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Microelement composition of soil and vegetation in a forest-steppe reserve in technogenesis conditions

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Abstract
In Troitsk forest-steppe reserve studied microelement composition of soils and vegetation. The reserve occupies an area of 1200 hectares and is a reserved area of black soils and meadow steppes surrounded by technologically loaded territories of Transurals. Humus horizons of black soils and meadow solonetzes are enriched in Zn, Pb, Cu, Co, V, Ni, Mn, Cr, Ti. Content of these elements is several times higher than global and regional clarks and due to a combination of geochemical and anthropogenic factors. Accumulation of heavy metals in the aboveground parts of herbal plants is slightly different from the average for terrestrial vegetation and neighboring regions. The heavy metal content in the roots is usually several times higher than in the aboveground parts. Plants were incubated on the solutions of lead and nickel. Localization of metals was found in the cell walls of cortex and periderm of underground organs by histochemical method.

Keywords: Forest-steppe reserve; pollution; microelement composition; forming rocks; soils; plants; the barrier role of the rhizome.

Introduction

Interaction of plants with soil, especially the microelement metabolism has a twofold character. On the one hand, plants regulate the absorption and accumulation of metals, maintaining the genotypically specified "microelement homeostasis"; on the other hand, they cannot completely neutralize a "geochemical pressure" of the environment with an increase in concentrations of elements in soils above the optimum. Ilyin (1991) defines these factors as genotypic and environmental.

With the development of the heat power, metal, mining, and chemical industries the pollution of soils by the artificially produced substances happens everywhere. Plants are able to grow on soils contaminated with a large number of various microelements. Metal tolerance develops rather quickly and has a genetic basis. Evolutionary changes caused by heavy metals have been found in a large number of species growing on soils enriched with metals. These changes distinguish the plants from populations of the same species growing on normal soils [1-4]. Implementation of genetic possibilities of the higher plants during adaptation to pollutants is of particular importance for the conservation of biodiversity in reserve areas located in technologically loaded regions.

The Troitsky forest-steppe reserve occupies an area of approximately 1,200 hectares and is a reserved piece of black soil and meadow steppes surrounded by technologically loaded territories of Transurals. Studies were conducted on the black soil and meadow-solonetz observation stations of the reserve. *Stipa zalesskii* and *Stipa pennata* are the edificators of the vegetation cover on the ordinary, medium, medium-humic, heavy loamy black soil; they make up 30-45% of the cover. Medium-natric, medium columnar meadow solonetzes, and high columnar, clay solonetzes are solonchak-like and characterized by the medium salinity, mixed chemistry of salinization with the participation of soda. Vegetation cover of the meadow solonetz is formed by various factors of grass-fescue steppes, the edificator is *Festuca sulcata* (*Hack.*) *Nym.*, also there grow species typical of saline soils (*Artemisia nitrophilous*, *Plantago cornuti*, *Silaum silaus*).

The purpose of this work is to assess the level of accumulation of some microelements in soils and plants of this protected area.

Materials and Methods

Samples of the humus horizon of black soil and solonetz were taken from the depth of 0-10 cm in ten locations to determine the content of microelements. Plant material was collected in five locations for each test species. The following species were used to study the chemical composition on the black soil: *Stipa pennata L.*, *Inula hirta L.*, *Galium ruthenicum Willd.*, *Fragaria viridis* (*Duch.*) *Weston*, *Genista tinctoria* (*L.*) *Maxim.*, on the meadow solonetz – *Filipendula ulmaria Juss*, *Artemisia pontica L.*, *Festuca sulcata* (*Hack.*) *Nym.*, *Artemisia nitrosa Web.*, *Plantago cornuti Gouan*, *Galatella biflora* (*L.*) *Nees.* Heavy metal content was determined with a spectrograph DFS-1 by an atomic absorption method with the vaporization of the carbon electrode sample and the control of measuring accuracy on standard samples.

To study the distribution of lead and nickel in plants, a histochemical method was used [5], based on the coloration of slices of the living root and stem with dithizone and dimethylglyoxime. Selected plants of *Filipendula ulmaria Juss*, *Galatella biflora* (*L.*) *Nees*, *Artemisia pontica L.* were transplanted into containers with $Pb(NO_3)_2$ and $NiCl_2$ solutions in concentration 10^{-4} and 10^{-3} M and incubated on the solutions. Localization of lead and nickel in the tissues of roots and stems was measured after 1, 24, 48, 72, and 120 h of incubation.

Significance of differences in the microelement composition of the soil samples and above and below ground parts of plants was evaluated statistically and by analysis of variance.

Results and Discussion

The Chelyabinsk region is located on the territory of ancient and badly damaged Ural Mountains. Previously hidden in the depth, rocks are exposed and, under the influence of external factors, metals are released and migrated. Here, large deposits of minerals are developed – titanomagnetite, chromite, copper, nickel, which can serve as a source of spread of metals in the surrounding areas. The main parent rock material in the reserve is a yellow-brown loam characterized by a high content of Ni, Ti, Cu, Mn compared with the percentage abundance in lithosphere, the amount of chromium in them is 5.5 times higher (Table 1).

Air pollutants in the region are the enterprises of fuel energy, coke, and electrode; among the most hazardous pollutants there are lead, hexavalent chromium, and manganese. According to studies, humus horizons of black soil and solonetzes are enriched in microelements relative to the parent rock material (Table 1). In black soil, they are characterized by significant accumulation of Co, V, Ti, Pb, and Zn, and in meadow solonetz, Mn is accumulated in addition to these elements; the quantity of V in soils

Table 1: Content of microelements in soils (layer 0-10 cm) and in the parent rock, mg/kg of the burnt soil.

Element	Content in the parent rock	Content in the black soil	Content in the solonetz	Percentage abundance in lithosphere (according to Vinogradov)	Percentage abundance in soil (according to Vinogradov)
Ni	84	83	90	58	40
Co	16	**20**	**25***	18	8
Cr	460	344	**320**	83	200
Mn	1,140	1,278	**1,660***	1,000	850
V	108	**213**	**236**	100	100
Ti	5,200	**6,111**	**7,000**	4,500	4,600
Cu	86	89	95*	47	20
Zn	54	**220**	**253**	85	50
Pb	10	**42**	**54***	10	10
Mo	3	2	2	2	2

Note: Bold text denotes significantly different data on the content of microelements in the soil relative to parent rock.
*Significant increase in the content of microelements in solonetz compared with black soil.

is 2 times higher, Pb and Zn – 4 times higher than in parent rock material. Apparently, the modern microelement composition of soils in the reserve is formed by both natural (geochemical) and technogenic factors; pollutants including those related to the work of Troitsk GRES are deposited in the surface layers of soil. Technogenic elements are redistributed in the soil cover, as solonetzes lower plains contain significantly more Co, Mn, Cu, Pb compared with the black soil of low ridges.

Comparison with the world percentage abundance in soils (according to Vinogradov) has shown that the concentration of Zn, Pb, Cu is 4-5 times exceeded and the concentration of Co, V, Ni, Mn, Cr, Ti is 1.5-2.5 times exceeded (Table 1). The average content of heavy metals in soils of the south of Western Siberia [6] is 5 times exceeded for Cr, and 2-3 times for other heavy metals (except Mo). According to Ilyin (1995), the level of accumulation of Ni, Co, Mn, V, Cu can be estimated as medium (tolerant) and the concentration of Cr, Zn, Pb is approaching to high (dangerous). Thus, the soil cover of the forest-steppe reserve suffers from the technogenic pollution apparently connected to the aerial transfer of pollutants. Due to the natural and technogenic environment, it is noted an elevated level of accumulation of the studied microelements except Mo in humus horizons of the soil. Content of microelements in the aerial parts of plants growing in the same soil was several times different (Table 2). Apparently, the plants maintain a genotypically predetermined "microelement homeostasis", which can be particularly ensured by the barrier function of the root system. Metals are bound by the cell walls and it is assumed that a change of carbohydrate composition of the cell walls has a particular importance in this [1, 7-12].

Plants growing on black soils and solonetzes of the forest-steppe reserve are rich in chromium, but poor in zinc compared to the world percentage abundance (according to Dobrovolsky) and to the regional values in the south of Western Siberia [1] and in Transurals near Orenburg [13]. Plants may be slightly different by the content of other microelements upward or downward relative to the percentage abundance. Consequently, plants of the reserve growing in high soil geochemical background conditions accumulate some trace elements only insignificantly, showing at the same time the species-specific features. Among the plants being studied stands out the meadowsweet (*Filipendula ulmaria Juss*) in connection with a high content of most microelements. Cereals showed low content of Mn.

Importance of the barrier function of the root system of plants growing in high soil geochemical background conditions of Transurals was found when comparing the content of microelements in the aboveground and underground parts of plants; an increased number of them in the roots was noted in more than 80% of cases. Vazhenin (1984) proposed to use the accumulation factor – ratio between the content of elements in the underground and aboveground

Table 2: Average content of microelements in the aboveground parts of plants, mg/kg of dry weight.

Species	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Mo
Stipa pennata L.	4.8	0.4	5.1	34.5	2.3	87.0	5.9	5.3	1.8	0.1
Inula hirta L.	8.8	1.5	4.0	388.6	2.4	29.1	10.6	12.1	1.2	0.3
Galium ruthenicum Willd.	3.4	0.5	3.3	99.7	1.6	21.3	4.6	9.2	1.1	0.2
Fragaria viridis (*Duch.*) *Weston*	9.2	1.2	6.3	221.0	2.1	34.0	13.8	11.9	5.1	0.3
Genista tinctoria (*L.*) *Maxim.*	4.9	0.6	2.4	118.0	0.8	9.5	10.9	4.8	0.8	0.6
Filipendula ulmaria Juss	9.8	1.1	9.4	420	4.6	108	11.0	23.0	2.4	0.9
Artemisia pontica L.	5.4	0.5	6.2	124	5.4	49	9.7	5.5	0.8	0.2
Festuca sulcata (*Hack.*) *Nym.*	7.6	0.5	12.6	32	2.1	19	6.4	13.9	2.0	0.2
Percentage abundance according to Dobrovolsky	2.0	0.5	1.8	202	–	–	8.0	30.0	–	0.5
Content according to Ilyin (1991)	8.1	0.3	1.3	105	–	–	10.0	53.3	4.0	0.9
Content according to Groshev and Grigoryeva (2006)	0.5-2.1	0.1-0.2	0.1-0.6	27.5-75.0	–	–	3.0-14.3	10.2-35.8	0.1-1.3	–

organs – as a bioindicator of the early phase of soil pollution [14]. Accumulation factor reflects the adaptive capacity of plants and is determined by properties of the soil and plants.

According to the accumulation factor in the roots of the plants of the reserve the amount of Co, Cr, Mn, V, Ti, Cu, Zn, Pb, Mo is 2-16 times higher than in aboveground organs (Table 3). The barrier function of the root system regarding to nickel is poorly expressed, the accumulation factor of six plants is 1, 4-1, 8; three species did not show the nickel accumulation in the roots.

Meadowsweet (*Filipendula ulmaria*) tends to have decreased accumulation factors of microelements in the underground parts of the plant; as indicated above, the absence of the barrier defense mechanisms led to the increased content of microelements in the aboveground parts of the plant. Experimental data on the incubation of plants in salt solutions has shown the importance of physiological barriers to the admission of microelements, the difference in microelement's behavior, and the species-specific features of the regulation of microelement "homeostasis". Results on the localization of Pb in the tissues of the roots of the *Fragaria viridis*, *Filipendula ulmaria,* and *Artemisia pontica* are shown in Table 4.

After the first hour of incubation, Pb was found in the cell walls of periderm of the rhizomes of all the plants, wherein a small amount of the metal was also found in the outer layers of the cortex of the *Filipendula ulmaria*.

Table 3: Microelements accumulation factor in underground parts of the plants as compared with the aboveground parts (data on the content in ash).

Species	Ni	Co	Cr	Mn	V	Ti	Cu	Zn	Pb	Mo
Genista tinctoria (L.) Maxim.	0.9	1.6	4.4	0.8	6.0	14.5	1.5	2.3	5.1	0.8
Inula hirta L.	0.8	1.0	6.0	0.6	4.4	10.0	1.4	1.7	3.2	4.9
Fragaria viridis (Duch.) Weston	1.6	2.2	5.4	1.3	8.1	15.7	2.1	3.3	1.2	3.3
Galium ruthenicum Willd.	1.7	2.0	8.4	1.1	2.6	9.6	1.6	2.2	1.4	2.7
Filipendula ulmaria Juss	0.8	1.3	1.3	0.4	1.8	2.1	1.2	1.1	1.0	0.7
Galatella biflora (L.) Nees.	1.4	1.9	2.3	1.2	1.7	13.7	1.9	3.7	8.6	2.2
Plantago cornuti Gouan	1.8	1.4	2.6	2.7	7.5	10.6	4.1	4.1	13.6	1.0
Artemisia pontica L.	1.4	1.6	1.0	1.7	4.1	1.6	1.0	1.3	1.3	1.5
Artemisia nitrosa Web.	1.7	2.2	2.6	2.2	4.1	3.6	2.1	4.4	3.7	0.6

Table 4: Distribution of Pb in the tissues of rhizome of the plants.

Species	Time (h)	Periderm	Outer bark	Inner bark	Endoderm	Pericycle	Vascular bundles
Fragaria viridis (Duch.) Weston	1	+	–	–	–	–	–
	24	++	+	–	–	–	–
	48	++	+	–	–	–	–
	72	++	+	–	–	–	–
	120	+++	++	–	–	–	–
Filipendula ulmaria Juss	1	++	+	–	–	–	–
	24	++	+	–	–	–	–
	48	+++	+	–	–	–	–
	72	+++	++	+	–	–	–
	120	+++	++	+	–	–	–
Artemisia pontica	1	+	–	–	–	–	–
	24	+	–	–	–	–	–
	48	++	++	–	–	–	–
	72	++	++	–	–	–	–
	120	+	+	–	–	–	–

Note: – no coloring, + very weak, ++ weak, +++ strong, ++++ very strong coloring.

Table 5: Distribution of Ni in the rhizome tissues of the plants.

Species	Time (h)	Periderm	Outer bark	Inner bark	Endoderm	Pericycle	Vascular bundles
Fragaria viridis (*Duch.*) *Weston*	1	+++	++	–	–	–	–
	24	+++	++	++	++	++	++
	48	++++	+++	+++	+++	+++	+++
	72	++++	++++	++++	+++	+++	+++
	120	++++	+++	+++	+++	++++	++++
Filipendula ulmaria Juss	1	++	+	–	–	–	–
	24	+++	+++	++	++	+	+
	48	+++	+++	+++	++	++	++
	72	++++	++++	++++	++	++	+++
	120	++++	+++	+++	+++	+++	++++
Artemisia pontica	1	++	+	–	–	–	–
	24	++++	+++	+++	++	++	++
	48	++++	++++	+++	+++	+++	+++
	72	++++	+++	+++	++++	++++	++++
	120	++++	+++	+++	++++	++++	++++

Note: – no coloring, + very weak, ++ weak, +++ strong, ++++ very strong coloring.

After 24 h of incubation, cell walls of the periderm showed weak coloring. The coloring of the outer bark of *Fragaria viridis* and *Filipendula ulmaria* was very weak. The localization of Pb in the bark cells of the *Artemisia pontica* was not found. Over time (48-120 h), the coloring of the periderm slightly increased, which testifies the increase of the concentration of the metal, while the coloring of the outer bark remained weak or very weak. After 48 h of incubation, there were observed weakening of turgor of cells and emergence of brown spots on the leaves. By the end of the experiment, a significant mucilaginization and destruction of periderm and bark cells were observed.

Distribution of Ni in the root tissues was markedly different from the localization of Pb (Table 5).

Within 24 h, Ni was detected in all tissues of the root – from the periderm to the vascular bundles. The strongest coloring and, thus, the highest metal content were noted in the periderm and bark. Over time, the concentration of Ni in the conductive tissues increased, after 120 h a very strong staining was observed. It was detected a slight concentration of Ni in the conducting tissues of aboveground organs, although the coloring in aboveground organs was weaker than in underground.

As described previously, the studied species show a differential accumulation of metals; barrier absorption of Pb by the rhizome tissues causes its comparatively low accumulation in aboveground organs, and a weak manifestation of the rhizome barrier mechanisms with respect to Ni determines its increased accumulation in aboveground parts.

Conclusions

1. Soils of the forest-steppe reserve in Transurals suffer from the technogenic pollution apparently connected to the aerial transfer of pollutants, due to the natural and technogenic environment in humus horizons of the soil it is noted an elevated level of Zn, Pb, Cu, Co, V, Ni, Mn, Cr, Ti.
2. Plants of the reserve under the conditions of high content of heavy metals in soils slightly accumulate some microelements showing the species-specific features at the same time.
3. As a rule, the amount of the heavy metals in the rhizome of plants is few times higher than in the aboveground organs; it is marked their localization in the periderm and bark cell walls.

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