Zinc in Environmental Objects of Transbaikalia

V. K. KASHIN

Institute of General and Experimental Biology, Siberian Branch of the Russian Academy of Sciences, Ul. Sakhyanovoy 6, Ulan Ude 670047 (Russia)

E-mail: kashin@biol.bscnet.ru

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Abstract

The content of zinc in abiotic components (soil-forming rocks, natural waters, soils) and plants of forest-steppe, steppe, arid steppe and floodplain landscapes of Transbaikalia has been studied. A complex character of zinc distribution in environmental objects have been revealed: the content of zinc in soil-forming rocks and the soils of steppe and arid steppe landscapes approximately corresponds to the clarke, being for the rocks and soils of the forest-steppe landscapes equal to 0.4–0.7 of the clarke. It has been established that a deficient content of zinc (20–80 %) in the vegetation of steppe, meadow and agricultural landscapes is inherent in the most part of the territory under investigation.

Key words: zinc, distribution, soil-forming rocks, natural waters, soils, plants, landscapes

INTRODUCTION

Zinc represents a vitally important microelement for all the taxonomic groups of organisms on condition that its content is normal. At the same time it is a hazardous toxicant when superfluously contained in an organism.

Zinc is involved in the structure of about 300 enzymes those belong to all six classes listed in the catalogue of enzymes, and in the structure of hormones (thymulin, prolactin, somatin). This element supports the structure of more than 200 proteins, transcription activators those participate in the genetic information transfer [1, 2]. Due to this fact zinc can be considered to be a unique microelement: none microelement forms such a number of bioinorganic compounds (bioclusters) and exhibits so many various functions. The most important enzymes containing zinc include carbonic anhydrase providing the hydration of CO_2 in biological systems, and superoxide dismutase catalyzing the disproportionation of superoxide ion (O_2^-) and playing an important role in the protection of cells from free radicals [3]. Zinc-containing enzymes take part in the metabolism of proteins, carbohydrates, lipids and nucleic acids.

The daily demand of an adult human for zinc amounts to 15–20 mg. The coefficient of its absorption from dietary intakes of vegetable and animal food mixture is as high as 33 %. The symptoms of this element deficiency for human and animal organisms are exhibited *via* growth inhibition and development delay, disorder of reproductive function, bone formation and hemogenesis, cutaneous diseases, decrease in immunity [4–6].

The deficiency of zinc in soils results in occurrence of various diseases of plants, decrease in their productivity and deterioration of qualitative composition. At the same time a considerable part of the territories of Russia (75 %), the USA (43 States) and other countries are characterized by the deficiency of zinc in soils [7, 8], which represents a serious problem for the health of population, livestock farming and agriculture. This is especially urgent for the optimum development of children and teenagers as the most vulnerable part of population Zinc-containing fertilizers take a leading place in the developed countries abroad among other fertilizers with microelements concerning the assortment and production volumes [8].

At the same time the increased concentration of zinc exert a toxic effect on living organisms. So, the proficiency of zinc in a human organism results in nausea, vomiting, respiratory embarrassment, pulmonary fibrosis [9]. Under the conditions of an increased concentration of zinc in soils the population morbidity rate value with respect to cancer is observed to grow; in this connection zinc is referred to priority toxic elements. However, the toxicity of zinc exhibits a restricted distribution being connected mainly to a man-caused environmental contamination due to corresponding manufactures.

Thus, the problem of zinc in biosphere is characterized by two practically important aspects biological one, connected with zinc deficiency, and ecotoxicological one caused by the increased content of zinc. In this connection it is necessary to carry out monitoring of zinc content in various parts of biogeochemical food chain for different regions.

The content of zinc is poorly known for the landscapes of Transbaikalia. There are only separate data concerning zinc content in the some soils and fodder plants of the southern areas of Buryatia [10, 11], as well as about the accumulation of this element by plants growing on ore deposits [12]. The purpose of the present work consisted in the studies on the features of zinc distribution in soil-forming rocks, natural waters, soils and plants of various Transbaikalian landscapes constituting the major portion of water collecting area of the Baikal Lake basin.

EXPERIMENTAL

The studies were carried out over the 12 most populated areas of Buryatia (Western Transbaikalia) located within the Selenga River basin that is the main tributary of the Baikal Lake. The key sampling sites, plots 100 × 100 m in size were chosen at the typical areas of the steppe, meadow and agricultural landscapes according to the methodical recommendations presented in [13]. Each plot was treated to obtain a basic soil section and 4 to 6 semi-sections. At all the points a conjugate sampling was carried out for the determination of zinc content in soil horizons and rocks, in some plant species as well as in phytomass harvested from 1 m^2, upon 4- to 6-fold repetition. The sampling was carried out during the period of a higher biologic efficiency of dominant plants. Water sampling from the water sources neighbouring to the key plots was carried out during low-water season (August–September). The destruction of the organic matrix in samples was carried out using a dry ashing technique at 480 °C. The content of zinc was determined by atomic absorption spectroscopy technique, analytical replicated trials being triple. The detection limit of zinc for soils and plants amounted to 0.5 and 0.1 mg/kg, respectively, for water it was equal to 1.0 μg/L. The relative error of determination was about 8–10 %. Mathematical data processing was carried out using standard techniques described in [14].

RESULTS AND DISCUSSION

Zinc in soil-forming rocks

The content of zinc in soil-forming rocks varied from 23 to 157 mg/kg while the average variation level was equal to 41 % (Table 1). The lowest content of zinc (26–30 mg/kg) was observed in alluvial and diluvium sandy deposits of the taiga landscapes, and the highest one (100–140 mg/kg) was noted for diluvium loamy deposits of the steppe landscapes. For the most part the content of zinc varies within the range of 40–100 mg/kg (75 % of samples) with the average value for all the set of soil-forming rocks under investigation amounting to 71 mg/kg, which value is corresponding to the clarke of zinc in the lithosphere.

From the geological staindpoint Transbaikalia represents rather non-uniform territory where Pre-Cambrian, Palaeozoic, Mesozoic and Cainozoic igneous, metamorphic, sedimentary formations are developed. Granitoids prevail among the rocks, and there are diorites, syenites, gabbro, dunites, basalts, limestones, sandstones, clay slates, too [15]. The rocks often replace spatially each other; this fact exhibits a lithologic variety of the territory, which is connected with the variability of the lithogeochemical background. Zinc belongs to chalcophilous chemical elements accumulated in

TABLE 1

Content of zinc in soil-forming rocks of Transbaikalia

Soil-forming rock	*n*	Content, mg/kg		C_c
		Fluctuation range	Average	
Northern part of the territory under investigation				
Taiga landscapes				
Diluvium sandy deposits	5	24–36	29	0.4
Alluvial deposits	5	23–31	26	0.4
Sandy deposits	8	34–45	38	0.6
Forest-steppe landscapes				
Diluvium deposits, loams	16	40–60	49	0.7
Diluvium deposits, sandy loams	10	32–47	37	0.5
Alluvial deposits	16	27–45	33	0.5
Southern part of the territory under investigation				
Arid steppe landscapes				
Diluvium deposits, loams	15	76–107	93	1.4
Diluvium deposits, sandy loams	15	64–91	79	1.2
Alluvial deposits	15	60–96	77	1.1
Ancient lacustrine deposits	6	83–97	90	1.3
Aeolian sands	7	59–71	65	1.0
Steppe landscapes				
Diluvium deposits, loams	5	90–157	120	1.8
Diluvium deposits, sandy loams	22	85–112	99	1.5
Aeolian sands	9	65–87	76	1.1
Alluvial deposits	18	65–115	86	1.3

Notes. 1. The Earth's crust clarke amounts to 68 mg/kg [16]. 2. C_c is the clarke of concentration related to Earth's crust clarke.

the base rocks in increased amounts (84 mg/kg). In the intermediate and acid rocks its content is to some extent lower, amounting to 73 and 58 mg/kg, respectively [16]. Zinc is present in rocks mainly as zinc sulphide ZnS, as well it uses to substitute magnesium in silicates.

The analysis of spatial distribution of zinc in soil-forming rocks has allowed one to reveal the following regional feature. For the rocks those compose the southern part of the territory under investigation (steppe and arid steppe landscapes) the content of zinc is on the average 2.3 times higher as compared to that for the rocks composing the northern part (taiga and forest-steppe landscapes): 89 and 38 mg/kg, respectively. This difference is caused mainly by the character of basement rocks: the northern part is mainly combined by acid rocks, whereas there are also intermediate and base rocks in the southern part. In particular, for the alkaline basalts of the Dzhida district the content of zinc in rocks ranges from 108 to 177 mg/kg [17].

The content of zinc depends on grain-size composition of rocks, too. So, for sandy loams and sand this parameter is 1.5–1.9 times lower as compared to that for loamy deposits. It is connected with the fact that zinc, as well as many other dispersed chemical elements are concentrated at the negatively charged surface of superfine clay particles due to the sorption via electrostatic interaction and even the incorporation into interlamellar space, and formation of stronger inner-sphere complexes [18]. The content of clay fraction in various soil-forming rocks of Transbaikalia varies from 5 up 15 %.

The relationship between silicon oxide and the total of the oxides of other elements is considered to be important for estimating the level of zinc content in rocks and in soils. With the increase in the content of silica the of dispersed elements decreases. The content of SiO_2 in soil-forming rocks of Transbaikalia ranges from 61 to 73 %, and the fraction of the oxides of other elements varies within the range from 27 to 39 % [19]. The differences in the content of clay minerals and the relationship between SiO_2 and the oxides of other elements are responsible for the content of zinc in rocks as well as for the heterogeneous character of its spatial distribution.

Zinc in natural waters

The content of zinc in water of the rivers of the Selenga River basin ranges from 3 to 69 μg/L (Table 2). The average concentration of zinc in river waters is equal to its clarke amounting to 20 μg/L [20]. A higher content of zinc was revealed in water of large rivers (the Selenga, the Dzhida), which could be caused by a relatively increased salinity (150 mg/L) as compared to small mountain rivers and rivulets (10–30 mg/L), as well as by the element entering with atmospheric precipitation. The contribution of the latter to large rivers running over vast territories could be as much as 50 % of the total content [21].

For water of the freshwater lakes under investigation the content of zinc ranges from 5 to 34 μg/L (14 μg/L on the average). A low content of zinc is inherent in water the Baikal Lake ranging from 5 to 12 μg/L (7 μg/L on the average). This fact could be explained by its ultrafresh type (the mean salinity amounting to 97 mg/L) and a high level of oxidation processes occurring. High concentrations of zinc (27–93 μg/L) are observed for waters of closed saline lakes (with the salinity of 35 000 mg/L) attached to arid steppe landscapes. However, these values do not exceed the background values for zinc content in superficial waters (5–300 μg/L).

For the subsoil well-waters the content of zinc is demonstrated to vary within the range from 4 to 32 μg/L (15 μg/L on the average). For the majority of underground potable deep-well water from boreholes the content of zinc amounts 15–24 μg/L (average value being at 20 μg/L), whereas for the underground waters of an arid steppe landscape this value is 2.4 times higher than the abovementioned amounting to 45–82 μg/L (48 μg/L on the average). At the same

TABLE 2

Content of zinc in naturally occurring waters of Transbaikalia

Water source, sampling site	Content, μg/L	
	Fluctuation range	Average
Rivers		
Kizhinga, Kizhinga village	55–69	65
Selenga, Shigayevo village	48–63	56
Dzhida, Dzhida station	44–58	52
Zheltura, Zheltura village	46–57	50
Burgultayka, Nizhniy Burgultay village	42 –53	48
Irkilik, Zyryansk village	36–44	40
Tugnuy, Tugnuy village	34–40	38
Angyr, Zyryansk village	32–39	36
Bichura, Bichura village	27–36	32
Orongoy, Orongoy village	25–36	30
Il'ka, Novoil'insk village	13–19	16
Kurba, Novaya Kurba village	15–23	18
Zagustay, Yagodnoye village	8–15	11
Chikoy, Povorot village	5–11	8
Ubukun, Ardatsan village	3–9	5
Lakes		
Shchuch'ye, Yagodnoye village	12–25	18
Gusinoye, Gusinoozersk city	19–34	26
Kamyshovoye, Yagodnoye village	12–19	15
Baikal, Istomino village	5–12	9
Underground waters		
Artesian well, Kyakhta city	69–82	75
Artesian well, Zyryansk village	64–76	70
Artesian well, Nizniy Torey village	47–56	52
Spring, Dzida road	45–53	50
Artesian well, Turuntayevo village	42–50	46
Artesian well, Ust-Kyakhta village	19–33	24
Artesian well, Kizhinga village	14–30	22
Artesian well, Mukhorshibir village	21–26	20
Artesian well, Kulskiy Stanok village	13–21	17
Artesian well, Yagodnoye village	11–19	15
Artesian well, Gusinoozersk city	5–12	8
Artesian well, Novoselenginsk village	3–8	5

time, the clarke of zinc for underground waters of the hypergenesis zone is equal 41.4 μg/L [20].

The analysis of zinc spatial distribution for various water sources of the Selenga River basin has allowed one to establish that for the waters of the southern part of arid steppe landscape (42–58 μg/L, Dzida district) zinc concentration is higher as compared to the forest-steppe landscape of the northern part of the territory under investigation (4–21 μg/L, Zaigraevo distrrict). This fact could be to a considerable extent caused by a different level of zinc content in rocks, the basic sources of this chemical element for natural waters.

Thus, the content of zinc in natural waters is characterized by a significant contrast ranging from 3 to 82 μg/L (27-fold). For the most part, the content of zinc in superficial waters is close to the clarke of zinc for river waters, whereas for the underground potable deep-well water from boreholes this value is twice lower than the clarke of zinc for underground waters of the hypergenesis zone.

Zinc in soils

A geographical heterogeneity of zinc distribution in soils, caused by the differences in its content in rocks is inherent in the region under study [22, 23]. The close contingency of these parameters is reflected by the linear correlation coefficient value: $r = 0.84$. This is connected with the fact that the bulk of the soils under our investigation include 94.5–98.8 % of a mineral substance (the content of humus ranging within 1.2–5.5 %).

The differentiation of microelements within the soil profile is determined by the content of the organic matter, sludgy fraction, the presence of sorption geochemical barriers and pH value in the medium. For the conditions of Transbaikalia one should distinguish the two most characteristic types of the vertical zinc distribution.

For the chestnut soils and farinaceous carbonate chernozem soils of steppe and arid steppe landscapes in the presence of an alkaline sorption barrier in the carbonate horizon one can observe an increased (1.6–1.8-fold) zinc accumulation level as compared to a soil-forming rock. This fact is caused both by the pH value increase within the horizon B_c up to 7.6–8.7 (within the horizon A the pH value being at about 7.0–7.2) and, consequently, the sedimentation of zinc in the form of zinc hydroxide, and its fixation in a non-exchangeable form *via* the chemisorption by iron oxides. It is experimentally established that iron hydroxides use to absorb heavy metals more actively, than clay minerals and organic matter, being able to bind up to 50 % of the total amount of metals [18]. In particular, for farinaceous carbonate chernozem soils the content of Fe_2O_3 within the horizon B_c amounted to 10.8–15.4 %, whereas within the horizon this value ranged within 5.1–6.8 %.

In the soils where the carbonate horizon is not present, zinc is distributed in the profile with a considerable homogeneity: the difference in its content in separate horizons is statistically nonsignificant amounting to ±1.2 times. The main types of Transbaikalian soils are characterized by a low content of humus, therefore no correlation in the humus–zinc system is observed ($r = 0.10$). The biogenic accumulation of zinc is noted only for the soils with an increased content of organic matter such as meadow chernozem permafrost soils and bottomland-meadow soils.

In the arid steppe landscapes the soils of chestnut type are prevailing those are characterized by neutral or alkalescent pH value of the medium within the humus horizon. The content of zinc in such soils ranged from 57 p to 101 mg/kg (78 mg/kg on the average) (Table 3). With the close pH values and humus content, such a considerable difference in the content of zinc could be mainly caused by different concentration level of this element in soil-forming rocks ranging from 64 to 107 mg/kg (1.7-fold difference) as well as by the variety of grain-size composition of soils, from sandy soil up to medium-loamy soil.

Farinaceous carbonate chernozem soils are the most distributed within steppe landscapes on the slopes of intermountain declines of the northern exposition; they are characterized by neutral pH value of the soil medium. The grain-size composition varies from sandy soil up to loamy soil (the content of the fraction <0.01 mm ranging within 13–35 %). The content of zinc in the chernozem soils of steppe landscapes ranges from 96 to 115 mg/kg (the average value amounting to 107 mg/kg).

Grey woodland soils (pH 6.2–7.7) are formed on the northern slopes of the intermountain declines of taiga, forest-steppe and steppe land-

TABLE 3

Content of zinc in Transbaikalian soils (within the layer of 0–20 cm)

Soil type	n	Humus content, %	Aqueous pH	Zinc content, mg/kg		C_c
				Fluctuation range	Average*	
Northern part of the territory under investigation						
Taiga landscapes						
Peaty swamp (peat bog) soils	5	–	5.2	31–42	37	0.4
Grey woodland soils	13	2.3–2.6	6.2–6.4	44–59	52	0.6
Alluvial sod soils	4	1.4–1.8	6.4	39–47	44	0.5
Forest-steppe landscapes						
Chestnut soils	21	2.0–2.3	6.8–7.8	35–57	46	0.5
Farinaceous carbonate chernozem soils	10	2.9–3.7	6.8–7.0	35–48	42	0.5
Grey woodland soils	8	2.2	7.0	41–52	45	0.5
Alluvial meadow soils	15	2.8–5.5	6.9–7.5	38–55	47	0.5
Southern part of the territory under investigation						
Arid steppe landscapes						
Chestnut soils	31	1.4–3.2	6.9–7.9	57–101	78	0.9
Farinaceous carbonate chernozem soils	5	3.4	7.1	89–103	95	1.1
Grey woodland soils	10	2.2–3.8	7.1–7.3	97–119	113	1.3
Alluvial meadow soils	28	2.7–4.7	7.3–8.0	70–93	82	0.9
Alluvial sod soils	8	1.2–1.5	7.8–8.1	88–107	92	1.0
Steppe landscapes						
Chestnut soils	14	1.2–1.8	6.9–7.8	75–136	97	1.1
Farinaceous carbonate chernozem soils	11	2.4–2.8	6.9–7.2	96–115	107	1.2
Grey woodland soils	21	2.4–2.9	6.8–7.7	91–108	97	1.1
Alluvial meadow soils	7	2.8	8.0	89–116	100	1.1
Alluvial sod soils	12	1.4–2.1	7.3–7.7	84–100	90	1.0

* The average zinc content in soil all over the world amounts to 90 mg/kg [16].

scapes. According to the grain-size composition there are light loamy and medium loamy varieties (the content of the fraction <0.01 mm ranging within 18–38 %). Depending on the composition of soil-forming rocks, on the grain-size composition and on pH value the content of zinc in the soils ranges from 44 to 108 mg/kg.

Meadow soils are formed on alluvial deposits in the valleys of the rivers of the Baikal Lake basin for all the Transbaikalia landscapes under our investigation. These soils are characterized by a wide range of pH values (6.4–8.4). The grain-size composition varies from sandy soil up to medium loamy soil (the fraction <0.01 mm amounting to 12–35 %). Depending on moistening conditions the content of humus in alluvial soils is quite different: for alluvial meadow soils its value amounts to 2.7–5.5 %, whereas for alluvial sod soils it is equal to 1.2–2.1 %. The content of zinc in alluvial soils ranges from 38 to 116 mg/kg (76 mg/kg on the average).

A distinct correlation between the content of zinc in soil-forming rocks and the soils formed on them is observed upon the analysis of separate sections (S). So, for example, the content of zinc in grey woodland soil and soil-forming rocks for the forest-steppe landscape amounts to 48 and 43 mg/kg, respectively (S51Kzh), for the arid steppe landscape these values are equal to 100 and 113, respectively (S38K), whereas for the steppe landscape they are 95 and 91 mg/kg, respectively (S22T). The content of zinc in alluvial soils and alluvial sediments for the taiga landscape amounts to 44 and 40 mg kg, respectively (S104Pb), for the forest-steppe landscape the corresponding values are 38 and 30, respectively (S52Kzh), for arid steppe landscape they are 87 and 84 (S59D), for the landscape steppe landscape being at 87 and 80 mg/kg, respectively (S20T). Similar dependence of zinc content in soils on the content of zinc in soil-forming rocks was observed for chestnut and chernozem soils formed on diluvium deposits of the forest-steppe, steppe and arid steppe landscapes.

There are considerable lands of peaty swamp soils in Transbaikalia. A vast tract of lowland peaty soils (20 000 ha) is located within the delta of the Selenga River. The content of zinc in soils of this land ranged from 31 to 42 mg/kg, which is in a good correspondence with zinc concentration in the peaty swamp soils of the European part of Russia [24].

Thus, the background content of zinc in the main types of soils in the region varies within the range of 31–136 mg/kg at the average variation level of 37 %. The average content of zinc in soils amounts to 76 mg/kg and almost corresponds to its content in soil-forming rocks. Thus, it is just the composition of soil-forming rocks that is a primary factor determining the content of zinc in soils not subjected to man-caused impact. No statistically significant difference was revealed in the average content of zinc for various types of soils. However, the increase in zinc content in the soils from the north to the south of the territory under investigation is traced as distinctly, as it is for soil-forming rocks: for the soils of the northern part this value varies within the range of 35–59 mg/kg (45 mg/kg on the average), whereas for the southern part it ranges within 57–136 mg/kg (the average value amounting to 91 mg/kg). The zinc reserves in soils as compared with the clarke for the northern part amounts to 0.5–0.6, whereas for the southern part it is equal to 0.9–1.3.

The biological activity of zinc in soils and its ability to enter plants depend on the presence of biologically accessible species of this element. The results of the determination of the mobile zinc extracted with the use of ammonium acetate buffer solution (pH 4.8) indicate a low reserve in the soils of steppe and arid steppe landscapes with respect to such species of the element ranging within 20–60 % of the standard value for the plants with a low zinc withdrawal. The investigated soils of the region are mainly (82 % of the area) characterized by 40–80 % deficiency of mobile zinc. A higher content of zing was revealed in peaty swamp soils (2.9 times higher as compared to the standard). The mobile zinc reserves in the soils of the taiga and forest-steppe landscapes amounting to about 16 % of the area of agricultural lands are in a good correspondence with the standard.

One of the major factors determining the low content of mobile zinc species in the soils of steppe and arid steppe landscapes is their saturation with calcium. For the absorbing soil complex of chernozem, chestnut, grey woodland and bottomland soils the content of calcium was as high as 20–26 mg-eq, which is 4 times higher as compared to the content of magnesium. The mechanism of zinc mobility regulation effected by calcium consists in the fact that such stable compounds as zinc hydroxide and carbonate are formed in neutral and alkalescent media [25]. The low mobility of zinc in soils results in the deficiency of its accumulation in plants and, hence, in the organisms of humans and animals.

Zinc in plants

Different species of plants exhibit a selective ability to accumulate zinc even when growing within the same ecotope. In order to estimate specific features of the accumulation of chemical elements by plants one should consider not absolute, but the relative content of the element under investigation in the species of plants (RCSP) under comparable conditions [12].

The use of this parameter for the comparison of 12 basic species growing within the same ecotope, has allowed us to distinguish the groups of plants with the increased (1.4–1.8 times), medium (0.8–1.2 times) and low (0.4–0.7 times) zinc accumulation level. The largest group (seven species) was characterized by a medium zinc accumulation level. The maximum difference in the content of zinc in such contrast plant species as *Potentilla lanacetifolia* Willd. and *Agrostis mongolensis* was as high as 4.7-fold (28 and 6 mg/kg, respectively). These features of plants are caused by a long-term evolution

TABLE 4

Statistical and variation parameters for the content of zinc in soils, in the vegetation of different phytocenoses and the coefficient of biological absorption (K_b)

Parameter	n	$M\pm m$	Variation range	Confidence interval	V, %	r
			Steppe phytocenoses			
In soil, mg/kg	16	81±7	42–136	67–96	33	0.57
In plant incineration ash	16	414±46	200–800	315–512	45	
K_b	16	5.1±0.41	2.5–8.2	4.3–6.1	31	
			Meadow phytocenoses			
In soil, mg/kg	14	70±6	38–100	55–84	35	0.65
In plant incineration ash	14	276±33	100–500	204–347	45	
K_b	14	3.9±0.39	2.0–6.3	3.2–4.9	36	
			Agricultural phytocenoses			
In soil, mg/kg	27	79±5	40–136	68–91	36	0.59
In plant incineration ash	27	224±17	100–375	189–259	39	
K_b	27	2.8±0.19	1.5–4.7	–	33	

of the organism–geochemical environment integrated system resulted in developing a certain biogeochemical specialization in plants.

In order to estimate the intensity of the absorption of chemical elements by plants from a soil it is conventional to use the ratio K_b between the content of elements in plant ashes to the content in soil or in the Earth's crust [12]. According to this parameter one can judge the degree of bioavailability of the elements and their behaviour in the soil–plant system. As it is seen from data presented in Table 4, zinc belongs to chemical elements of rich accumulation. It should be noted that there is an increased K_b value for zinc in the vegetation of steppe landscapes as compared to meadow and cultivated phytocenoses (1.3- and 1.8-fold, respectively). This fact could be caused by a more vigorous activity of the root system of xerophytic vegetation of steppes as compared to that for mesophytic vegetation of meadows and cultivated phytocenoses. As against the majority of microelements, zinc it characterized a valid positive average correlation between its accumulation level in plants (for incineration ash) and the total content of this element in soils: at t_{fact} = 2.6, 3.0, 3.6 and t_{theor} = 2.2, for steppe vegetation r = 0.57, for meadow vegetation r = 0.65, for cultivated vegetation r = 0.59.

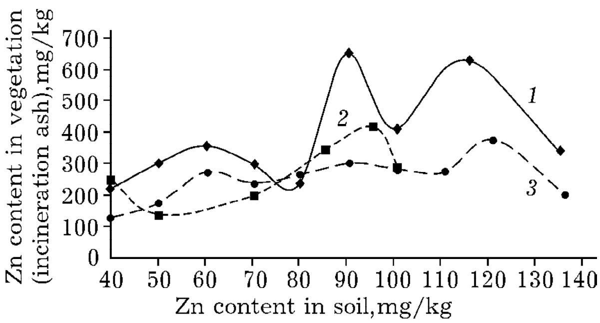

Fig. 1. Zinc accumulation within aerial biomass of steppe (*1*), meadow (*2*) and cultivated (*3*) phytocenoses (for incineration ash) depending on Zn content in soils.

The accumulation level of zinc in aerial parts of the vegetation biomass of steppe, meadow and cultural cenoses depending on zinc content in soils is expressed as sinusoidal curves with several rises and decays (Fig. 1).

The same plant species under different environmental conditions within the same vegetation stage (flowering) exhibit a considerable difference in the content of zinc. So, for the 48 plant species under our investigation the difference could range from 1.5-fold value (for crested grass *Agropyron cristatum* (L.)) to 8.4-fold one (for wormwood sage *Artemisia frigida*), 8.0-fold difference for yellow bedstraw *Galium verum* L., 7.9-fold one for sickle alfalfa *Medicago falcata* L. and 7.8-fold value for locowed (*Astragalus Adsugens* Pallas*)* [26]. The plants specified are characterized by wide ecological amplitude of growth.

The data obtained indicate a barrier-free type of zinc accumulation for these species and their possible use as indicators of soil contami-

TABLE 5

Content and accumulation of zinc in the aerial biomass of Transbaikalian vegetation

Vegetation type (sampling site)	n	Zinc content, mg/kg	Biological productivity, centners/ha	Zinc accumulation level, g/ha
Steppe (overall)	54	20.0	6.0	15.4
Motley grass (forb) steppe (Belozersk village)	5	41.3	6.7	27.7
Wormwood sage steppe (Yagodnoye village)	4	18.2	6.2	11.3
Wild rye sedge steppe (Borgoy village)	6	16.8	3.2	5.4
Cereal steppe (Tokhoy village)	5	7.8	5.6	4.4
Cereal wormwood sage steppe (Ivolginsk village)	5	15.4	9.8	15.1
Natural meadow (overall)	117	18.3	47.3	86.6
Motley grass (forb) meadow (Ust-Kyakhta village)	5	36.0	50.4	181.4
Cereal-forb meadow (Kizhinga village)	6	19.8	44.0	87.1
Cereal meadow (Verkhniye Taltsy village)	4	7.4	25.0	18.5
Cereal meadow (Petropavlovka village)	5	15.6	38.0	59.3
Motley grass (forb) meadow (Tugnuy village)	5	31.0	54.0	167.4
Cereal meadow (Kokorino village)	5	10.7	88.4	94.6
Cereal meadow (Kalenovo village)	6	8.4	37.6	31.6
Forb-cereal meadow (Unegetey village)	5	15.6	42.0	65.5
Swamp meadow (overall)	25	27.6	44.4	122.5
Cultivated vegetation (overall)	133	15.9	46.4	73.7
Cultivated cereals (Ivolginsk village)	6	8.3	41.0	34.0
Cultivated cereals (Oshurkovo village)	5	13.4	64.0	85.8
Cultivated cereals (Bolshaya Kudara village)	5	17.1	24.0	41.0
Standard [4]		40		
Excess amount [4]		500		

nation with this chemical element. The majority of the species (39 or 81 %) exhibit an insignificant difference in the content of zinc depending on growing within in different boitopes (up to 3 times), *i. e.* these species demonstrate the accumulation of the element according to a background barrier type.

The content of zinc in hay crops of the aerial biomass harvested from steppe, meadow and cultivated vegetation was characterized by a significant heterogeneity and varied within the range of 6.1–51.4 mg/kg (Table 5).

The content of zinc in steppe vegetation changed from 6.4 to 48.6 mg/kg. The minimal content is inherent in cereal phytocenoses, whereas the maximal content is typical for miscellaneous herbs. The extreme environmental conditions with respect to moistening supply (200–250 mm of atmospheric precipitation during the vegetative season) determine a low biological productivity of the steppe plant communities: the withdrawal of zinc with steppe vegetation is insignificant (5.4–27.7 g/ha).

The content of zinc in the vegetation of the meadow landscapes ranges from 6.1 to 51.4 mg/kg with the maximal values for sedge of the bog meadows and minimal ones for cereal vegetation of the natural meadows. Meadow phytocenoses are formed within the flood-lands of the rivers the Baikal Lake basin under the conditions of normal (natural meadows) and superfluous (bog meadows) moistening; thee are characterized by a high bioproductivity of the aerial mass and high zinc withdrawal with aerial parts of plants ranging within 19–181 g/ha (97 g/ha on the average).

The aerial mass of the plants of cultivated crops for the fodder purposes is characterized by the content of zinc ranging from 6.6 to 31.2 mg/kg. The basis of the agronomical phytocenoses is formed by cereals (mainly oats), therefore these cenoses are to the least extent provided with zinc (40 % with respect to the standard). The productivity of the phytomass within agrocenoses on the average amounts to 46.4 centners/ha, whereas zinc withdrawal due to the phytomass is as high as 74 g/ha.

The optimum zinc content in fodder plants according to contemporary requirements must be equal to 30–50 mg/kg (40 mg/kg on the average), the deficient content is less than 20 mg/kg, whereas the maximum permissible zinc content amounts to 500 mg/kg [5]. The zinc deficiency based diseases of animals are observed within biogeochemical provinces and spots whose soils contain less than 3.0 mg/kg of exchangeable zinc, with fodder containing less than 20 mg/kg.

Basing on the standards presented, one could note mainly low zinc content in the vegetation of the region. The content of zinc in the vegetation taken from the 61 key sampling sites (91 %) of the 67 ones under investigation, appeared lower than the standard value, and the deficiency of zinc for 45 of them ranged within 50–80 %, for 16 of them amounting to 20–50 %. The content of zinc in the vegetation, which meets the standard (34–46 mg/kg), was revealed only for six (9 %) key sampling sites.

The low content of zinc in the vegetation of natural and agronomical cenoses (except for the vegetation of swamp meadows) could be caused by the two factors such as a low content of mobile zinc in the main types of soils and a barrier nature of zinc accumulation in

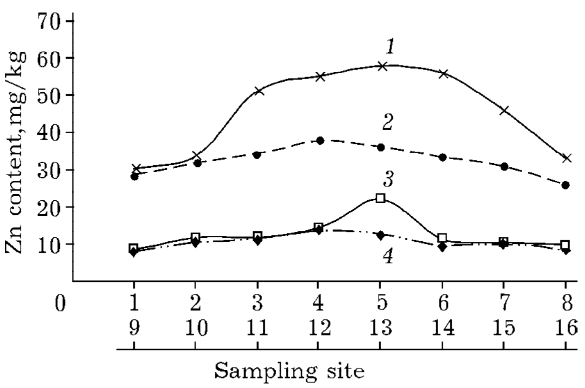

Fig. 2. Zn content in wheat grain (*1*, *3*) and in straw (*2*, *4*), growing in forest-steppe (1–8) and steppe (9–16) landscapes of the Western Transbaikalia: 1 – Korymsk, 2 – Stepnoy Dvorets, 3 – Kabansk, 4 – Selenginsk, 5 – Zyryansk, 6 – Turuntayevo, 7 – Nyuki, 8 – Il'inka, 9 – Shibertuy, 10 – Tarbagatay, 11 – Kharashibir, 12 – Tugnuy, 13 – Maly Kunaley, 14 – Sharalday, 15 – Bichura, 16 – Pesterevo.

cereals, the dominant vegetation of the steppe, meadow and agricultural landscapes.

It is revealed, that the content of zinc in grain of the main cereal crops (wheat and oats) can vary over a wide range. So, for the grain of wheat the difference between the maximal content of zinc (58 mg/kg) and minimal one (24 mg/kg) amounts to 1.6 times, exhibiting 2.1-fold value for the grain of oats (the maximum and minimum being of 45 and 21 mg/kg, respectively). The content of zinc in the grain of wheat and oats grown on soils of the forest-steppe landscapes is 1.4–1.6 times and 1.3–1.4 times, respectively, higher as compared to its content in grains of these crops cultivated under the conditions of the steppe and arid steppe landscapes (Fig. 2). The level of zinc content in grain is much higher than that in straw. The grain/straw zinc content ratio value ranges from 2.3 to 5.0 for wheat and from 2.8 up to 4.5 for oats. This fact indicates the absence of a barrier at the boundary between vegetative and generative organs with respect to the element under consideration and the fundamental difference in the character of zinc accumulation in grain as compared to other microelements.

CONCLUSIONS

The variety and complexity of the geochemical processes occurring within natural landscapes attached to either lithogeochemical background cause spatial heterogeneity of zinc content in soil-forming rocks, natural waters, soils and plants.

It has been established that the content of zinc in soil-forming rocks for steppe and arid steppe landscapes of the southern part of the territory studied (65–120 mg/kg) is higher as compared to that for taiga and forest-steppe landscapes of the northern part (33–49 mg/kg). The content of zinc in soil-forming rocks of the southern part amounts to 1.0–1.8, and for the northern part ranges within 0.4–0.7 with respect to its clarke in the lithosphere.

The content of zinc in natural waters of the region is characterized by a maximum contrast ranging from 3 to 69 μg/L that is 23-fold. Zinc concentration in superficial water is on the average equal to the clarke in river waters, whereas the concentration in underground water is twice lower than its clarke in underground waters within the hypergenesis zone.

The differentiation of zinc in the soil profile occurs in accordance with two types. In the first case in the presence of the alkaline sorption barrier the maximal content of zinc is inherent in carbonate horizons of chestnut and chernozem soils. The second type is characterized by relatively uniform distribution of zinc in grey woodland and alluvial soils (0.9- to 1.2-fold difference in zinc content). It is revealed that there is a close contingency between zinc content in soils and its content in soil-forming rocks and no correlation with the content of humus. Zinc reserves in soils for the taiga and forest-steppe landscapes amounts to 0.4–0.6 of the clarke, being for the steppe and arid steppe landscapes at a level of the clarke.

The accumulation of zinc by different species of plants within the same ecotope can differ to a considerable extent (4.8 times). The differences in the level of zinc accumulation by the same plant species growing in different ecological conditions (1.3 to 5 times) are significant, too. The majority of the species under investigation (81 %) demonstrates an insignificant difference in the content of zinc (less than 3 times), *i. e.* these species accumulate this element according to the barrier type. An average positive correlation is established between the content of zinc in the vegetation of the steppe, meadow, agricultural landscapes and its total content in soils. The content of zinc in hay crops of vegetation harvested from steppe, meadow and cultivated cenoses is non-uniform (ranging within 6.1–51.4 mg/kg), which could be caused both by biological features of plants, their interrelation in communities, and by different availability of the element in soils. Over the most part of the territory studied the vegetation is insufficiently provided with zinc (the deficiency ranging within 20–80 % of the standard). Most intensively zinc is involved in biological migration within meadow and cultural phytocenoses (86.6 and 73.7 g/ha, respectively), whereas a minimal zinc bio-migration intensity is observed for low-productive steppe phytocenoses (15.4 g/ha). The content of zinc in wheat and oats grain cultivated within the forest-steppe landscapes is higher as compared to those for the steppe landscapes. It is established that there is a barrier-free accumulation of zinc in grain with respect to straw.

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