of this element increases by 3–8 times, respectively. At insignificant 1.5 times gradient of soil pollution by lead in our case, its removal remains practically unchangeable, but return to biogenic cycle increases by 2.5 times. Of most toxic elements, cadmium in soils increases by ten times, while its removal and return to biogenic exchange show only3–4 times increase.

These data are inconsistent with some published data, which suggest that the destruction rate of leaf litter in soils subjected to pollution by HM and sulfur compounds decreases (Vorobeichik, 2002; *Reduction of Decomposition Rate...,* 1991, and others). At the same time, the decomposition of plant material on polluted soils could be more rapid than on background

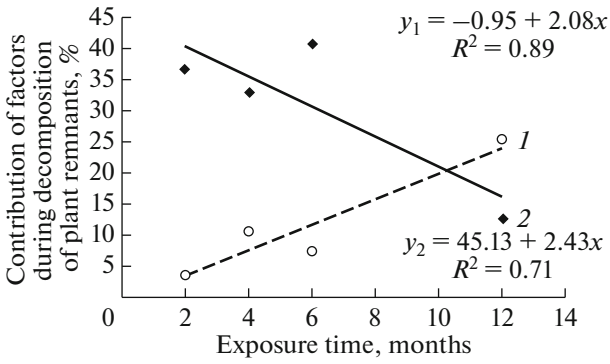

Fig. 2. Contribution of factors of "soil group" (*1*) and "agrobotanical group" (*2*) in the decomposition of plant remnants.

soils (Pomazkina, 2011). It is possible that at high HM content in soils, the role of pollution-resistant destructors (bacteria and fungi) increases, which leads to the acceleration of decomposition (Ivashina et al., 2014).

The intensity of biogeochemical cycles to greater extent is characterized by the ratio of HM removal with plant phytomass to the level of their return to geochemical exchange. The obtained data showed a clear difference of this parameter between the agrozem and technozem test sites (Fig. 3). For all studied elements, the fraction of their return to the biogenic exchange on agrozems is lower than that on technozems, even at relatively low lead contents in soils of test site B-2. These data are of special importance, because they show that the mineral exchange in the herbaceous phytocenosis is determined in our case by not only HM pollution of soil. An important role belongs to the phytocenotic factors, as well as edaphic specifics of conditions of plant community.

Role of agrobotanical groups in the HM exchange in herbaceous bgc. Numerous studies demonstrated a species peculiarity of HM accumulation by suprasoil and subsoil organs of plants. Our data also indicate that the composition of decomposed agrobotanical groups plays a decisive role during first six months of exposure (Fig. 2). The proportion of phytomass of agrobotanical groups "forbs–legume–grasses" varies in a gradient of anthropogenic transformation of environment (%): from 46.8 : 21.3 : 31.9 at test site A-1 to 17.7 : 19.1 : 63.2 at test site T-2 for suprasoil phytomass; from 45 : 23 : 32 to 21 : 17 : 62, respectively, for subsoil phytomass.

Since fraction of phytomass of agrobotanical groups decomposed within a year is different at different studied sites (Table 3), their involvement in biogenic cycles is determined not only by volume of synthesized phytomass, but also by the rate of its decomposition. Figure 4 shows a fraction of annual return of their elements to biogenic exchange by suprasoil and subsoil organs of plants of different agrobotanical groups. At

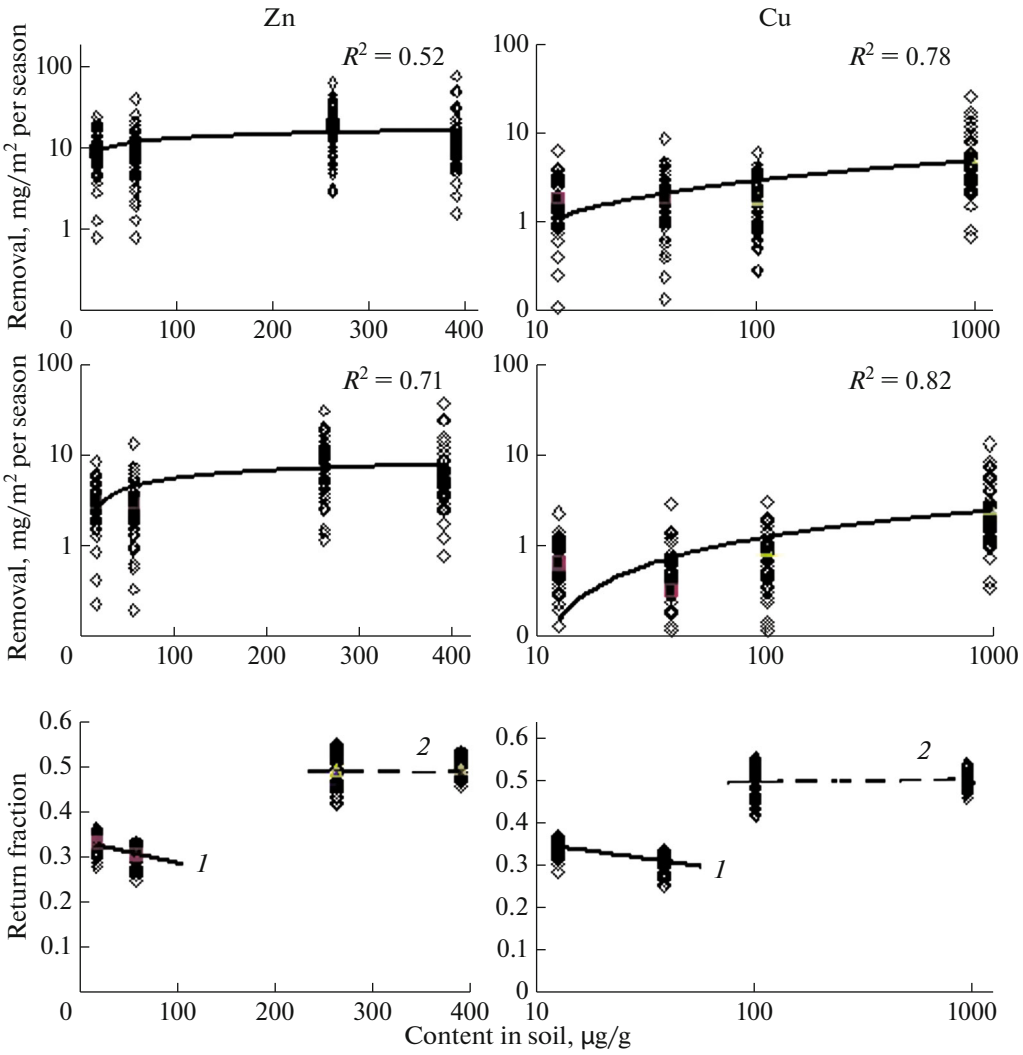

Fig. 3. Annual removal of HM by suprasoil and subsoil phytomasses, return, and fraction of their return to biogenic cycle at decomposition of plant remnants: (*1*) agrozems, (*2*) technozems.

low HM contents in soils, the maximum contribution to the biogeochemical exchange of almost all studied elements was made by forbs amounting from 30 to 80% of total exchange pool of Cu^{2+}, Zn^{2+}, Pb^{2+}. The contribution of legumes and grasses is lower (from 15 to 30%). The exception is Cd^{2+}, the return of which to the biogenic exchange at its low content was mainly controlled by grasses.

With increase of Zn^{2+} and Cu^{2+} contents in soils, the contribution of forbs in the biogenic cycles decreases, while that of legumes and grasses increases. At the same time, at our gradient, the contribution of forbs to the biogenic exchange of Pb^{2+} and Cd^{2+} increases owing to the decrease of legumes and grasses.

Thus, the different agrobotanical groups of the studied herbaceous phytocenoses owing to their different contents in the total suprasoil and subsoil phytomasses and different chemical composition of their tissues, are involved in the element exchange with different intensity.

Role of microbiological complex of soil. An important component of the edaphic state of soil, which finally determines the intensity of cycles of biogeochemical exchange, is the composition and abundance of soil microflora. Previous microbiological studies allowed us to determine the qualitative and quantitative difference of microbiological complex at the considered sites (Ivshina et al., 2014).

Anaerobic and aerobic cellulosolytic bacteria, the number of which positively correlates with soil pollution by HM, play an important role in the decomposition of plant remnants. The rank correlation coefficients Rs are, respectively, 0.65–0.74 for aerobic bacteria, 0.79 for anaerobes and mesophylls, and 0.60 for thermophylls ($N = 15$; $p < 0.05$–0.001). Thereby, the total population of soil microorganisms at polluted territories is higher than that of background one.

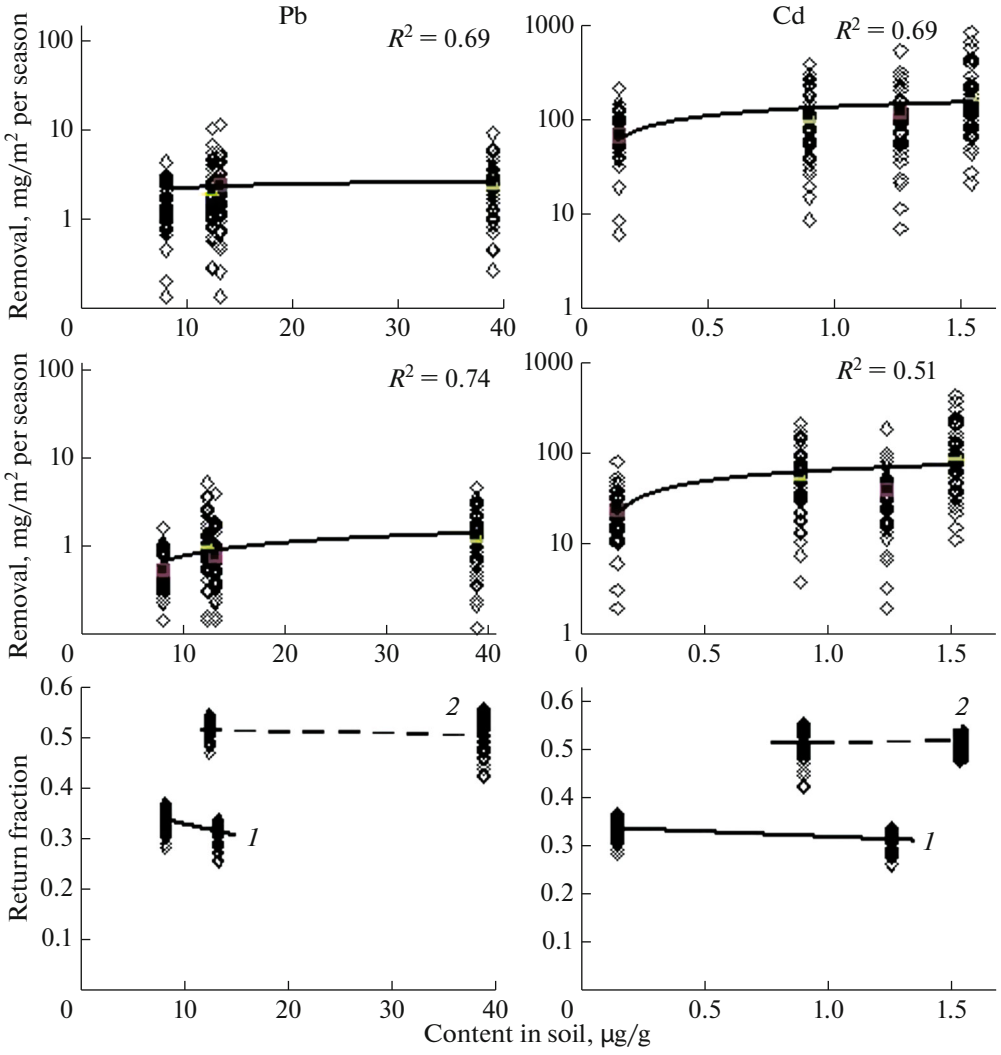

Fig. 3. (Contd.)

Thus, it was established that the return of zinc and copper to biogenic exchange increases with increase of total number of microorganisms. The maximum influence of microorganism abundance on the HM return is observed during decomposition of forbs (Fig. 5). The influence of this factor on the decomposition of two other agrobotanical groups is less expressed. Since the high intensity of these processes is revealed at the highest total abundance of microorganisms on technozems (test sites T-1 and T-2) as compared with agrozems (test sites A-1 and A-2), then a simplified structure of microbial community with the predominance of *r*-strategists is likely to be formed under these conditions. This also explains the high metabolic activity of microorganisms (Ivshina et al., 2014). The high total amount of cellulose-decomposing bacteria in microbiocenosis determines the high rates of decomposition of plant remnants on technozems and the greater return of chemical elements to biogenic cycles compared to agrozems. This is maximally expressed for zinc and copper (Fig. 6).

CONCLUSIONS

The participation of chemical elements in biogeochemical cycles is determined by an intricate complex of interrelated biocenotic and edaphic parameters of natural bgc, including their possible anthropogenic transformation.

The data on HM removal by suprasoil and subsoil phytomass of herbaceous phytocenosis during synthesis of primary organic matter and their subsequent return through destruction of plant remnants and mineralization of organics allowed us to compare the intensity of biogeochemical exchange of some essential (zinc, copper) and toxic (lead, cadmium) elements in natural biogeocenosis subjected to different degree of anthropogenic transformation.

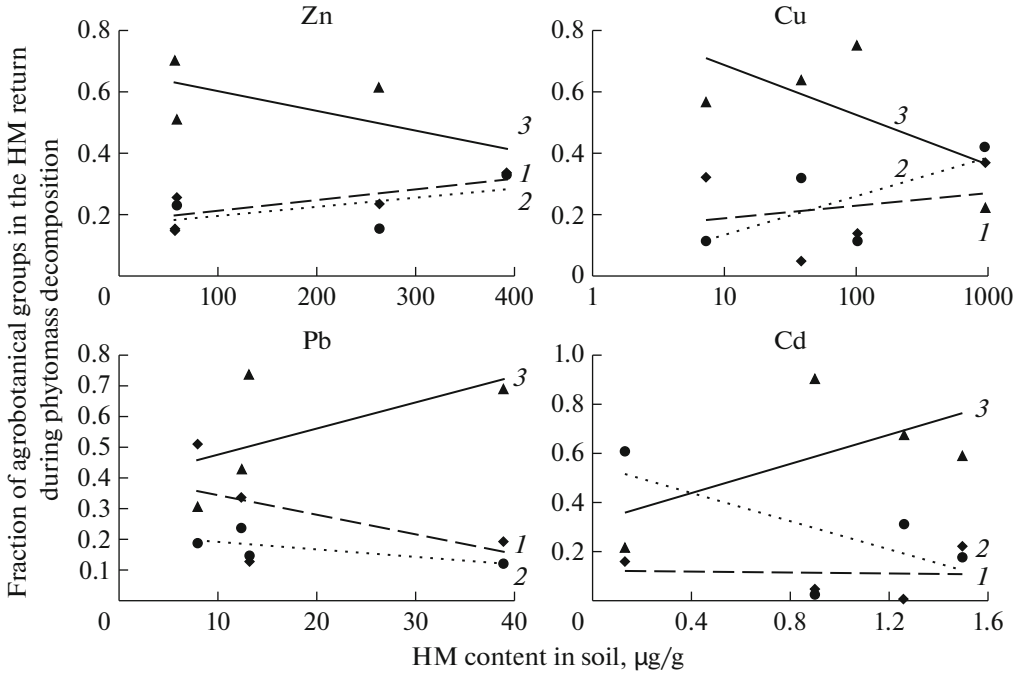

Fig. 4. Fraction of legumes (*1*), grasses (*2*), and forbs (*3*) in the return of HM during decomposition of their plant remnants.

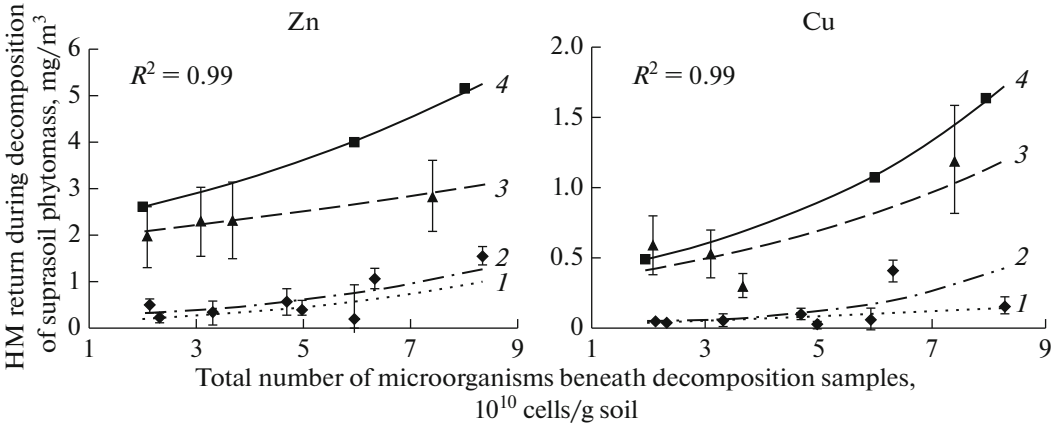

Fig. 5. Return of zinc and copper to biogeochemical exchange during decomposition of plant remnants depending on the microorganism abundance in soil: (*1*) legumes, (*2*) grasses; (*3*) forbs, (*4*) total return.

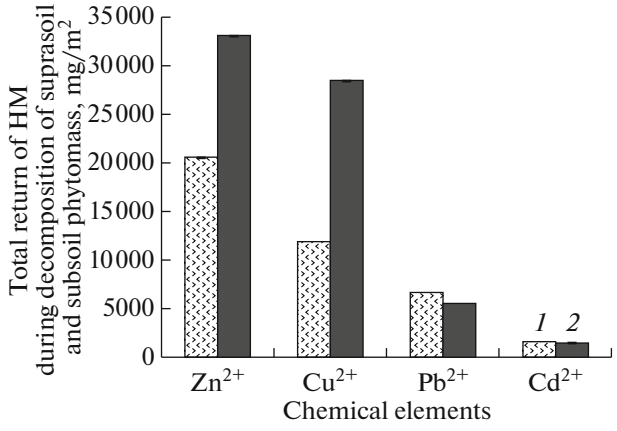

Fig. 6. Total return of HM during decomposition of suprasoil and subsoil phytomass on agrozem (*1*) and technozem (*2*).

It is shown that the intensity of biogeochemical exchange of HM in anthropogenically modified landscapes of the Middle Urals depends not only on the content of mobile species of chemical elements serving as environmental pollutants in soil, but also is significantly determined by a combination of cenotic and edaphic conditions. The presence of forbs in herbaceous phytocenosis facilitates more intense HM accumulation in plant phytomass, while their subsequent intense decomposition provides an active return of ions to biogenic cycle. The intensity of exchange processes in natural bgc is also controlled by the composition and abundance of soil microflora, including the number of cellulose-decomposing microorganisms.

The obtained data indicate that the intensity of biogenic cycles under considered levels of HM soil pollution significantly depends on the degree of anthropogenic transformation of soil, which is related not only with direct HM influence, but also significantly with the abundance and proportions of agrobotanical groups in plant community and the degree of the development of soil microbiocenosis.

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Translated by M. Bogina