Analysis of Element Distribution in Biogeocenoses on the Basis of Composts of the Wastes from Pulp and Paper Industry

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Abstract

Analysis of the distribution of elements in biogeocenoses based on organomineral composts is performed. Introduction of composts of the wastes from plant and cardboard industry, heat-and-power engineering, cattle breeding did not cause accumulation of microelements in soils in concentrations exceeding the phytotoxicity level and maximum permissible values. Differences in microelemental composition of the experimental and reference plants were insignificant. Compost made of the wastes from industry can be used for reclamation of land disturbed by man's impact.

INTRODUCTION

Ecological aspects of the use of large-scale wastes of industry and heat engineering, as well as composts based on them attract increasing attention during the recent years. A positive example of utilization of industrial wastes is the work performed by us at the Selenga Pulp and Cardboard Plant, which are situated at a distance of 60 km from Lake Baikal and 10 km from the Selenga River inflowing into the Baikal. Here, about 10 000 m^3 of solid wastes are accumulated annually; total amount is 150 000 m^3. The presence of settling tanks for lignin tailings, ash dumps, accumulated dung, etc. bring substantial danger to the ecosystem of the Baikal.

Composting of the wastes from the Selenga Pulp and Cardboard Plant (lignin tailings, bark, wood dust), ash from heat plants and wastes from agricultural works (dung) allowed obtaining highly efficient organomineral fertilizers. The application of these organomineral composts in plant cultivation provides the creation of artificial biogeocenoses with the biogeochemical cycling of elements governed by man.

The introduction of these composts enriched soils with organic substances, nutrition elements and biophylic microelements, promoted the development of plant root age, activated soil microorganisms, created the combination of the necessary conditions for the formation and conservation of water-proof macro- and microstructure in topsoil. With the introduction of composts, the level of reductive-oxidative enzymes in soil increased in comparison with the hydrolytic ones. This provided more favourable ratio between mineralization of organics and humification [1].

However, the use of organomineral composts based on industrial wastes should be preceded by the examination of the behaviour of toxic and biophylic microelements which get accumulated in soil and in plant in high concentrations and can cause danger for biogeocenoses. Toxicological studies of redistribution of elements, first of all heavy metals, in the agricultural ecosystem including compost, soil and plants are a key factor in the problem of utilization of industrial wastes in agriculture.

EXPERIMENTAL

Experimental investigations were carried out in a field experiment with alluvial turf medium-loamy soil (flood lands of the Selenga river) characterized by the following parameters: total carbon (according to Tyurin), 2.0 %; total nitrogen (according to Kieldal), 0.3 %; pH_{salt}, 5.1; soluble forms of phosphorus and potassium (according to Kirsanov), 28.2 and 16.8 mg/100 g, respectively; sum of absorbed bases (according to Kappen), 20.2 mg-eq./100 g. The soil of the experimental strip possesses specific properties (low humus content, sandy soil profile, high water permeability, weakness of the humus layer) and is distinguished by high vulnerability toward man's impact. Reproduction of its fertility under intensive involvement in agricultural activities is impossible without introduction of increased amounts of organic fertilizers.

A field experiment aimed at the investigation of the effect of various doses of the compost on chemical composition of the soil and cropped plants included six versions: control (soil without fertilizer), soil + compost 50 t/ha, soil + compost 100 t/ha, soil + compost 150 t/ha, soil + compost 200 t/ha, compost (bulk layer 30 cm thick). Compost was introduced into the topsoil before sowing (experiment was repeated three times, the area of allotment was 12 m^2 (3 × 4 m), the cropped plant was barley). The compost was prepared from wastes of the Selenga Pulp and Cardboard Plant (SPCP), ash from the Heat and Electric Power Plant (HEPP) of SPCP burning coal of the Azeisk deposit, and dung of cattle. The percentage was as follows: lignin tailings, 20 %; bark and wood dust, 20 %; ash of SPCP HEPP, 30 %; dung, 30 %. Physicochemical characteristics of the compost used in experiment are: humidity, 51 %; ash content, 32.8 %; organic matter, 67.2 %; total nitrogen, 2.0 %; C : N, 22.6; total phosphorus, 0.75 %; total potassium, 0.68 %; $pH_{salt,}$ 7.1

At the end of vegetative period, compost, soil and plants were sampled. Macro- and microelemental composition of the samples, the content of mobile forms of chemical elements (extracted by ammonium-acetate buffer solution with pH 4.8) in the samples of soil and compost were determined by atomic absorption. Physicochemical properties of the compost were analyzed using the procedure for the analysis of organic fertilizers [2]. Barley crop capacity was completely taken into account from each allotment. The data were processed by means of variance analysis [3]. Toxicity of the compost under investigation and the soil fertilized by the compost was determined with barley germs by means of soil plates. Petri dishes were filled with even layers of soil without fertilizer (control), soil + compost (1 : 1), compost, wetted with distilled water. Next day, barley seeds (germinating capacity 98 %) were placed on the surface of substrates under examination, 30 seeds per dish. The experiment was carried out at a temperature of 22 °C with triple repetition for six days. On the seventh day, the number of germs was counted, the length of roots and germs was measured. The data obtained for the versions were compared with control. The results were numerically processed according to [4].

In order to estimate overall toxicity of the objects under investigation, biological testing with *Daphnia magna*. The procedure involved the following: 50 ml of aquarium water was poured into each glass beaker with a volume of 100 ml, 10 Daphnia individuals 1–3 days old were put into each beaker, and 1 g of sample under investigation or 0.5 ml of aqueous solution was added. The initial status of Daphnia was recorded. Individuals were considered normal if they were mobile, drifting through water column. In parallel, control (reference) with the same volume of aquarium water was taken. For reliability, the samples under investigation were tested with 50–60 Daphnia individuals. The criterion of toxicity was death of Daphnia individuals within 24 h.

RESULTS AND DISCUSSION

Laboratory investigations of the toxicity of compost under investigation were performed with the help of germ procedure before es-

TABLE 1

The effect of compost on germinating power of seeds and length of barley germs

Version	Germinating power, %			Length, mm					
				Germs			Roots		
	$M + m$	m_d	$M_k - M_i$	$M + m$	m_d	$M_k - M_i$	$M + m$	m_d	$M_k - M_i$
Soil (control)	84 ± 6	–	–	21 ± 2	–	–	28 ± 3	–	–
Soil + compost	96 ± 3	6.7	12.0	28 ± 5	5.4	7.0	34 ± 5	5.8	6.0
Compost	90 ± 5	7.8	6.0	26 ± 4	4.5	5.4	39 ± 6	6.7	11.0

Note. M is arithmetic mean; m is the error of arithmetic mean, m_d is error of the difference, $M_k - M_i$ is the difference between the arithmetic means of the control and version of experiment.

tablishing the field experiment. The results of the laboratory experiment (Table 1) showed that the investigated compost as a fertilizer does not contain phytotoxic concentrations of microelements. The germ phase is characterized by barrier-free accumulation of chemical elements [5]. In case of excess amounts of microelements in the substratum, especially such elements as Hg, Cu, Ni, Pb, Co, Cd, Ag, Be, Sn, various metabolic processes are disturbed, sprout growth and development of roots are inhibited [6]. No inhibiting action of the compost and soil fertilized with the compost on seed germination and on development of barley germs was observed.

The results of experiments with Daphnia demonstrated the absence of acute toxic action for a 24 h exposure to aqueous samples of the ingredients of compost, compost itself, and compost with soil. Among numerous methods of toxicological estimation, the sensitivity of Daphnia is specially marked as being high for biological tests. In the majority of cases, the absorption of compounds by Daphnia is not selective, thus, they can absorb toxic compounds; their presence in the product under investigation causes a complete or partial inhibition of vital functions of the test object. Survival of the experimental individuals in the tested samples was 80–90 %. No deaths of Daphnia were observed in water extracts of the green mass of experimental plants. The data demonstrating that the ash of the coal from the Azeisk deposit, included into the compost under investigation, is almost non-toxic for test objects (Elodea, Nytella, photogenic bacteria, Daphnia).

One of the advantages of the proposed lignin-containing compost is high content of organic matter; its destruction products are the most important ingredients of humus formation [8]. The major part of nutrient elements (nitrogen, phosphorus, potassium) in the fertilizer under investigation is provided by inclusion of cattle dung into the compost (Table 2). In turn, lignin, due to its high adsorption ability, rather strongly retains nitrogen and phosphorus of mobile compounds [9]. The major part of nitrogen and phosphorus present in the compost is incorporated into difficultly hydrolyzed and non-hydrolyzed compounds. The content of nitrate nitrogen in it was 33.1 mg/100 g, ammonium nitrogen 0.03 %, easily hydrolyzed compounds 44.8 mg/kg. The mobile forms of phosphorus accounted for 5.3 % of its total content. The ash from HEPP of the SPCP, used to neutralize the acidic reaction of the compost, brings the oxides of iron, magnesium, calcium, and a substantial part of microelements. The main fraction of manganese is brought into the compost by its organic components (lignin tailings, bark and wood dust) (see Table 2). The presence of cadmium, mercury, arsenic in the fertilizer under investigation did not exceed maximum permissible level in the soil and was 0.2, 0.1, 0.8 mg/kg, respectively, which is much below the standard for organic composts [10].

The results of calculation of the introduction of chemical elements into the plough layer of the alluvial turf medium-loamy soil with the maximal dose of compost (200 t/ha) are shown in Table 3. The effect of the fertilizer under investigation on the chemical composi-

TABLE 2

Chemical composition of the initial components and compost based on them

Composition	Lignin tailings	Bark and wood dust	Dung	Ash from HEPP	Compost	
					Calculation	Analysis
Macroelements, % of the mass of dry substance:						
N_{total}	1.9	0.9	2.25	–	1.76	2.0
P_2O_5	0.9	0.6	125	0.17	0.73	0.75
K_2O	0.2	0.4	1.3	0.65	0.68	0.71
Na_2O	–	–	–	0.20	0.07	–
CaO	–	–	–	3.2	0.51	–
MgO	–	–	–	1.04	0.30	–
Fe_2O_3	1.65	2.4	0.03	8.4	3.34	3.27
Microelements, mg/kg of the dry mass:						
Mn	600	1000	220	300	476	465
Cu	20	30	10	50	28	23
Co	5	5	0.3	10	5.1	4.3
Ni	5	5	1.0	20	8.3	5.2
Pb	6	20	1.5	10	8.7	7.4
Cd	not detected	not detected	not detected	0.2	0.06	<1
Zn	40	60	50	100	65	69.2
Cr	20	not detected	4.2	30	14.3	14.7
Mo	2	0.4	0.07	1.5	0.95	<1

Notes. 1. Be, W, Se were not detected. 2. Dash means «was not determined».

tion of the soil is of complex character. By introducing the compost into the soil, not only the content of nitrogen, phosphorus and potassium increases; so do microelements. On the other hand, as a result of introduction of the compost made of industrial wastes, one cannot exclude the possibility of the accumulation of chemical elements in increased toxic concentrations. For instance, nitrogen content increases by 27 % when the compost dose of 200 t/ha is introduced into the plough layer. It should be noted that the major part of nitrogen in this fertilizer is represented by the forms unavailable for plants. Easily hydrolyzed and mineral nitrogen compounds account for only 4 % of its total content in the compost. The accumulated amount of phosphorus increases substantially, too, due to the introduction of the compost into the soil. However, in this case the major part of its compounds is represented by low-mobile forms. In the opinion of some authors [12–14], fertilizers based on lignin are of slow action; the duration of their action is not limited by one year. A noticeable increase in the level of iron-containing compounds is observed in the soil fertilized with the compost. After the introduction of 200 t/ha compost dose, Fe content increases by 8.3 %, but still does not achieve the mean level of iron content of alluvial soils.

The most substantial change in the microelemental composition of the soil of the experimental allotment is observed in versions with the compost doses of 150 and 200 t/ha. In this case, the plough layer of the soil get enriched with Mn, Cu, Co, Ni, Zn-containing compounds. However, microelements are present in the fertilized soil in all the versions of the experiment in amounts several times smaller than the maximum permissible levels for soil (see Table 3). The Hg content of the soil was 0.027 to 0.039 mg/kg in all the versions of the experiment.

An increased (in comparison with the soil of the experimental allotment) content of the mo-

TABLE 3

Introduction of macro- and microelements into the alluvial soil with the compost, mg/kg of the dry mass

Component	Soil (control) without fertilizer	Soil + compost, 200 t/ha		MPC in soil [11]
		1	2	
N_{total}	3000	2000	833	–
P_2O_5	200	750	312.5	–
K_2O	17 000	680	283.3	–
Na_2O	30 000	70	29.2	–
CaO	32 000	510	212.5	–
MgO	15 000	300	125.0	–
Fe_2O_3	15 700	3270	1362.5	–
Mn	272	46.5	19.4	1500
Cu	7.0	2.3	0.96	23
Co	2.0	0.43	0.18	50
Ni	6.0	0.52	0.22	35
Pb	4.0	0.74	0.31	20
Cd	<1	0.09	0.04	3
Zn	40	6.92	2.9	110
Cr	13.0	1.47	0.61	100
Mo	<1	0.1	0.04	5

Note. 1 – introduction of an element into the plough layer of the soil with the compost dose, kg/ha; 2 – an increase in the content of the element in the plough layer of the soil caused by the introduction of the compost dose.

bile forms of Mn, Cu, Co, Cr, Zn is characteristic of the compost under investigation (Table 4). However, when introduced into the soil, the compost caused an increase only in the fraction of the mobile Mn-containing compounds below the phytotoxicity level. According to the data of [6], the trend to decrease the solubility of zinc compounds in the soil is connected with the action of the compost, which causes an increase in the level of phosphorus compounds and the degree of soil saturation with calcium, which decreases the acidity of the soil [6].

Plant organs usually exhibit active reaction to an increase in the concentrations of chemical elements in the soil; their content in plant tissues increases above the level necessary for normal growth [15]. In the case under consideration, phonological observations of the development of barley during the vegetating period did not reveal any examples of phytotoxicity in any version of the experiment.

A reliable increase in the harvest (green mass) of barley was obtained with the compost introduced into the soil at a level of 150,

TABLE 4

Content of mobile forms of microelements in the soil, compost and soil fertilized with the compost (in extract with ammonium acetate buffer solution with pH 4.8), mg/kg of the dry mass

Version	Doza, t/ha	Mn	Cu	Co	Ni	Pb	Cd	Zn	Cr	Mo
Control		32.1	0.20	0.8	0.20	0.30	<0.1	1.07	0.2	<0.1
Compost		90.4	0.70	1.2	0.30	0.50	<0.1	1.76	0.8	<0.1
Soil + compost	50	44.4	0.20	0.8	0.20	0.30	<0.1	1.08	0.2	<0.1
	100	46.9	0.22	0.9	0.22	0.30	<0.1	1.07	0.2	<0.1
	150	47.2	0.25	0.9	0.23	0.29	<0.1	1.02	0.2	<0.1
	200	48.5	0.27	0.9	0.25	0.29	<0.1	1.02	0.2	<0.1
MPC in soil [16]		–	3.0	5.0	4.0	–	0.5	23.0	6.0	–

TABLE 5

The effect of compost made of industrial wastes on barley crop

Version	Barley crop, kg/m^2	
	Green mass	Root residues
Soil (control)	1.40	0.32
Soil + compost, 50 t/ha	1.54	0.36
Soil + compost, 100 t/ha	1.78	0.40
Soil + compost, 150 t/ha	1.96	0.52
Soil + compost, 200 t/ha	2.24	0.60
HCP^*_{05}	0.48	0.04

*Statistical factor used for the processing of data of field experiments.

200 t/ha. The mass of barley root residues in fertilized allotments exceeded the control level by a factor of 1.5–2 (Table 5). An indirect indication of the absence of soil pollution with heavy metals after the introduction of the compost can be macroelemental composition of the experimental plants, since an excess of some microelements (Zn, Hg, Cr, Ni, *etc.*) inhibits the absorption of Fe, K, Ca, Mg by plants [6]. Macroelemental composition of barley grown on allotments with the compost or on the compost as it is exhibited only insignificant differences from the control version; to the contrary, in the major part of cases a trend of some increase in the concentration of Ca, Mg, K, Fe in experimental plants was observed (Fig. 1). Chemical analysis of different organs of barley demonstrated that the content of elements under determination did not reach phytotoxicity level both in compost itself and in soil after the introduction of the compost. Concentrations of microelements in the experimental plants were similar to those of the control plants (Table 6). The largest changes, in comparison with the control plants, were observed in the elemental composition of the barley grown on compost. In all the versions of the experiment, in major part of cases the highest concentrations of microelements were detected in roots. The roots of experimental plants, unlike those of the control plants, were more active in absorbing Mn, Cu, Ni, and less active for Zn, Pb, Cr, Co. These differences are smoothed down in the above ground parts of the plants. Chemical composition of leaves, stems and ears of barley in the soil + compost version only slightly differed from the reference. The concentrations of microelements in plants, for any

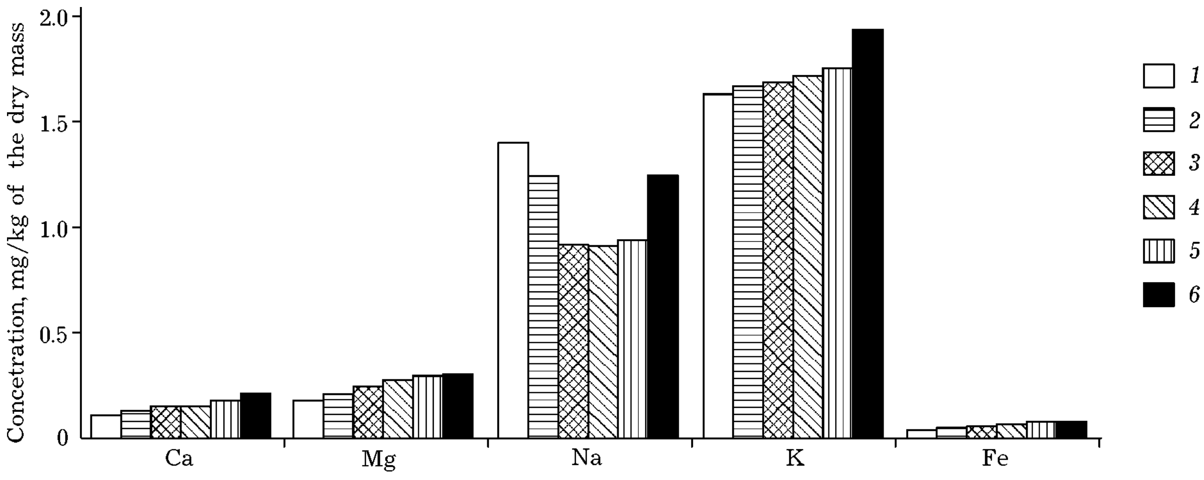

Fig. 1. Changes in the content of microelements in the above ground parts of barley under the action of the compost made of the wastes from the SPCP: *1* – control; *2–5* – soil + compost, t/ha: 50 (*2*), 100 (*3*), 150 (*4*), 200 (*5*); *6* – compost.

TABLE 6

Overall content of microelements in the experimental and control barley plants, mg/kg of the dry mass

Version	Doze, t/ha	Mn	Cu	Co	Ni	Pb	Cd	Zn	Cr	Mo
					Roots					
Control		81.0	2.4	4.1	5.6	3.0	<0.1	110	0.8	<0.1
Compost		300.0	3.7	5.4	6.2	2.0	<0.1	93.0	0.7	<0.1
Soil + compost	50	90.0	2.6	3.0	5.7	3.0	<0.1	79.0	0.6	<0.1
	100	106.0	2.9	3.0	5.9	2.0	<0.1	68.0	0.6	<0.1
	150	106.0	2.9	3.0	6.0	<1.6	<0.1	65.0	0.5	<0.1
	200	109.0	3.2	2.5	6.2	<1.4	<0.1	63.0	0.5	<0.1
					Stems					
Control		18.2	1.4	2.3	<1	<1	<0.1	78.3	0.2	<0.1
Compost		48.0	2.0	3.4	<1	<1	<0.1	76.0	0.2	<0.1
Soil + compost	50	19.3	1.3	3.3	<1	<1	<0.1	77.0	0.2	<0.1
	100	19.0	1.4	3.2	<1	<1	<0.1	76.6	0.3	<0.1
	150	19.0	1.5	3.3	<1	<1	<0.1	73.0	0.4	<0.1
	200	19.5	1.5	3.3	<1	<1	<0.1	73.0	0.3	<0.1
					Leaves					
Control		38.6	1.1	1.3	<1	<1	<0.1	30.0	0.4	<0.1
Compost		35.5	0.54	1.5	<1	<1	<0.1	33.4	0.3	<0.1
Soil + compost	50	20.8	1.1	1.3	<1	<1	<0.1	31.0	0.5	<0.1
	100	32.0	1.1	1.3	<1	<1	<0.1	28.8	0.5	<0.1
	150	32.0	1.2	1.4	<1	<1	<0.1	28.9	0.5	<0.1
	200	35.0	1.3	1.4	<1	<1	<0.1	28.9	0.5	<0.1
					Ears					
Control		22.4	1.7	5.3	<1	<1	<0.1	51.1	0.4	<0.1
Compost		94.0	2.3	4.3	<1	<1	<0.1	57.4	0.7	<0.1
Soil + compost	50	26.0	1.7	5.3	<1	<1	<0.1	50.0	0.5	<0.1
	100	26.0	1.8	5.1	<1	<1	<0.1	48.3	0.5	<0.1
	150	27.0	1.8	5.0	<1	<1	<0.1	47.1	0.5	<0.1
	200	27.8	1.8	5.0	<1	<1	<0.1	47.1	0.5	<0.1
Leave tissues*	–	20–300	5–30	0.02–0.1	0.1–5.0	5–10	0.05–0.2	27–150	0.1–0.5	0.2–1

Note. Hg, As were not detected in samples.

*Normal concentrations of microelements in the mature plant tissues according to the generalized data for many plant species [6].

introduction dose, were within the level of concentrations necessary for normal growth of plants.

CONCLUSION

The results of field and laboratory investigations showed that the compost made of wastes from the Selenga Pulp and Cardboard Plant (lignin tailings, bark, wood dust), Heat and Electric Power Plant (ash of the coal from Azeisk deposit) and cattle breeding (cattle dung), at a dose of 50 to 200 t/ha, did not cause pollution of the soil of the experimental allotment with heavy metals. The content of chemical elements in fertilized soil did not exceed permissible level. Introduction of the fertilizer at a dose of 200 t/ha resulted in an increase in the concentrations of Ca, K, Fe, Mn, Cu in the plough layer in comparison with the reference soil. The content of toxic elements (Hg, As, Cd, Pb, Zn) was much lower than their maximal permissible concentrations in soil. No excess concentrations of microelements were observed in plants grown on soil with compost (doses 50 to 200 t/ha). The roots of experimental plants differed from the reference ones by lower content of Pb, Zn, Cr, Co and higher content of Mn, Cu, Ni. The differences in the chemical composition of the above ground parts of the experimental and reference barley plants are insignificant.

The compost made of industrial wastes can be used in agriculture, forestry, laying out of parks for reclamation of disturbed soil, dumps and ash tailings. Rational utilization of the wastes of the indicated industries will allow one to decrease to some extent the anthropogenic load onto the ecosystem of Lake Baikal.

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