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Cesium-137 distribution in soil and Leccinum aurantiacum in a spruce-aspen forest ecosystem

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Abstract. The assessment of caesium-137 accumulation in parts of fungi fruiting bodies of Leccinum aurantiacum (Bull.) Gray in a mixed spruce-aspen forest on sod-podzolic soil was carried out. Average specific activity of cesium-137 for caps is 1814±112 Bq/kg and for stems 873±73 Bq/kg. It was found that the specific activity of cesium-137 does not exceed the permissible values, but significantly differs between the cap and stem of fruit bodies. The coefficients of cesium-137 accumulation from soil vary for caps from 4.6 to 6.1 and for stems from 1.7 to 2.8. High specific activity of cesium-137 in aspen leaf fall 289±27 Bq/kg and litter 339±23 Bq/kg compared to the underlying soil horizons was noted.

1 Introduction

Cesium-137 contamination of European ecosystems is global in nature. It is caused by the consequences of nuclear weapons testing [1] and accidents at nuclear power facilities [2], the largest of which is the accident at the Chernobyl nuclear power plant [3]. Even if the activity of the isotope does not exceed permissible values in soil, some components of ecosystems accumulate cesium-137 in quantities exceeding permissible values.

Mixed spruce-aspen forests are a common forest formation in the Leningrad Region. It is known that aspen and spruce prefer soils richer than birch and pine. One of the species of wild edible fungi forming ectotrophic mycorrhiza [4] in the forests of this type is *Leccinum aurantiacum* (Bull.) Gray [5]. The population harvests it as an additional source of food, due to its high nutritional value.

It is necessary to study cesium-137 distribution between wild edible fungi of *L. aurantiacum* species and sod-podzolic soil in a mixed spruce-aspen forest ecosystem, because cesium-137 contamination zones are marked in the study area actively used by St. Petersburg population for countryside recreation.

2 Materials and methods

Fruiting bodies of *L. aurantiacum* were collected and soil samples were taken in a mixed spruce-aspen forest (Figure 1) located between the Kremenka River and the Oredezh River

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(N 59°04.673', E030°28.099', H 58 m) (Gatchinsky District, Leningrad Region, Russian Federation). The cover of green mosses at the place of fruit body collection is insignificant. The shrub layer is represented by bilberry. The soil is soddy-podzolic, covered with fallen aspen leaves. The maximum number of roots is in the peated forest litter at a depth of 3 to 6 cm, the depth of the podzolic horizon from 13 cm (Figure 2).

At the base of the stems of fruiting bodies is a focus of white mycelium and ectomycorrhizal rootlets (figure 3). Each fruiting body was photographed (figures 4-8), unique photo numbers were used to number the studied fruiting bodies. The fruiting body on the left (figure 4), heavily damaged by insect larvae, was lost due to lysis.

Soil samples and of fungi fruiting bodies were dried in a stream of warm air to constant air-dry weight. The specific activity in the cap and stem of fungi fruiting bodies was measured separately. Specific activity of cesium-137 in soil and fruit bodies of fungi was measured by beta-radiometry, radionuclide composition of the sample was determined by gamma spectrometry.

To characterize the uptake of cesium-137 by of fungi fruiting bodies of *L. aurantiacum* species from sod-podzolic soil, we used the accumulation factor in relation to the soil layer with the maximum number of tree species roots.

Fig. 1. Mixed aspen-spruce forest.

Fig. 2. Soil at the fruit body collection site.

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Fig. 3. White mycelium focus at the base of the fruiting bodies.

Fig. 4. Fruiting bodies of L. aurantiacum – 8377.

Fig. 5. Fruiting bodies of L. aurantiacum – 8383.

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Fig. 6. Fruiting body of L. aurantiacum – 8391.

Fig. 7. Fruiting body of L. aurantiacum – 8395.

Fig. 8. Fruiting body of L. aurantiacum – 8397.

3 Results and their discussion

The choice of this site was due to the massively compact fruiting bodies of *L. aurantiacum* on a limited area. Besides, the specified forest ecosystem is located near a swampy area of the forest, where in the conditions of peaty-gley soil the specific activity of fungi fruiting bodies exceeds permissible values. It should be noted that in the area of research the specific activity of cesium-137 in peat soils is distributed unevenly and in a number of cases exceeds the permissible values [6].

The results of the measurement of specific activity in the upper part of the profile of sod-podzolic soil are given in table 1 and graphically presented in figure 9.

The high specific activity of aspen leaf fall (table 1) in comparison with activity in conifers and their fallen leaves attracts attention. In work [7] it was established that aspen Populus tremula possesses attributes of plants of hyperaccumulator of cesium-137 in terrestrial phytomass. Thus, aspen leaf fall (table 1 and figure 9) is a source of cesium-137 enrichment of litter.

Cesium-137 deposition has different effects on ecosystem components. Thus, in [8] it was found that the seeds of conifers have a low level of contamination. The authors also point out that despite the absorption of cesium-137 by roots from the soil, the activity of the radionuclide in the seeds is low. Our observations show that in the presence of cesium-137 in podzolic soil, in comparison with aspen leaf fallout, coniferous fallout, branches and roots have low activity.

Table 1. Specific activity of cesium-137 in soil horizons.

№	Soil horizon	H, cm	m, g	$\bar{Q}\pm\Delta Q$* Bq/kg
1	Aspen leaf litter	-	10.0	289±27
2	Litter	0-1.5	10.0	316±17
3	Litter	1.5-3.0	10.0	311±18
4	Litter	3.0-4.5	10.0	352±25
5	Litter	4.5-6.0	10.0	325±21
6	Humus	6.0-10.0	25.0	288±11
7	Humus	10.0-13.0	25.0	265±11
8	Podzolic	13.0-20.0	40.0	195±7

* – the average activity confidence interval was calculated at the significance level $p<0.05$

Study of soil and vegetation of boreal forests subjected to cesium-137 fallout as a result of the Chernobyl accident is of significant interest in connection with the study of isotope migration processes as a result of forest fires [9] contributing to radionuclide transfer. The obtained data allow us to estimate the content of cesium-137 in various components of the spruce-aspen forest ecosystem on sod-podzolic soil.

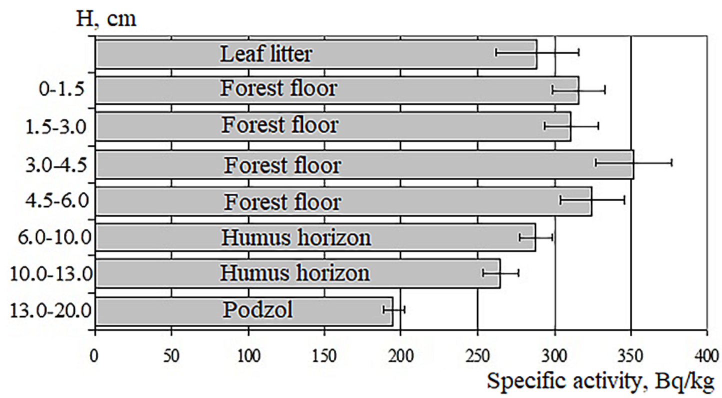

Fig. 9. Distribution of specific activity of cesium-137 in the profile of sod-podzolic soil.

It has been determined that caesium-137 accumulation occurs in the upper part of soil profile both in natural ecosystems [10] and in agrolandscapes [11] which have been subjected to contamination as a result of accidents at atomic power plants. Moreover, for natural ecosystems a sharp decrease of caesium-137 activity with depth was noted [10]. The obtained data on cesium-137 distribution in the soil profile (table 1 and figure 9) agree with these facts.

The main mass of aspen and birch roots with which *L. aurantiacum* forms ectomycorrhizal rootlets is located at the depth of 3.0 to 6.0 cm: the cut roots of woody species are visible on the cross section of the upper soil horizon (figure 2). Therefore, to calculate the accumulation coefficient we used the average value for these layers (lines 4 and 5 of table 1), which was 339±23 Bq/kg.

The data obtained from the results of measurement of cesium-137 specific activity in the cap and stem of fruit bodies of *L. aurantiacum* species fungi are presented in Table 2.

Table 2. Cesium-137 specific activity in fruiting bodies of *Leccinum aurantiacum.*

No	Photo No	Fig.	Cap $\bar{Q}\pm\Delta Q$* Bq/kg	CA_{cap}**	Stem $\bar{Q}\pm\Delta Q$ Bq/kg	CA_{stem}**	R***
1	8377 r	4	1545±134	4.6±0.7	843±41	2.5±0.3	1.8±0.2
2	8383 l	5	1942±124	5.7±0.8	697±71	2.1±0.3	2.8±0.5
3	8383 r	6	1767±111	5.2±0.7	699±37	2.1±0.2	2.5±0.3
4	8391	7	2082±146	6.1±0.8	984±100	2.9±0.5	2.1±0.4
5	8395	8	1832±81	5.4±0.6	984±114	2.9±0.5	1.9±0.3
6	8398	9	1715±75	5.1±0.6	1029±77	3.0±0.4	1.7±0.2

Notes: * - calculation of the confidence interval of the average activity was performed at the significance level $p<0.05$; ** - coefficient of accumulation of cesium-137 by cap and stem of a fruit body from a root-inhabited soil layer; *** - ratio of specific activities in the cap and stem of a fruit body of the fungi.

The coefficient of variation of the specific activity for dry caps of fruit bodies (table 2) is 10.3 %, which allows characterizing its variability as being on the border between insignificant and average. The coefficient of variation of specific activity for dry stems of fruit bodies (table 2) is 17.1 %, which allows us to characterize its variability as average.

The coefficients of accumulation by caps of fruit bodies in relation to the soil horizon with the maximum root content varied from 4.6 to 6.1 (table 2), which is higher than the values for fungi stems from 1.7 to 2.8 (table 2).

The ratio of specific activities in the cap and stem of fruiting bodies of *L. aurantiacum* fungi (table 2) shows that the cap accumulates 1.7-2.8 times more cesium-137 than the stem. This is caused by the fact that the cap hymenophore is the site of the sexual process in fungi. Any reproductive structure has an active metabolism, which leads to an increased concentration of radionuclides. In addition, the cap is the ultimate consumer of cesium-137. Fruiting bodies of fungi with tubular hymenophores are 90% composed of water, which actively evaporates, which also contributes to the concentration of cesium-137 in the cap, while the fungi stem performs supporting and conducting functions.

The average specific activity of cesium-137 on the studied fruiting bodies of fungi for caps makes 1814±112 Bq/kg, and for stems 873±73 Bq/kg. At present in the Russian Federation the permissible activity of cesium-137 for dry fungi makes 2500 Bq/kg [12]. Thus, the collected fungi can be consumed as food.

Regarding the last aspect it is necessary to make the following clarification. For fungi with tubular hymenophores, culinary use is allowed without preliminary boiling and draining of water. However, it should be taken into account that pre-cooking fungi containing cesium-137 significantly reduces its concentration. Although the permissible concentration is not exceeded, it should be remembered that cesium-137 is an isotope that was not found in nature until mankind began mining, concentrating, and using radioactive materials. The effect of this isotope in low doses on a test biological object has been established [13].

4 Conclusion

The specific activity of137 Caesium in dry caps and stems of fruit bodies of *L. aurantiacum* does not exceed the permissible values. It is established that the activity in caps is 1.7-2.8 times higher than the activity in the stems of fungi fruiting bodies. Coefficients of caesium-137 accumulation from soil varied for caps from 4.6 to 6.1 and for stems from 1.7 to 2.8. The study found that the maximum specific activity of caesium-137, amounting to 339±23 Bq/kg, is confined to peated forest litter, where in a layer 3-6 cm deep the main amount of spruce and aspen roots is concentrated. Ectomycorrhizal connection of *L. aurantiacum* mycelium with roots of tree species and their obligate symbiotrophic nutrition are the reason for both redistribution of cesium-137 in the soil profile and its selective absorption by fruiting bodies of fungi.

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