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The content of toxic elements in soil-plant system based on ombrotrophic peat with the copper smelting slag recycling waste

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ABSTRACT

Mining wastes occupy huge areas around the world, therefore, research aimed at their disposal and reclamation of disturbed territories is very relevant. We studied artificial soil based on neutralized ombrotrophic peat (Histosols Fibric) with different content (5% and 10% by weight) of copper smelting slag recycling waste ("technical sand"): finely dispersed (less than 0.05 mm), mechanically activated material. We analyzed the content of toxic element in peat, underground and aboveground parts of lawn grasses and potatoes. The coefficients of concentration and accumulation of elements were calculated. It was found that the introduction of 5% waste leads to exceeding the maximum permissible concentrations and approximately permissible concentrations (the regulated values for Russia) for zinc, copper, arsenic, antimony, and lead. The molybdenum content exceeds the Soil Quality Guidelines accepted in Canada, for selenium the values are at the limit level. The content of zinc, copper, cobalt, arsenic, molybdenum, antimony is significantly reduced (by 2-3 times) during the growing season. Ecological assessment of agricultural plants grown on artificial soil with 5% of "technical sand" showed that there are no excesses of the maximum permissible levels for any regulated element for potato tubers; a slight excess of arsenic was detected for lawn grasses. We additionally assessed the safety of potato tubers using the maximum permissible concentrations for food and established an excess of cadmium (3.4 times on the peat, with the addition of waste almost unchanged) and zinc (1.6 times on peat, 2.8 times for a peat with 10% waste).

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INTRODUCTION

Mining waste occupies huge areas around the world (Sun et al., 2018; Rahmonov et al., 2021; Zhang et al., 2021). In the USA and Western European countries, up to 85–90% of dumps are recycled, whereas in Russia it is only 20-25% (Malyshev, 2013). Non-ferrous metallurgy dumps pose a special environmental hazard due to the high content of heavy metals (Karbassi et al., 2016; Filimon et al., 2021; Luo et al., 2023).

Restoration of soil and vegetation in man-made landscapes is an extremely important environmental task and is solved in two ways: reclamation and self-overgrowing of dumps, the second process is extremely slow in most cases (Tamakhina et al., 2020; Tang et al., 2022; Zolotova, 2021). The reclamation of disturbed landscapes takes place in two stages: mining-technical and biological. The goal of the first stage is to create habitats with specified properties

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and regimes in the substrate, and the main goal of the second stage is to accelerate the restoration of soil- environmental functions and the ecosystem as a whole.

The use of mineral waste from the mining industry for the reclamation of disturbed landscapes will allow solving several urgent environmental problems at once (disposal of dumps, restoration of territories) and contributes to the sustainable development of regions (Antoninova et al., 2020; Mikheeva & Androkhanov, 2022).

The copper smelting slag recycling waste, the so-called "technical sand" (the size of slag particles is less than ≤0.05 mm, waste of hazard class 4-5), has now been accumulated by the Sredneuralsky copper smelter ("SUMZ", Revda) in significant volumes and is promising for the reclamation of disturbed lands of the mining complex (Guman et al., 2020). It is of interest to evaluate the possibility of using this waste as a trace element additive for creating artificial soils, as well as to analyze the safety of agricultural plants grown on such a modified soil substrate.

The researcher (Kotelnikova, 2012) experimentally proved that the copper smelting slag recycling waste is more easily leached by soil solutions, the more they contain organic compounds. As a result of this process, iron, manganese and heavy metals pass into solution in the form of organometallic complexes; finely dispersed fayalite, clay phase are formed. At the same time, finely dispersed hydroxides of iron, aluminum and silicon are formed with sorption of heavy metals on their surface.

The high content of water-soluble organic compounds (20-50 mg/l) is typical for ombrotrophic peat. This substrate consists of sphagnum mosses (Sphagnum fuscum, Sphagnum magelanicum, etc.) of varying degrees of decomposition, has a high acidity (pH 3.5-4.5), low mineral content. A large amount of humic acids in peat provides a high sorption capacity for metals and other trace elements (Boguta et al., 2016; Mayans et al., 2019). The content of extractable humic acids increases by 2-7 times during the mechanochemical treatment of ombrotrophic peat, the maximum - when using alkaline agents (sodium carbonate or hydroxide). Humic acids are converted into sodium humate.

The availability of heavy metals for plants depends on such soil properties as acidity (pH is considered one of the most important factors) (Neina, 2019; Hou et al., 2019), organic matter content (Hou et al., 2019), oxygen saturation (Magnuson et. al., 2001), sorption capacity (Adamovich et al., 2020), microorganism activity (Abdu et al., 2017), humidity and water-holding capacity (Rakesh Sharma & Raju, 2013).

Insufficient amounts of micronutrients in the soil often lead to excessive accumulation of a number of heavy metals in plants (Fijalkowski et. al., 2012). The distribution of chemical elements in plant organs is determined mainly by the properties of the elements and plant species (Minkina et al., 2018). An excess of heavy metals causes disturbances in plant morphology and metabolism (Goyal et al., 2020), suppresses the development of soil microorganisms (Diaconu et al., 2020), which strongly affects the processes of decomposition and transformation of organic matter (Fijalkowski et. al., 2012).

The ecological assessment of soils in Russia is carried out using the maximum permissible concentrations (MPC) and approximate permissible concentrations (APC) of toxic elements (SanPiN 1.2.3685-21). Recommendations on maximum permissible levels of toxic element (MRL) have been developed for agricultural plants (MRL, 1987, SanPiN 2.3.2.1078-01; VetPin 13.7.1-00).

Other countries have developed their own systems for rationing the content of toxic elements, such as Soil Screening Values (SSV), Soil Quality Guidelines (SQG), and they may differ from each other by tens of times (Semenkov & Korolyeva, 2019). For example, for molybdenum: in the Dutch rationing system it is 254 mg/kg (Crommentuijn et al., 2000), and in the Canadian system it is 5 mg/kg for agricultural land and 40 mg/kg for industrial land (CCME). The Netherlands, Finland, Germany, Canada and the USA have relatively similar climatic conditions with Russia, therefore it is of interest to use their standards for the environmental assessment of soils.

The purpose of our research is to analyzed the content of toxic elements in soil-plant system based on ombrotrophic peat with the copper smelting slag recycling waste. The obtained data will make it possible to assess the environmental safety of peat with different contents of "technical sand", as well as the possibility of using this mineral waste as a trace element additive to create artificial soils during the reclamation of disturbed lands.

MATERIALS & METHODS

The experiment was laid on the territory of the Institute of Geology and Geochemistry, Ural Branch of the Russian Academy of Sciences (southwestern part of the city of Yekaterinburg, Sverdlovsk region) (Fig. 1). The climate is the temperate continental, characterized by high variability of weather conditions and well-defined seasons. This climate is considered Dfb according to the Köppen-Geiger climate classification. July is the warmest month of the year: the temperature averages 18.1°C. January is the coldest month, with temperatures averaging -14.7°C. Westerly and southwesterly winds are predominant. The average annual rainfall is 491 mm. Most of the precipitation here falls in July, with an average of 93 mm. The height above sea level is 250 meters. The growing season averages 110 days.

The object of study is an artificial soil based on ombrotrophic peat (neutralized with lime to pH 6.6) with the copper smelting slag recycling waste from the Sredneuralsky copper smelter ("technical sand"). We added waste to the soil in a ratio of 5% and 10% by weight: 9.5 kg of peat per 0.5 kg of waste and 9.0 kg of peat per 1.0 kg of waste. "Technical sand" is a finely dispersed (particle size less than 0.05 mm) material, mechanically activated during crushing of cast copper

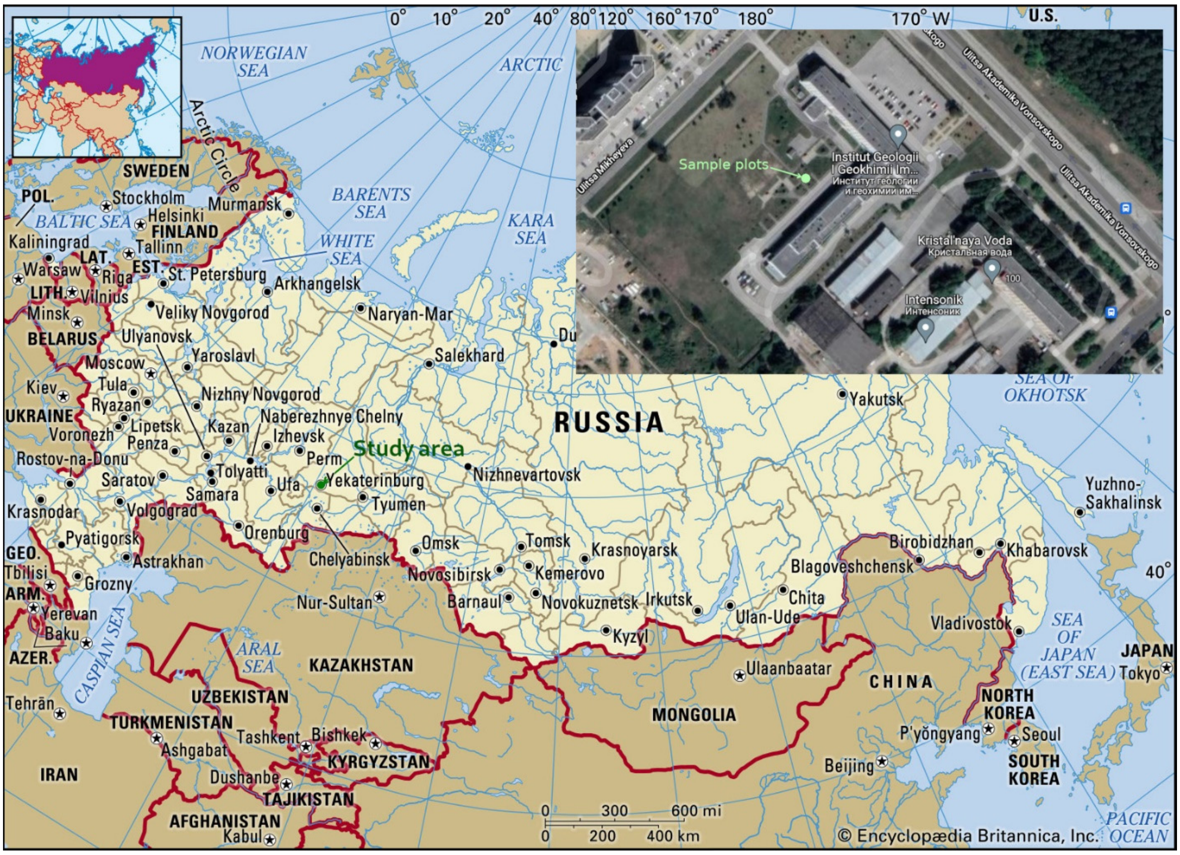

Fig. 1. Study area on the map of Russia and sample plots on the territory of the Institute of Geology and Geochemistry Ural Branch of RAS (southwestern part of the Yekaterinburg city, Sverdlovsk region, Middle Urals)

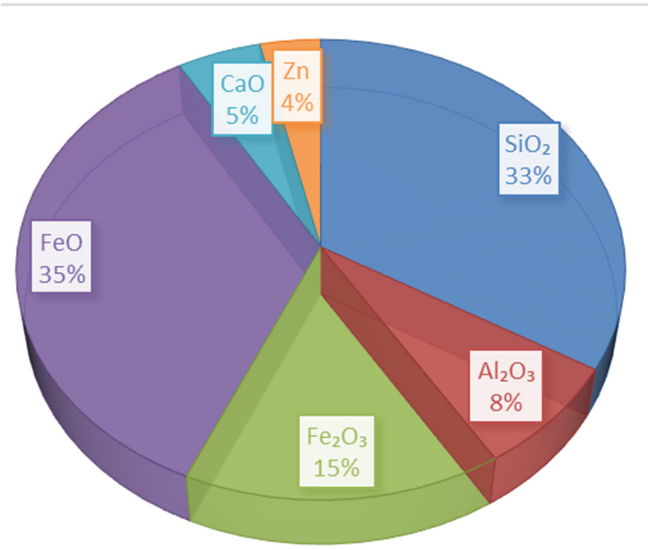

Fig. 2. The content (in weight %) of the main elements in the copper smelting slag recycling waste from the Sredneuralsky copper smelter ("technical sand")

smelting slag, fayalite (Fe_2SiO_4) and ferrous glass predominate in the phase composition. Heavy metals are mainly concentrated in matte and speiss in the form of sulfides and intermetallic compounds (Kotelnikova & Ryabinin, 2018). The main chemical composition of the waste is shown in Figure 2. Arsenic contains 0.53% by weight, copper - 0.44%, lead - 0.2%, mercury – 0% (Kotelnikova & Ryabinin, 2018).

We used potatoes and a mixture of lawn grasses (*Festuca pratensis* Huds. – 30%, *Phlum pratense* L. – 30%, *Lolium perenne* L. – 30%, *Loliym multiflorum* Lam. – 10%) to assess the environmental safety of peat with different content of the copper smelting slag recycling waste. Potatoes were chosen as an object of research to address the issue of the possibility of using "technical sand" in agriculture as a trace element additive. Moreover, the cultivation of potato seedlings on an industrial scale is often carried out in a peat.

We conducted a field experiment from May to August 2017. The plants were watered during planting, and then grew at natural humidity. The precipitation data were obtained from a weather station (Yekaterinburg, latitude 56.83, longitude 60.63, altitude 281 m): May - 37 mm; June – 111 mm; July – 114 mm; August – 50 mm.

The experiment with lawn grasses was carried out on sample plots with an area of 1 m^2 (the substrate is granite screening): the control is the ombrotrophic peat, and 2 plots with peat containing different concentrations of "technical sand" (5% and 10% by weight). The thickness of the soil profile is 15-18 cm. We took samples of lawn grass together with the root part and peat after the growing season (at the end of August). The selection was carried out by an "envelope" method (5 sample points evenly distributed over the test plot - a garden bed). Then its were combined into an average sample for each trial plot: peat, peat + 5% of waste; peat + 10% of waste. The samples were dried at room temperature to a constant weight and then crushed. We took an average sample of the soil, aboveground and underground parts of plants without separation by species. The plant roots were removed from the peat sample at the stage of sifting with a 1 mm sieve, washed in distilled water, dried, crushed and submitted for analysis.

The potatoes were planted in bags with the artificial soil (V_{peat} = 0.45 m^3: soil height in bags is 0.7 m, diameter - 0.45 m) containing 5% and 10% by weight of the copper smelting slag recycling waste (similar to the experiment with lawn grasses). The aboveground part and tubers part were selected at the end of the growing season. The samples were crushed and dried at room temperature.

The chemical composition of the “technical sand”, modified peat, aboveground and underground parts of plants was determined at the “Geoanalytic” Collective Use Center of the Institute of Geology and Geochemistry, Ural Branch of the Russian Academy of Sciences. The analysis was performed by inductively coupled plasma mass spectrometry (ICP-MS) using NexION-300S ICP mass-spectrometer. Sample preparation was carried out by the acid decomposition method: weighed portions (50 mg) were dissolved in an open way in 3 ml of 14M HNO_3 with the addition of 1 ml of 42M H_2O_2 at 150°C. Several state standard samples for soils (GSO, Russia) were used to verify the results of the analysis: State register No. - 2499-83, 2509-83. The obtained element concentrations agree with available reference values to a tolerance of about 15%.

We used the concentration coefficient (Kc) to evaluate the artificial soil. It was calculated as the ratio of the element concentration in the artificial soil to their concentration in the peat. The accumulation coefficient (Kn) was calculated to assess the absorption of toxic elements by plants from artificial soil. It was defined as the ratio of the concentrations of elements in the aboveground and underground parts of plants to their content in the root layer of the soil.

RESULTS & DISCUSSION

The addition of copper smelting slag recycling waste to peat leads to an increase in heavy metals and arsenic (Table 1). The concentration coefficients showed that the strongest increase is observed for zinc (27.5), copper (21.1), antimony (15.3), lead (10.5), molybdenum (9.8), arsenic (5.5). (Fig. 3).

We observed a decrease in the nickel content in the modified peat with an increase in

Table 1. The content of toxic elements in an artificial peat with the copper smelting slag recycling waste, mg/kg

	Waste	MPC, APC* (Russia)	MPC’ (Netherlands)	CCME (Canada)	Peat with different content of waste					
					before experiment (spring)			after experiment (autumn)		
					0%	5%	10%	0%	5%	10%
Mn	331	1500	-	-	207	186	175	257	221	181
Co	65.0	-	33	40	3.10	10.0	20.0	4.46	5.66	8.59
Ni	8.39	80*	38	45	15.8	10.8	9.00	17.1	14.5	10.8
Cu	2123	132*	40	63	15.5	327	669	16.6	104	281
Zn	13600	220*	160	250	74.7	2049	4831	55.0	647	1694
As	495	10*	34	12	6.81	37.6	70.5	6.16	12.7	31.7
Se	3.74	-	0.81	1.0	1.03	0.76	1.17	0.81	0.7	0.8
Mo	149	-	254	5	1.47	14.4	31.0	1.02	4.24	12.6
Cd	5.11	2.0*	1.6	1.4	0.73	1.27	2.11	0.61	0.85	1.43
Sn	19.3	-	19	5	1.86	4.18	5.42	1.67	1.69	3.53
Sb	141	4.5	3.5	20	1.12	17.1	25.1	0.48	3.85	14.1
Pb	1020	130*	40	70	15.3	161	340	15.6	39.7	170
Ba	1046	-	165	750	42.3	131	231	99.1	96	134
Cr	132	-	100	64	9.18	16.2	25.4	14.0	11.7	13.6
V	41.4	150.0	43	130	5.04	6.18	8.16	15.3	10.2	6.26
Tl	0.75	-	1.3	1.0	0.09	0.09	0.1	0.13	0.1	0.1

Note: MPC - the maximum permissible concentrations for gross forms of elements (SanPiN 1.2.3685-21); APC* - Approximately permissible concentrations for gross forms of elements are given for close to neutral soils (SanPiN 1.2.3685-21); MPC’- the maximum permissible concentrations approved in the Netherlands (Crommentuijn et al., 2000); SQG - soil quality guidelines (CCME); “-” - not regulated; “**” - values for farmland.

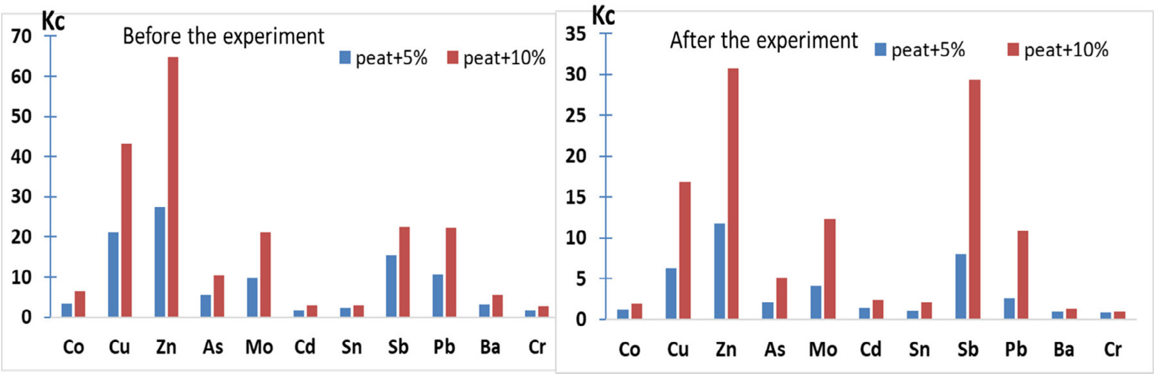

Fig. 3. Concentration coefficient (Kc) of toxic elements in peat with different content of the copper smelting slag recycling waste from the Sredneuralsky copper smelter

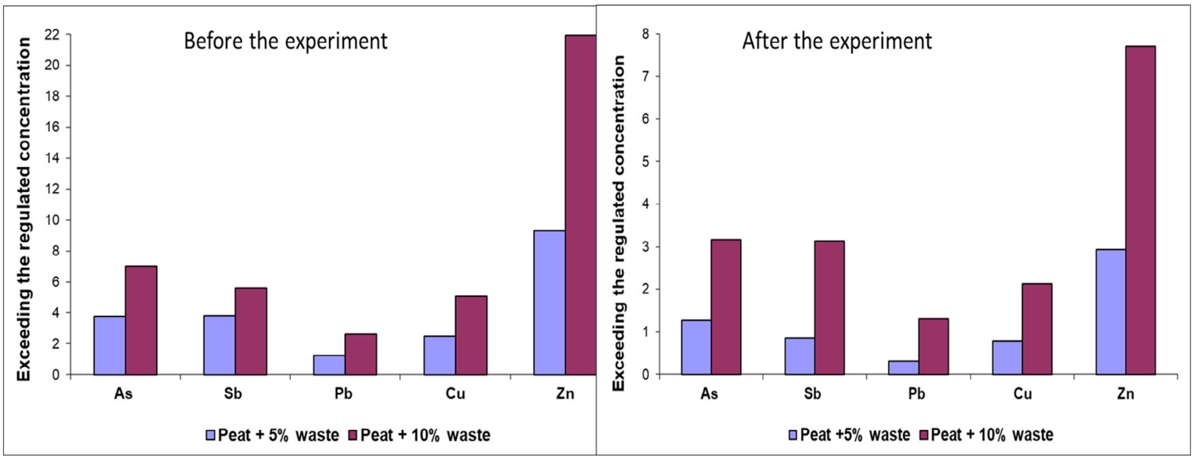

Fig. 4. Exceeding the Maximum permissible (MPC) and approximately permissible concentrations (APC) of toxic elements in peat with different content of the copper smelting slag recycling waste from the Sredneuralsky copper smelter

the proportion of "technical sand", which is most likely due to the dilution effect, since its concentration in peat is higher than in the waste. "Technical sand" is heavier than peat and this effect becomes noticeable.

The concentration coefficient (Kc) clearly shows the degree of soil contamination with toxic elements when "technical sand" is added (Fig. 3). Maximum values are set for zinc (27.5 – peat with 5% of waste; 64.7 - peat with 10% of waste), copper (21.1 – peat with 5% of waste; 43.2 - peat with 10% of waste), and antimony (15.3 – peat with 5% of waste; 22.4 - peat with 10% of waste).

We found exceeding the maximum permissible concentrations and the approximate permissible concentrations for zinc, copper, arsenic, antimony and lead (Fig. 4) in artificial soil with waste. The maximum excesses were noted in the peat with 10% of the copper smelting slag recycling waste for zinc (22 times); for copper - 5.1 times; for lead - 2.6 times.

The values for cobalt, selenium, molybdenum, tin, barium, chromium, and thallium are given in the Netherlands and Canadian systems of rationing of toxic elements (Table 1). Their exceedances for modified peat were revealed only for molybdenum (according to the SQG): peat with 5% of waste – 2.9 times; peat with 10% of waste – 6.2 times. The selenium concentration is at the level of regulated values.

The contents of the studied elements in the peat change significantly during the growing season (Table 1). We found that the antimony content in the peat decreased the most (of the considered elements) (2.3 times) by the autumn under the influence of natural factors. The concentrations of vanadium, chromium, manganese increase.

The most elements content in artificial soil decreases during the growing season. The most significant changes (2-3 times) were found for zinc, copper, cobalt, arsenic, molybdenum, and antimony. The content of vanadium and manganese increased, as well as in the original peat (Table 1). The concentration coefficient also decreased (Fig. 3).

The excess of the maximum permissible concentration for antimony remains for peat with 10% of "technical sand" (Fig. 4). Excesses of approximately permissible concentrations by autumn remain for arsenic and zinc, even for peat with 5% of waste; for lead and antimony - only at a content of 10% of "technical sand", this artificial soil also contains excess molybdenum (2.5 times) according to the Canadian systems of rationing of toxic elements.

During visual control, we did not reveal the relationship between the content of "technical sand" in artificial soil and the condition of lawn grasses growing on it. However, the plants on peat developed slightly slower, which is most likely due to the lack of trace elements.

We conducted a chemical analysis of the aboveground and underground parts of lawn grasses (Table 2) and potatoes (Table 3) to assess the migration of toxic elements from the artificial soil into plants. The elements content in plants is the most informative indicator characterizing the amount and activity of heavy metals in the soil (Selyukova, 2020).

The aboveground part of the studied lawn grasses has a lower concentration of toxic elements in comparison with the roots (Table 2). The maximum difference in content was revealed for the peat with 10% of "technical sand": cobalt - 16.4 times more in the roots than in the aboveground parts of plants; copper - 8.7 times; cadmium - 7.9 times.

We compared the elements content in plants grown on artificial peat with a 10% of the copper smelting slag recycling waste and on the original peat. The maximum increase in content was

Table 2. The content of toxic elements in lawn grasses grown on an artificial peat with different content of the copper smelting slag recycling waste, mg/kg

Element	MRL	Underground part of plants			Aboveground part of plants		
		Peat	Peat+5%	Peat+10%	Peat	Peat+5%	Peat+10%
Mn	-	146	93.8	261	137	64.3	67.6
Co	1.0	2.39	2.15	4.93	0.26	0.14	0.3
Ni	3.0	6.5	5.59	8.79	2.16	1.16	1.44
Cu	30	8.66	22.6	75.9	5.59	4.27	8.75
Zn	50	37.4	121	314	22.5	27.0	56.1
As	0.5	1.88	2.77	5.13	0.6	0.58	1.39
Mo	1.0	1.22	1.5	1.92	1.72	1.76	2.01
Cd	0.3	0.87	1.06	1.46	0.2	0.1	0.18
Sn	-	0.53	0.4	0.44	0.16	0.06	0.1
Sb	0.5	0.24	0.8	1.53	0.1	0.11	0.51
Pb	5.0	4.11	7.3	13.5	1.55	1.03	3.15
Ba	-	28.1	26	31.6	44.8	40.8	27.1
Cr	0.5	2.1	1.51	2.48	2.3	0.94	1.36
V	-	1.9	1.12	1.92	1.11	0.38	0.49
Tl	-	0.19	0.24	0.25	0.09	0.07	0.06

Note: MRL - the maximum permissible levels of toxic elements for agricultural plants (rough and succulent animal feed) (VetPin 13.7.1-00; MRL, 1987); "-" - not regulated. Mercury was not considered, since it is not contained in the waste established for the following elements: copper (roots 8.8 times/ aboveground part 1.6 times); zinc (roots 8.4 times / aboveground part 2.5 times); antimony (roots 6.3 times/ aboveground part 5.2 times) and lead (roots 3.3 times/ aboveground part 2 times) (Table 2). However, the concentration of such elements as vanadium (2.3 times higher than in plants on a peat with 10% of waste), manganese (2 times), chromium and barium (1.7 times), tin (1.6 times) is higher in the aboveground parts of the lawn grasses growing on peat.

The accumulation coefficients of elements (Kn) for the underground part of lawn grasses grown on peat and on artificial soil with 5% of the copper smelting slag recycling waste differ slightly (Fig. 5). Exceptions are the following elements: molybdenum (Kn in peat/peat+5% =

Table 3. The content of toxic elements in potatoes grown on the artificial peat with different content of the copper smelting slag recycling waste, mg/kg

	MRL	MPC**	MAL	Potato tubers			Aboveground parts of potato		
				Peat	Peat+5%	Peat+10%	Peat	Peat+5%	Peat+10%
Mn	-	-	500	3.87	3.42	3.55	149	193	167
Co	2.0*	-	50	0.05	0.04	0.07	0.58	0.72	0.64
Ni	3.0	-	67	0.29	0.26	0.28	3.84	4.99	4.16
Cu	30	-	73	2.77	2.81	3.78	8.35	11.5	11.7
Zn	100*	-	100	16.0	13.1	28.2	25.0	37.5	44.8
As	0.5	0.2	-	0.07	0.07	0.08	0.7	1.07	0.9
Mo	2.0*	-	-	0.3	0.19	0.28	0.65	0.63	0.85
Cd	0.3	0.03	0.1	0.1	0.08	0.1	1.48	1.78	1.44
Sn	-	-	-	0.07	0.04	0.03	0.71	0.6	0.54
Sb	0.5	-	-	0.06	0.06	0.07	0.33	0.43	0.43
Pb	5.0	0.5	0.3	0.45	0.31	0.42	2.78	3.35	3.33
Ba	-	-	-	1.13	1.1	1.32	108.0	88.0	96.1
Cr	0.5	-	-	0.18	0.26	0.19	3.27	3.09	3.12
V	-	-	-	0.05	0.02	0.02	1.61	1.5	1.36
Tl	-	-	-	0.22	0.09	0.11	0.07	0.03	0.04

Note: MRL - the maximum permissible levels for agricultural plants (MRL, 1987); * - values for root crops; MPC** - the maximum permissible concentrations for fresh and frozen vegetables (SanPiN 2.3.2.1078-01); MAL - the maximum allowable limits of heavy metals in vegetables have been established by Food and Agricultural Organization (FAO) (Chiroma et al., 2014).

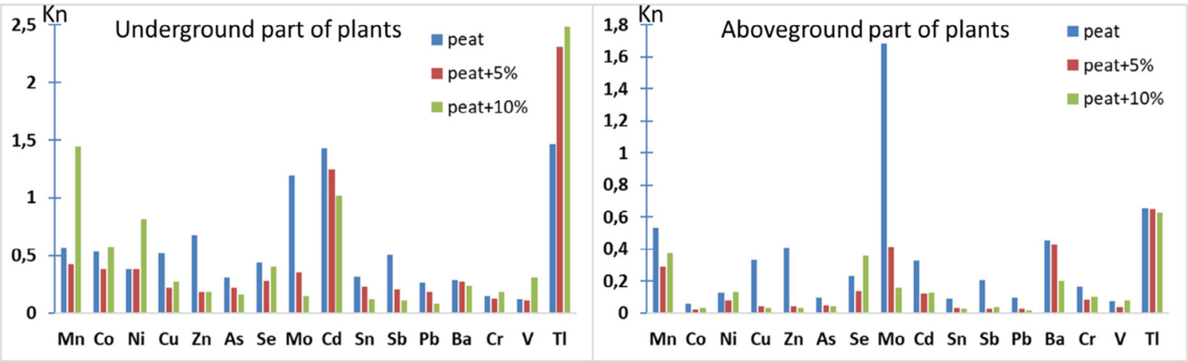

Fig. 5. The accumulation coefficient of toxic elements for lawn grasses grown on ombrotrophic peat with different content of the copper smelting slag recycling waste

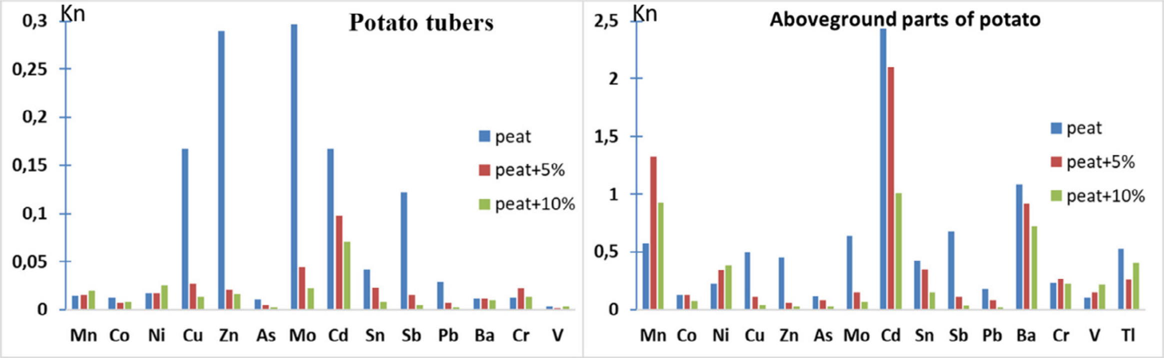

Fig. 6. The accumulation coefficient of toxic elements for potatoes grown on ombrotrophic peat with different content of the copper smelting slag recycling waste

1.19/0.35), thallium (1.47/2.31). The minimum elements accumulation in the roots on peat with 5% waste was found for vanadium (Kn=0.11), and the maximum - for thallium. The element accumulation in the underground part of plants changes more noticeably with an increase in the concentration of “technical sand” in peat up to 10%. The accumulation coefficients are minimal for lead (Kn in peat/peat+10% = 0.26/0.08), antimony (0.51/0 .11), tin (0.32/0.12); maximum - for the thallium (1.47/2.48). The addition of “technical sand” into peat had a more significant effect on the ability to absorb toxic elements for the aboveground parts of the lawn grasses than for the roots. The minimum accumulation coefficients have been identified for cobalt, lead, antimony; maximum - for the thallium (Fig. 5).

Ecological expertise showed that lawn grasses grown on neutralized ombrotrophic peat do not exceed the established values of maximum permissible levels of toxic elements (MRL) of heavy metals (VetPin 13.7.1-00), but exceed the previously regulated values (MRL, 1987) for chromium (4.6 times) and molybdenum (1.7 times). A slight excess of the maximum permissible level of arsenic was found when adding 5% “technical sand”. We found that lawn grasses grown on artificial peat with 10% waste exceeded the MRL for arsenic (by 2.8 times), chromium (by 2.7 times) and molybdenum (by 2 times); the limiting concentration for zinc and antimony has been reached (Table 2).

Ecological expertise showed that lawn grasses grown on neutralized ombrotrophic peat do not exceed the established values of maximum permissible levels of toxic elements (MRL) of heavy metals (VetPin 13.7.1-00), but exceed the previously regulated values (MRL, 1987) for chromium (4.6 times) and molybdenum (1.7 times). A slight excess of the maximum permissible level of arsenic was found when adding 5% “technical sand”. We found that lawn grasses grown on artificial peat with 10% waste exceeded the MRL for arsenic (by 2.8 times), chromium (by 2.7 times) and molybdenum (by 2 times); the limiting concentration for zinc and antimony has been reached (Table 2).

The aboveground part of potatoes grown on peat with the “technical sand” contains a higher concentration of toxic elements compared to tubers (Table 3). The maximum difference was noted for vanadium, barium and manganese, these elements are 60-80 times more contained in leaves and stems of potatoes than in tubers.

We compared the concentration of toxic elements in potatoes grown on the original peat and on the peat with 10% of the copper smelting slag recycling waste, the largest increase in the content was found for the following elements (Table 3): zinc (concentration in tubers and aboveground parts is 1.8 times higher on the artificial soil); copper and cobalt (tubers and aboveground parts by 1.4 times). However, some elements have a higher concentration in potatoes grown on peat compared to the artificial soil with 10% of "technical sand": tin (2.5 times in tubers / 1.3 times in the aboveground part), vanadium (2.1 times in tubers / 1.2 times in the aboveground parts) and thallium (2 times in tubers / 1.7 times in the aboveground part).

The accumulation coefficients (Kn) showed that element absorption by potatoes grown on peat and on artificial soil is different (Fig. 6). Such toxic elements as thallium, molybdenum, copper, zinc, lead, antimony accumulate more strongly in potato tubers grown on peat than on an artificial soil with different content of the copper smelting slag recycling waste. On peat, the maximum accumulation coefficients were found for thallium (1.69), molybdenum (0.3), zinc (0.29), and cadmium (1.17); minimum coefficients - for vanadium (0.003), arsenic and barium (0.011). For an artificial soil, the maximum accumulation coefficients were also found for thallium (peat + 5% - 0.88; peat + 10% - 1.1) and cadmium (peat + 5% - 0.1; peat + 10% - 0.07); the minimum - for vanadium (peat + 5% - 0.002; peat + 10% - 0.004), arsenic (peat + 5% - 0.005; peat + 10% - 0.003). Other trends in element sorption were revealed for the aboveground part of the potato. The maximum accumulation coefficients are revealed for cadmium and barium. Most toxic elements accumulate more strongly in the stems and leaves of potatoes grown on peat than on artificial soil, with the exception of manganese, nickel, and vanadium (Fig. 6).

Exceeding the maximum allowable levels was not detected in potato tubers grown on the peat and on the artificial soil with "technical sand". Exceeding the maximum permissible concentrations (MPC) for cadmium (by 3 times) in potatoes are established using regulated values for food products (vegetables) (SanPiN 2.3.2.1078-01). The addition of waste to peat did not lead to an increase in the concentration of regulated elements (cadmium, arsenic, lead) for potato tubers.

CONCLUSION

The our field experiment showed that the addition of 5% of the copper smelting slag recycling waste to neutralized ombrotrophic peat leads to soil contamination with heavy metals (metalloids). We have shown the maximum and minimum concentration coefficients for the obtained artificial soil, illustrated the excess of the maximum permissible concentrations for regulated (in different countries) toxic elements. The concentration of most elements (also their concentration coefficients) significantly decrease (especially for zinc, copper, cobalt, arsenic, molybdenum, antimony) towards the end of the growing season. By autumn, exceeding regulated values (approximately permissible concentrations) for peat with 5% of waste was established only for arsenic and zinc.

The aboveground part of lawn grasses has a lower concentration of toxic elements in comparison with the roots: the maximum difference was noted for cobalt, copper and cadmium. The aboveground part of potatoes contains a higher concentration of heavy metals (metalloids) compared to tubers: the maximum difference was noted for vanadium, strontium, barium, and manganese. The accumulation coefficients clearly showed the features of the absorption of toxic elements by the aboveground and underground parts of the studied plants grown on neutralized peat and on an artificial soil with different contents of "technical sand". It has been established that the roots of lawn grasses and potato tubers accumulate heavy metals worse in artificial soil than in peat.

The environmental assessment of agricultural plants showed that the introduction of 5% "technical sand" does not lead to an excess of the maximum allowable levels of any element for potato tubers, and to a slight excess of arsenic for lawn grasses. Excesses in cadmium (with the addition of waste almost does not change) and zinc in potato tubers were detected using the maximum permissible concentrations of elements for vegetables.

Based on the results obtained, we consider that the use of "technical sand" as a trace element additive to create artificial soils for the reclamation of disturbed areas is quite promising, but it is worth conducting additional interdisciplinary research and considering a dosage of less than 5% of waste.

GRANT SUPPORT DETAILS

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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