Iodine 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: ioeb@bsc.buryatia.ru

(Received March 20, 2007; revised June 22, 2007)

Abstract

Iodine content within abiotic components and plants of Transbaikalian landscapes has been studied. A low iodine reserve of soil-forming rocks, natural waters, soils and plants has been revealed. A possibility has been studied for enriching plants with iodine by means of iodine micro-fertilizing.

Keywords: iodine, soil-forming rocks, natural waters, soils, plants, Transbaikalia

INTRODUCTION

Iodine is one of unique microelements vitally important for humans and animals. The uniqueness of iodine is determined by the fact that it plays a specific role in thyroid hormones those are of key value in the physiological control of vital functions of an organism. Moreover, iodine is the only microelement among the others known by now; those participate in the biosynthesis of hormones. Iodine deficiency causes the endemic (adenomatous) goitre to occur that is a widespread disease inherent to the central continental and mountain regions, since the most part of iodine comes to the environment from the World Ocean [1].

Moreover, according to all available information, the deficiency in iodine gives rise to about 40 diseases and unhealthy symptoms, which could cause a considerable reduction in the level of health and life expectancy of the population as well as the reproductivity of humans and animals. Rather significant areas are considered to be iodine-deficiency biogeochemical provinces, including about 70 % of the territory of Russia and more than 30 % of China. According to the data presented by WHO, there is about 400 million people on terrestrial globe who is sick with the endemic goitre [2].

Thus, the deficiency in iodine represents a global environmental problem whose practical decision for medicine and an agriculture is of extremely important value.

By the end of 1940s Russian scientists had theoretically proved the concept of the complex solving the problem of struggling against the endemic goitre as a mass disease. Already by the beginning of 1970s it was possible to reach everywhere the principal change in the goitre endemic condition and to lower manyfold the adenomatous goitre sickness rate in the population [3, 4]. Within the period of reorganization called as Perestroika, owing to financial difficulties the monitoring and prophylaxis of endemic goitre in Russia have been stopped, which resulted in growing the endemic goitre sickness rate among the population in 1990s. Today the problem of the endemic goitre is much as urgent as it was prior to the beginning of the prophylaxis [5, 6].

The territory of Transbaikalia represents one of a scantly known iodine-deficiency biogeochemical province with a tense situation concerning the endemic goitre and the other diseases of humans and animals connected with iodine deficiency. According to [7–10], up to 60 % of the human population and animals of Transbaikalia suffer from the goitre in a various severity degree, whereas a number of other diseases connected with the deficiency in iodine, are merely not studied up till now. First of all, there is moronism among these diseases; Buryatia surpasses much the other regions of Russia in the sickness rate related to the mentioned disorder. The sickness statistics is caused by the Transbaikalia position in the centre of Asia, as well as by the combination of such ecological factors as an enormous remoteness of this territory from oceans (2000–2500 km), a mountain relief (460–3500 m above sea level) and a prevalence of iodine-depleted granitoids as basement rocks (90 %).

The purpose of the present work consisted in the studies on the features of iodine the content and distribution in the basic components of the landscape such as soil-forming rocks, natural waters, soils and plants, as well as the investigation of the iodine micro-fertilizers efficiency for enriching the plants with this chemical element.

EXPERIMENTAL

The studies were carried out over the 12 most occupied areas of Buryatia (Western Transbaikalia) located at the Selenga River basin that is the main tributary of the Baikal Lake. The key platforms 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 [11]. Each platform was backfilled with a basic soil section and 4 to 6 semi-sections. At all the points a conjugate sampling was carried out for the determination of iodine 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 springs neighbouring to key platforms was carried out during low-water season (August–September). Field investigations with the use of KI for the presowing treatment of presowing treatment of corn and oats seed, introducing KI into soil prior to sowing and non-root treatment of crops during the paniculation phase were carried out according to standard techniques [12]. The content of iodine was determined using a kinetic thiocyanate/nitrite method [13] that consists in determining the reaction rate of iron thiocyanate (a reducer) oxidation by nitrite anions used as an oxidizer. The analytical replicated trials were triple. Mathematical data processing was carried out using standard methods according to [14].

RESULTS AND DISCUSSION

Iodine in soil-forming rocks

Soil-forming rocks in the region are the deposits of intermontane depressions, mountain slopes and river valleys of the Baikal Lake basin, heterogeneous in composition. Main soil-forming rocks are presented by dealluvial deposits of transeluvial landscapes. The principal feature of soil-forming rocks consists in a sandy and rubbly composition as well as in a lower content of clay particles, which does not promote neither accumulation, nor retention of iodine in them. The content of sandy fraction is as high as 70 %, the content of clay fraction ranging from 5 to 15 %. A close correlation (r = 0.93) is established between the iodine content in rocks of and the presence of particles with size <0.01 mm in the rocks.

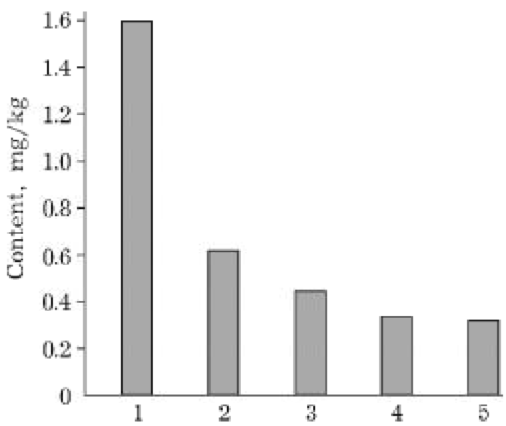

Fig. 1. Iodine content within soil-forming rocks of Transbaikalia: *1* – alluvial deposits of the Selenga River delta (muddy loams); *2* – eluvial-dealluvial deposits of mountainsides; *3* – ancient lacustrine sediments of the Gusinoozersk depression; *4* – aeoline sand of the terraces of intermountane depressions; *5* – alluvial sandy-pebble deposits of the flood-plain of the rivers of the Selenga River basin.

The average iodine content in the soil-forming rocks of the region amounts to (0.49±0.05) mg/kg, the variation coefficient being 62 % and margins of fluctuation ranging from 0.27 to 1.8 mg/kg.

With respect to the degree of decrease in iodine content the soil-forming rocks could be arranged to form the following series: muddy loams > eluvial-dealluvial deposits > ancient lacustrine sediments > aeoline and eagreal sand > alluvial sandy-pebble deposits (Fig. 1). The maximum content of iodine may be recorded for alluvial sediments such as muddy loams located at lowered relief details (superaqual landscapes).

The lowest content of iodine was established for alluvial sandy-pebble formations. The content of iodine in loamy rocks is 1.3–1.9 times higher as compared to sabulous rocks. From the comparative analysis of iodine content in various rocks of Transbaikalia with the clarke of iodine for the Earth's crust (0.5 mg/kg) [15] one can conclude that geochemical conditions of muddy loams promote the accumulation of this

TABLE 1

Content of iodine in natural waters of Transbaikalia

Water source (sampling site)	Mineralization level, mg/L	Iodine content, μg/L	
		Fluctuation range	Mean value
	Rivers		
The Selenga (Ulan Ude)	145	2.1–2.8	2.4
The Barguzin (Barguzin settlement) [9]	–	–	1.6
The Dzida (Dzhida station)	–	1.7–2.5	2.1
The Khilok (M. Kunaley village)	–	1.3–2.2	1.8
The Zagustayka (Yagodnoye village)	–	1.1–1.7	1.4
The Ivolginka (Ivolginsk village)	–	0.9–1.5	1.2
The Orongoy (Orongoy station)	–	0.6–1.5	0.9
The Ubukun (Ardatsan village)	–	0.6–1.2	0.8
The Bayangol (Khurumsha village)	–	0.4–0.8	0.6
The Itantsa (Turuntaevo village)	60	0.2–0.7	0.4
Klyuch (Zaganckiy ridge)	27	0.2–0.7	0.5
Ruchey(Istok village)	18	0.2–0.6	0.4
Average		0.2–2.8	1.1
	Freshwater lakes		
The Baikal (Posolsk village)	97	1.3–2.0	1.7
The Baikal (Istomino village)	–	0.9–1.4	1.2
The Gusinoe (Gusinoe Ozero station)	180	2.1–2.8	2.4
The Shchyuch'e (Yagodnoye village)	–	2.9–3.8	3.3
The Okunevoe (Tokhoy village)	130	1.3–1.9	1.6
Average		0.9–3.8	2.0
	Underground waters		
City water supply (Ulan Ude)	–	1.2–5.0	2.7
Artesian well (Yagodnoye village)	230	1.8–2.3	2.1
« (Tokhoy village)	–	1.6–2.1	1.8
« (Khurumsha village)	–	1.1–1.6	1.4
« (Troitsk village)	520	1.9–2.5	2.3
« (Turuntaevo village)	–	1.1–1.4	1.2
« (Barguzin settlement) [9]	–	–	2.2
« (Sakhuly village) [9]	–	–	5.6
Average		1.1–5.0	2.8

Note. A dash means the absence of data.

element, whereas the conditions of alluvial sandy-pebble deposits, as well as of aeoline and eagreal sand are favourable to its dispersion.

The content of iodine in soil-forming rocks those dominate in Transbaikalia averages about 4.5 times lower value as compared to the content of iodine in soil-forming rocks of the regions safe with respect to the endemic goiter (the mean content of iodine amounting to 2.15 mg/kg) [16, 17].

Iodine in natural waters

The most important factor that determines the content of iodine in natural waters consists in a mineralization level of the waters, since the presence of positively charged ions such as K^+, Na^+, Mg^{++}, Ca^{++} and others promotes the retention of negatively charged ions such as I^- and IO_3^-, in the form of those the species of iodine use to exist in the aqueous phase [1].

The hydrosphere of Transbaikalia is presented by superficial water (rivers and lakes) and underground types of waters with various, but low mineralization level, which restricts the accumulation of iodine in them.

For river waters the content of iodine ranges from 0.20 to 2.8 μg/L with the variation coefficient equal to 57 % (Table 1). An extremely low content of iodine in water (0.20 μg/L) was established for small mountain rivers and rivulets those are characterized by a minimal mineralization level (10–20 mg/L) due to a permafrost-based feeding. A higher content of iodine was recorded for the waters of the Selenga River, the largest one in Transbaikalia (2.4 μg/L) with the mineralization level amounting to about 130–145 mg/L. However, this parameter is also 4 times lower than the required standard value of iodine content in water for humans and animals equal to 10 μg/L [18]. The average content of iodine in river waters of Transbaikalia amounts to 1 μg/L, which is an order of magnitude lower than the physiological standard.

The content of iodine in the lake waters of Transbaikalia varies within the range of 0.3–2.7 μg/L with the variation coefficient equal to 71 %. A low content of iodine (0.3–1.9 μg/L) is inherent to the waters of the Baikal Lake. This fact is apparently caused by a low mineralization level (on the average being 97 μg/L) and a high level of the oxidizing processes occurring in the Baikal waters, which the processes could promote a volatilisation of this element from superficial water layers. A higher content of iodine (1.6–3.9 μg/L) is registered for the waters of the lakes located within the area of arid steppes with a slightly increased mineralization level. The average content of iodine in the waters of Transbaikalian freshwater lakes those are used as sources of water supply for some population aggregates, amounts to 1.6 μg/L, which value is 6.3 times less than the physiological standard for iodine.

Due to a higher mineralization level (up to 0.5 g/L) inherent to underground waters of wells those represent one of the basic sources of drinking water supply for the population and animals the iodine content here is, as a rule, higher than in superficial waters. This value is as high as 1.2–5.6 μg/L with the variation coefficient equal to 62 % (the average content being 2.8 μg/L, *i.e* 28 % of the standard).

Thus, the average content of iodine in natural waters of Transbaikalia can be presented by the following series (in μg/L): underground waters (2.8)–lake waters (1.6)–river waters (1.0). One can conclude, that the natural waters are characterized by a rather low iodine concentration, since owing to a remote location with respect to oceans the formation of iodine composition of natural waters proceeds mainly at the expense of local sources such as rocks and atmospheric precipitates impoverished with this element. Iodine supply of potable water in Transbaikalia averages to about 13 % of the conventional standard.

Iodine in soils

Accumulation and distribution of iodine in soils is controlled by a set of their genetic properties such as the presence of organic matter, grain-size composition, the acid-base reaction of media, *etc.* [19, 20].

One of the major factors determining the level of this microelement in soils is presented by the amount of organic substances, since in the humus layers the most part of iodine is

TABLE 2

Iodine content in the basic soil types of Transbaikalia (within the layer of 0–20 cm)

Soil type	n	Humus content, %	Iodine content, mg/kg			V, %	Average to world soil average ratio
			$M \pm m$	Variation range	Confidence interval		
Chestnut soils	75	1.2–2.6	1.5±0.13	0.8–2.2	1.2–1.9	32	0.3
Farinaceous carbonate chernozem soils	20	2.4–3.7	2.8±0.21	1.4–3.8	2.1–3.1	28	0.6
Grey woodland	30	2.1–3.8	2.1±0.18	0.8–3.4	1.7–2.5	33	0.4
Alluvial meadow	41	2.7–5.5	2.9±0.18	1.2–4.8	2.5–3.2	30	0.6
Alluvial sod	25	1.4–2.1	1.7±0.17	0.6–3.0	1.3–2.0	13	0.3
Peat bog	12	–	6.1±0.52	3.3–8.4	3.9–7.2	17	1.2

Note. 1. n is the quantity of tests, V is the variation coefficient. 2. The world averaged iodine content in soils is equal to 5.0 mg/kg [15].

strongly bound with an organic matter. As it was demonstrated in the experiments with the stable and radioactive iodine isotopes, iodine uses to be bound with various fractions of humus compounds to the extent of about 65–80 % [21]. We have established a precise dependence: the more humus is in soil, the higher is the content of iodine and the closer is correlation between them.

The maximum iodine content is recorded for peaty soils (6.1 mg/kg), whereas in the series of mineral soils it is observed for a bottomland-meadow soil (2.9 mg/kg); the minimal iodine content is registered for a low-humus podzolic soil (0.5 mg/kg) (Table 2). With respect to the correlation coefficient between the humus amount and the content of iodine, the soils could be arranged to form the following series: bottomland-meadow soil (0.83)–farinaceous carbonate chernozem soil (0.74)–grey woodland soil (0.52)–chestnut soil (0.46). The soils of Transbaikalia are characterized by a low humus content that ranges from 1.5 to 4.5 % (for the chernozem soils of the European part of Russia this parameter being as high as 10–15 %), which is not favourable to iodine accumulation.

The content of iodine in soils is also directly connected with the content of a sludgy fraction enriched with microelements (from 40 up to 80 % of the total microelemental content) comparing to the soil as a whole. This could be connected with the fact that the composition of the sludgy fraction includes organic matter and clay minerals with an extensively developed surface and a high sorptive power.

The acid-base reaction of a soil solution media represents one of the most important factors those determine a degree of mobility, and at the same time a level of iodine accumulation in soils. Within the superficial layer of acidic soils due to the influence of oxidizers such as Fe^{3+}, Mn^{4+}, O_2 as well as due to ultraviolet irradiation, I^- ion could readily transform to produce elementary iodine that is lost volatilising to the atmosphere, whereas there is a migration of the I^- ions together with a moisture from deeper parts of the humus layer towards underlying layers. In this connection for podzolic soils with pH ~ 6 the lowest content of iodine amounting to 0.5–0.8 mg/kg is observed, which content is 2 to 3 times lower as compared to chestnut soils with pH value of 7.1. In alkaline media, on the contrary, iodine ions react to be bound by carbonates and therefore iodine content is much higher in such soils.

The distribution of iodine amount throughout the soil profile is determined by the content of humus and carbonates. Basing on this fact one may distinguish the two following maxima of iodine accumulation in separate soil horizons.

The first, most typical maximum is observed in a humus horizon, which maximum is caused by the fact that gaseous iodine species those come from the atmosphere onto the surface of soil and migrate from the bottom upwards are strongly absorbed by humus (so-called biogeochemical barrier). The accumulation of iodine in the humus horizon of farinaceous carbonate chernozem and dark chestnut soil is 2.3 and 3.0 times higher, respectively, as compared to a rock.

The second maximum of iodine concentration is observed in the carbonate horizon where an increase of pH value and formation of almost insoluble iodine compounds with carbonates are considered to occur (so called alkaline barrier). The correlation coefficient for the iodine-carbonate system is of a high value amounting to 0.84. The carbonate horizon as an alkaline barrier is much more powerful as compared to the biogeochemical barrier on the path of iodine migration downwards a soil profile. The accumulation of iodine in the carbonate horizon of dark chestnut soil and of farinaceous carbonate chernozem are 4.6 and 5.1 times higher than the accumulation in a rock, respectively.

It is of a great value for the knowledge of ecological role of iodine in soils to determine the degree of iodine mobility. Water-soluble iodine represents one of the most important forms of the migration of this element in the nature, including in soils. The content of water-soluble iodine in Transbaikalian soils is very low, ranging from 1.7 to 6.5 % of the total value. Most likely, this fact is related to the atmosphere depletion with iodine, which atmosphere is a basic source of the most available species of this microelement within the top layer of soil.

The relative content of acid-soluble iodine species in various types of soils changes to an insignificant extent ranging from 14.2 in peaty soils to 18.1 % in chestnut soils. As expressed in absolute values, the content of iodine in soils could differ from each other within a nine-fold range, *i.e* from 912 to 108 μg/kg for peaty soils and grey woodland soils, respectively.

Basically, iodine in the soils of Transbaikalia is in a strongly bound state unavailable for plants, the value ranging from 77 % for grey woodland soil up to 84 % for peaty soil, with respect to the total iodine content.

Thus, with respect to the relative content of iodine the soils of Transbaikalia might be ranged according to the following succession: chestnut soils (1.0)–alluvial sod soils (1.1)–grey woodland soils (1.4)–farinaceous carbonate chernozem soils (1.9)–bottomland-meadow soils (1.9)–peaty soils (4.1). As compared to an ecological standard such as the iodine content in the chernozem soil of the Central Chernozem Reserve (5.4 mg/kg), for the chestnut soil of Transbaikalia the total iodine recourse averages about 28 %, for the farinaceous carbonate chernozem soil being 52 %, for the bottomland-meadow soil – 54 %, for the alluvial sod soil – 31 %, for the grey woodland soil – about 39 %, and for the peaty soil the total iodine recourse averages about 113 % against the ecological standard. The most widespread chestnut soils used in the agriculture could be classified as iodine-deficient soils.

Iodine in plants

Various species of plants exhibit different selectivity in the accumulation of iodine even though they grow under identical conditions. The use of a relative parameter for the classification of the 13 following plant species those grow under comparable conditions in floodplain meadow soils with iodine content of 2.5 mg/kg has allowed finding out the groups of plants with an increased (1.3–1.8-fold) (meadow clover *Trifolium pratense* L., orchid species *Dactylorhiza salina*, *etc.*), intermediate (0.9–1.2-fold) (yellow bedsraw *Galium verum* L., bastard lupine *Trifolium lupinaster* L., *etc.*) and lowered (0.6–0.8-fold) (barley species *Hordeum bulbosum* L., sedge species *Carex caespitosa* L., *etc.*) iodine accumulation value.

The maximum difference of iodine content in the most contrast species of plants such as meadow clover *Trifolium pratense* and a sedge species *Carex caespitosa* (0.27 and 0.06 mg/kg, respectively) was observed to be as much as 4.5-fold. The specific features exhibited by different plant species with respect to iodine accumulation given the same iodine content in soil is considered to be caused by entirely biological features of plants such as the selectivity of absorption by root systems and the metabolic processes in tissues.

The accumulation of iodine in the same species of plants growing on the varieties of chestnut soils (from sand soils to loam soils) appeared to be different, too. However, the analysis for iodine content in the three most widespread plant species demonstrated that these differences are less considerable (being from 2.0- to 2.5-fold) as compared to the differences between various plant species from the same habitat.

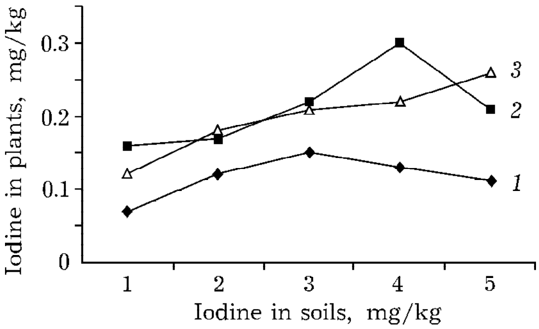

Fig. 2. Dependence of iodine accumulation within plants on the content of iodine in soils: *1* – couch-grass species (*Roegneria trachycaulon* Nevski); *2* – sickle alfalfa (*Medicago falcata* L.); *3* – locowed (*Astragalus Adsugens* Pallas).

The dependence of iodine accumulation in the two plant species (such as sickle alfalfa *Medicago falcata* L. and couch-grass species *Roegneria trachycaulon* Nevski) on iodine content in soils can be presented by a typical saturation curve with a maximum located in the range from 2.6 to 3.0 mg/kg and by the two following regions of proportional dependence. They are the curve portion of the direct proportionality within the range of low concentration and the curve portion of the inverse proportionality within the range of a relatively high concentration. For locowed (*Astragalus Adsugens* Pallas) within the range of in-soil iodine concentrations under investigation the dependence of iodine accumulation was observed to be directly proportional (Fig. 2).

The differences in iodine accumulation by the same plant species for different habitats may be explained both by biological features of plants, and by environmental conditions such as various content of the microelement and its availability. In this case the influence of biological features of some plant species appears to be more pronounced than the effect of

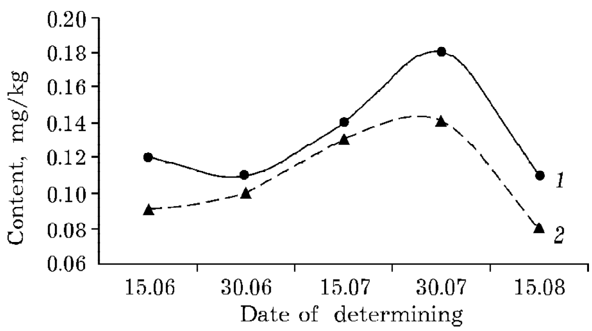

Fig. 3. Seasonal dynamics of iodine content variation in plants of pea *(1)* and oats *(2)*. Data of 1990.

environmental factors: a decrease in the element content in plants was observed even at the background content of iodine in soils.

The heterogeneity of iodine distribution of is inherent for a plant itself, too. Different organs, their parts and cellular organelles could to a considerable extent differ with respect to iodine content. The maximum content of this element is observed in roots, and as far as the aerial parts concerned it is registered in leaves. So, during the flowering period the content of iodine in the organs of oats amounted to (being expressed in mg/kg): for roots 0.49, for leaves 0.17, for stems 0.09 (the ratio of 5.4 : 1.9 : 1.0). A similar distribution of iodine throughout the organs of plants was revealed for a five-finger species *Cinquefoil tanacetifolia* (*Potentilla tanacetifolia* Willd.) and amaranth species *Amaranthus paniculatus*.

The seasonal changes in the content of iodine in aerial parts of plants reached threefold differences in value. The highest iodine content was registered during the flowering stage, *i.e.* during the highest physiological activity and the maximum development of leaf and root adsorbing and synthesizing organs (Fig. 3). At the end of the vegetative season the content of iodine in plants is reduced due to the ageing or the cellular cytoplasm and the decrease in its absorbing capability and retention properties.

For the plants of various agrobotanical groups the content of iodine decreases in the following sequence (in mg/kg): legumes (0.22)–motley grass (0.20)–cereals (0.13)–sedge species (0.07). Legumes and motley grass in equal conditions absorb iodine more actively and accumulate this element to a 2-3 times higher extent as compared to cereals and sedge species, which could be connected with the differences in the content of protein and carbohydrate compounds. Predominantly protein-based character of the metabolism inherent to legumes and motley grass promotes iodine accumulation in these plants since protein compounds contain a significant quantities of reactive functional groups capable to capture and retain both iodine and other microelements. The prevalence of low-reactive carbohydrate compounds in cereal and sedge species may result in a passive penetration of iodine and prevents its accumulation in plant tissues.

TABLE 3

Iodine content in the vegetation of Transbaikalian landscapes

Vegetation type	n	Content, mg/kg		V, %	Biological productivity, centner/ha	Iodine withdrawal, g/ha
		$M \pm m$	Fluctuation range			
Cereal-sedge steppe	4	0.09±0.02	0.06–0.13	22	3	0.03
Grassland steppe	5	0.17±0.04	0.12–0.25	24	6	0.10
Steppe (average)	33	0.14±0.03	0.06–0.26	22	5	0.07
Cereal meadow	5	0.09±0.03	0.05–0.12	32	38	0.34
Cereal grass meadow	10	0.20±0.02	0.10–0.28	30	54	1.08
Meadow (average)	112	0.16±0.03	0.05–0.28	32	44	0.70
Lowland swamp meadow (average)	41	0.11±0.03	0.03–0.18	37	39	0.46
Cultivated cereal	5	0.08±0.01	0.07–0.12	22	38	0.34
Cultivated cereal leguminous	5	0.20±0.03	0.15–0.25	26	35	0.70
Cultivated (average)	127	0.13±0.03	0.07–0.25	27	44	0.50

Note. Design. see Table 2.

The basis of the growth of Transbaikalian landscapes is formed by the steppe and meadow types of vegetation, as well as the crops of cultivated plants, cultivated with the food and fodder purposes. The low content of iodine in chestnut soils on those steppes are formed, the prevalence of cereals, the high level of infrared and ultraviolet solar radiation do not promote iodine accumulation in the vegetation of the steppe plant association.

The content of iodine in the phytomass of the steppe landscapes varies within the range from 0.06 to 0.26 mg/kg, the average index amounting to 0.14 mg/kg (Table 3). The extreme environmental conditions such as a low water supply (200–250 mm of atmospheric precipitates per year), result in a low productivity of the steppe phytocenoses. The biological harvest of the aerial mass ranges from 3 to 7 centner/ha, and iodine withdrawal with it amounts to only 0.03–0.10 g/ha. Taking into account the recommendations for the mineral feeding of animals [22], one can consider that the vegetation of the steppe landscapes is provided with this element only by 13–27 %, (on average by 20 %). Therefore, for 30 % of sheep grazing on the steppe pastures a considerable growth of the thyroid gland caused by iodine deficiency is observed [8].

The content of iodine in the phytomass of natural meadows on average amounts to 0.16 mg/kg with the fluctuations from 0.08 to 0.22 mg/kg. A higher content of iodine is registered in motley grass and leguminous vegetation (0.19 mg/kg), whereas a considerably lower content is observed in cereals (0.06 mg/kg). High biological productivity (25–54 centner/ha) of the aerial phytomass of the natural meadows causes the greatest withdrawal of the microelement (on average equal to 0.73 g/ha). Iodine reserve for the vegetation of the natural meadows averages 20 % of the standard necessary for animals ranging from 9 to 30 %.

The vegetation of lowland wet and swamp meadows, where a predominant position is held by sedge species and cereals, contains on average 0.11 mg/kg of iodine with fluctuations ranging from 0.07 to 0.16 mg/kg. The phytomass of lowland wet and swamp meadows is provided with iodine on average by 15 % of the standard value.

The content of iodine in the aerial mass of cultivated plants in various areas exhibits the fluctuations within the range from 0.04 to 0.28 mg/kg, the average iodine content amounting to 0.13 mg/kg. The minimum content of iodine (0.08–0.15 mg/kg) is inherent to the biomass of cereals, this parameter for legumes and crucifers being much higher than 0.15–0.20 mg/kg. The crop of the agrocenoses biomass during the end of the flowering period reached (achieved) 32–54 centner/ha, and carrying out of iodine has made 0.34–0.70 g/ha. Iodine reserve for fodder plants amounts to about 10 to 30 % of the physiological standard value for animals, *i.e.* it is approximately corresponding to the relative iodine reserve for the vegetation of hayfields and pastures.

Thus, the content of iodine in the aerial mass of the vegetation of Transbaikalian steppe, meadow and cultivated agricultural landscapes fluctuates within the range from 0.06 to 0.21 mg/kg, the average value being at 0.13 mg/kg. The value series for the accumulation of this element in the vegetation could be presented in the following form: the phytomass of natural meadows (0.16 mg/kg)–phytomass of steppes (0.14)–phytomass of cultivated plants (0.13)–phytomass wet and swamp meadows (0.11). The maximum to minimum ratio for the series amounts to only 1.45, which could be explained by a significant influence of plant physiological barriers those make complications for the iodine absorption from soil by the plants.

The most favourable conditions for the biogenic migration of iodine are observed for the superaqual landscapes distinguished by a higher productivity of meadow vegetation. For such landscapes the withdrawal of this microelement is the most significant, on average amounting to 0.73 g/ha. The biogenic migration of iodine the lowest in value for under productive landscapes such as arid steppes where the withdrawal of iodine by the phytomass averages only 0.05 g/ha, which is 15 times lower as compared to the withdrawal of iodine by the phytomass of the meadow agricultural landscape.

Thus, all the objects of Transbaikalia under our investigation such as soil-forming rocks, natural waters, soils, plants, thyroid glands of sheep and bovine animals [7] are characterized by very low iodine content. The reserve of iodine amounts to only 9–30 % of the standard value. The principal causes of iodine deficiency consist in a wide spread occurrence of the original and soil-forming rocks impoverished with this element, an overwhelming remoteness of the region from oceans, a mountaneous relief of the land, low-humus soils [7].

Efficiency of plants enrichment with iodine

Iodine mainly enters the organisms of humans and animals together with a nutrition ration, including the forages and phytogenous food. In this connection, an important way to solve the problem of iodine deficiency under the conditions of iodine-deficiency biogeochemical provinces consists in the optimisation of iodine content in food and fodder plants. Moreover, the consumption by an organism of such “biological” iodine occurring in foodstuffs is more efficient for the treatment and prevention of

TABLE 4

Effect of different methods of KI use on iodine content and withdrawal with respect to corn and oats aerial mass

Experimental mode	Corn		Oats	
	Content, mg/kg	Withdrawal, g/ha	Content, mg/kg	Withdrawal, g/ha
	With no macrofertilizers introduced into soil			
Control (reference)	0.12±0.004	0.29±0.010	0.11±0.002	0.11±0.002
KI, seed treatment, 0.02 % solution	0.14±0.006	0.37±0.017	0.15±0.004	0.15±0.004
KI, into soil, 1.5 kg/ha	0.21±0.011	0.45±0.030	0.22±0.008	0.22±0.008
KI, non-root treatment, 0.02 % solution	1.41±0.096	3.10±0.255	0.79±0.053	0.79±0.053
Same as above, 0.05 % solution	2.57±0.12	5.65±0.29	1.42±0.070	1.35±0.060
	Against the background of $N_{40}P_{60}$			
Background	0.13±0.006	0.46±0.022	0.12±0.007	0.19±0.011
Background + KI, seed treatment, 0.02 % solution	0.15±0.080	0.60±0.035	0.16±0.009	0.24±0.017
Background + KI, into soil, 1.5 kg/ha	0.23±0.014	0.76±0.056	0.26±0.012	0.41±0.022
Background + KI, non-root treatment, 0.02 % solution	1.20±0.072	4.00±0.281	0.88±0.054	1.30±0.090
The same, 0.05 % solution	2.42±0.10	7.10±0.35	1.58±0.09	2.47±0.15

hypothyroidism as compared to the use of mineral iodine compounds those are considered to play an auxiliary role.

However, the enrichment of local food stuffs and forages with iodine represents a complicated problem, since due to the structural and functional restrictions of iodine accumulation within aerial parts of plants and, particularly, within their edible parts (for example, in the grains of cereals), the introducing of optimum iodine dozes into soils does not uses to result in a physiologically required increase in iodine content within the aerial part of a harvest.

One of the efficient methods for aerial biomass enriching with iodine could be presented by a non-root spraying of crops with 0.02 to 0.05 % KI solutions. According to the data of our experiments, the non-root treatment of crops during the vegetative stages by means of the solutions of optimum KI concentration has resulted in increasing the content of iodine within the aerial biomass of fodder plants such as corn and oats from about 0.11–0.13 mg/kg (a reference) to the value within the range of 0.8–2.4 mg/kg (Table 4), the latter corresponding to the physiological standard for animals. The content of iodine in the biomass of the harvest after the non-root plant treatment has been 7- to 21-fold increased, whereas due to the presowing seed treatment with KI there was merely an 1.2- to 1.4-fold increase of this parameter observed increased, and after introducing KI into soil there was an 1.8- to 2.2-fold increase. As the content of iodine increased, iodine withdrawal together with the harvest phytomass also increased under the experimental conditions. In contrast to introducing iodine compounds into soil, the accumulation of iodine within aerial parts of plants due to non-root treatment of crops could be considered to proceed according to a barrier-free mechanism, the accumulation value being in direct proportion with iodine concentration in a nutrient solution. Due to this fact the non-root plant treatment represent one of the most efficient ways to control the amount of iodine within aerial parts of plants.

In order to increase the content of iodine within underground plant organs such as storage roots and tuberous roots, an introducing of iodine into soil is considered to be more appropriate, since iodine is more actively absorbed by underground edible parts of plants from soil. Introducing the optimum dozes of iodine compounds (0.25–2.0 kg/ha) promoted a 10- to 22-fold increase in the content of iodine within underground plant organs (storage roots and tuberous roots); in this case the content of iodine within aerial parts of plants increased insignificantly [23].

The selectivity of iodine accumulation is inherent also to the organs and tissues of animals, therefore under the addition of iodine compounds to the ration the content of this element within different organs and in livestock farming products is different. So, for the muscles (meat) iodine content grows insignificantly, whereas for the thyroid and mammary glands, as well as for cow's milk and hen's egg the accumulation of iodine is observed to occur according to a directly proportional dependence. By means of increase in the fraction of iodine content in the ration the content of iodine in eggs could be 100-fold increased, and that in milk could be increased 10 to 15 times [24]. In the USA the dietary intake of iodine entering together with dairy products (milk *etc.*) for the adult part of the population amounts to 58 % (being for children as much as 80 %) of daily standard [4] for iodine intake. Thus, the enrichment of fodder plants and livestock farming products with iodine is one of the most natural (*i.e.* biological) ways to solve the important economic problem of iodine deficiency for prevalent biogeochemical provinces with a scarcity of this vitally important microelement.

CONCLUSION

1. The features of iodine distribution have been studied as well as the levels of iodine content have been determined for soil-forming rocks (amounting to 0.27–1.8 mg/kg), superficial and underground potable water (0.4–5.6 μg/L), for dominating types of soils (1.5–6.1 mg/kg) and for the plants inherent in the steppe, meadow and agricultural landscapes (ranging within 0.08–0.20 mg/kg) characteristic of Transbaikalia. A low iodine reserve has been revealed for all parts of the biogeochemical food chain, which is the reason of endemic goitre wide spread occurrence among the population and animals over the region.

2. Non-root treatment of crops by the optimum solutions of potassium iodide represents an efficient way to enrich the aerial parts of plants with iodine, since the accumulation of this element due to the use of this method proceeds according to a "barrier-less" mechanism.

REFERENCES

1 A. P. Vinigradov, Vvedeniye v geokhimiyu okeana, Nauka, Moscow, 1967.
2 A. P. Avtsyn, A. A. Zhavoronkov, M. A. Rish, L. S. Strochkova, Mikroelementozy cheloveka, Meditsina, Moscow, 1991.
3 I. I. Dedov, O. A. Yudenich, G. A. Gerasimov, I. P. Smirnov, *Probl. Endokrinol.*, 3 (1992) 6.
4 S. Yu. Sukhinina, G. I. Bondarev, V. M. Poznyakovskiy, *Vopr. Pitaniya*, 3 (1995) 12.
5 V. L. Sviderskiy, A. E. Khovanskikh, E. V. Rosengart, *Dokl. RAN*, 5 (2004) 698.
6 L. M. Farkhutdinova, *Ibid.*, 396, 5 (2004) 705.
7 I. I. Zharnikov, III Sibirskaya konf. "Mikroelementy v biosfere i primeneniye ikh v sel'skom khozyaystve i meditsine Sibiri i Dalnego Vostoka" (Thesises), Ulan Ude, 1971.
8 S. N. Baldaev, S. A. Kirillov, Korma i profilaktika endemicheskikh bolezney ovets, Buryat. kn. izd-vo, Ulan Ude, 1986.
9 Yu. G. Pokatilov, Biogeokhimiya mikroelementov i endemicheskiye bolezni v Barguzinskoy kotlovine (Zabaikalye), Nauka, Novosibirsk, 1983.
10 L. A. Reshetnik, S. B. Tarmaeva, A. B. Bimbaev *et al., Sib. Med. Zh.,* 44, 3 (2004) 73.
11 N. I. Bazilevich, A. A. Titlyanova, V. V. Smirnov *et al.*, Metody izucheniya biologicheskogo krugovorota v razlichnykh prirodnykh zonakh, Mysl', Moscow, 1978.
12 B. A. Dospekhov, Metodika polevogo opyta, Kolos, Moscow, 1979.
13 G. F. Proskuryakova, O. N. Nikitina, *Agrokhim.*, 7 (1976) 140.
14 G. N. Zaitsev, Matematicheskiy analiz biologicheskikh dannykh, Nauka, Moscow, 1991.
15 Trebovaniya k proizvodstvu i rezultatam mnogotselevogo geokhimicheskogo kartirovaniya, IMGRE, Moscow, 2002.
16 A. Kabata-Pendias and H. Pendias, Trace Elements in Soils and Plants, CRC Press, Boca Raton, 1985.
17 H. J. Bowen, Environmental Chemistry of the Elements, Acad. Press, London, 1979.
18 I. P. Kondrakhin, Alimentarnye i endokrinnye bolezni zhivotnykh, Agropromizdat, Moscow, 1989.
19 D. C. Whitehead, *J. Soil. Sci.*, 24, 2 (1973) 260.
20 G. A. Konarbaeva, Galogeny v pochvakh yuga Zapadnoy Sibiri, Izd-vo SO RAN, Novosibirsk, 2004.
21F. A. Tikhomirov, S. V. Kasparov, B. S. Prister, *Pochvoved.*, 2 (1980) 54.
22 N. I. Lebedev, Ispolzovaniye mikrodobavok dlya povysheniya produktivnosti zhvachnykh zhivotnykh, Agropromizdat, Leningrad, 1990.
23 V. V. Shirokov, E. P. Kremlev, V. I. Panasin, *Khim. Sel. Khoz.,* 8 (1985) 40.
24 V. K. Kashin, Proc. XI Vsesoyuz. konf. (Thesises), Samarkand, 1990, pp. 367–368.