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DISTRIBUTION OF RADIONUCLIDES IN ARTIFICIAL FOREST ECOSYSTEM COMPONENTS OF THE FIELD PROTECTIVE PLANTATION IN THE STEPPE UKRAINE (DNIPROPETROVSK REGION)

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Abstract
A radioecological analysis of three components of the ecosystem of artificial forest plantations of *Robinia pseudoacacia*, as soil, forest litter, tree leaves was done. The highest concentrations of ^{226}Ra, ^{232}Th, ^{40}K natural radionuclides and the value of integral indicators of effective specific radioactivity and absorbed dose rate were found in forest litter, the lowest in foliage. The values of the indicators of the effective specific radioactivity and the absorbed dose rate in the forest litter decreased during the autumn-winter period, which indicates a seasonal decrease in the radiation background due to the migration of dose-forming radionuclides into deeper soil layers. In the autumn-winter period, the concentrations of ^{137}Cs and ^{90}Sr radionuclides in the soil layer of the artificial forest belt ecosystem increased by 1.5–2 times, although they did not exceed the permissible norms. As the age of the trees increased, the indicators of the content of natural radionuclides and the effective specific radioactivity decreased in the surface layer of the soil. The levels of ^{137}Cs and ^{90}Sr artificial radionuclides were 20–40 times lower than the natural ones.

Keywords: artificial forest plantations, radionuclides, effective specific radioactivity, absorbed dose rate.

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INTRODUCTION

Forest improvement is one of the priority measures aimed at the protection and rational use of land and the reproduction of soil fertility. Forests are the most powerful factor in counter acting the arid climate of the south eastern regions of Ukraine, they protect the natural environment, are of significant importance for soil protection and water regulation, prevent the formation of hot dry winds and dust whirls, change the hydrological regime of the territory, etc. (Rozum et al. 2017). The expansion of forest protective, recreational, decorative, reforestation plantations in the steppe Ukraine contributes to the improvement of soil fertility and an increase in the efficiency of using the natural resources of the territory. Resistant vegetation cover traps suspended sediment flow, shields part of the soil surface. The formation and development of the vegetation cover is accompanied by an increase in its buffer role in the migration of radionuclides (Irklienko et al. 2001). In this regard, the role of artificial windbreakers in limiting the migration of radioactive isotopes of natural and artificial origin attracts considerable interest.

The concept of sustainable development of agroecosystems for the period up to 2025, approved by the Presidium of the National Academy of Agrarian Sciences of Ukraine in 2003, provides for the intensification of work both to preserve forest gene pools and to purposefully increase the area of forest plantations (Furdychko, 2003). It has been established that a forest ecosystem is a type of ecosystem that firmly retains radionuclides. The forest can influence the migration of radionuclides on a global scale. Radionuclides deposited on tree crowns move to the forest litter under the influence of atmospheric precipitation and as a result of leaf fall and are involved in the main bioecological processes (Nishina & Hayashi 2005, Manigandan & Manikandan 2008, Krasnov & Landin 2013).

Naturally Occurring Radioactive Materials (NORM) refers to the natural origins of radiations i.e. from naturally occurring radioisotopes. Terrestrial radionuclides contain nucleogenesis or primordial natural radioactive isotopes. This can be classified into: natural radioactive decay series (^{235}U, ^{238}U, and ^{232}Th) and the daughter nuclides with relatively long half-lives and the daughter elements of these daughter nuclides, for example, ^{226}Ra, ^{210}Pb, and ^{210}Po. The second group is the long-life nuclei, which become stable daughter nuclides in one-step; ^{40}K is the most critical radionuclide in this group. Changing in the natural state of NORM causes technologically enhanced naturally occurring radioactive material (TENORM), or enhanced levels of NORM (Michalik et al. 2013). The anthropogenic activities such as coal mining, oil and gas extraction, coal combustion in thermal power plants, geothermal energy production, water and wastewater treatment, application of phosphate fertilizers, uranium, thorium and copper mining can increase the level of naturally occurring radioactive particles (Walther & Gupta 2015, Ahmad et al. 2019).

Artificial concentrations are the ones that results from human activities. Due to ^{137}Cs and ^{90}Sr comparatively long half-life (30 and 29 years respectively), considerable amounts of ^{137}Cs and ^{90}Sr are present in soil. The main sources of artificial radionuclides in the environment worldwide are from nuclear atmospheric testing and regionally from the releases from the Chornobyl accident in 1986 and the Fukushima accident in 2011 (Modelling… 2002, Environmantal… 2006, Hashimoto et al. 2021).

The accumulation of radionuclides in the constituent components of forest biocenoses is determined by the intake of radionuclides during root nutrition of plants (Markovic & Stevovic 2019). At the same time, the main place of concentration of radionuclides in the biogeocenosis is soil and organic litter fall. Moss carpet plays a significant role in the redistribution of radionuclides. Due to the decomposition of organic litter fall, there is a gradual deepening of radionuclides into the mineral part of the soil. The quantitative characteristics of this process differ from each other depending on the types of forest site (Krasnov & Landin 2013; Melnyk 2020).

The degree of soil moisture plays an important role for the rate of vertical migration. With an increase in humidity, the intensity of migration of radionuclides increases, and accordingly, their content in the forest litter increases. An important factor in the redistribution of radionuclides between the forest litter and the mineral part of the soil is the population composition of plantations. (Markovic & Stevovic 2019).

Extensive radioecological studies were carried out in the forest ecosystems of Ukraine after the accident at the Chornobyl nuclear power plant, but only a few of them were directly devoted to the study of the transition of radionuclides into plants, the characteristics of the accumulation and content of radionuclides in plant parts. The processes of migration of radioactive elements in artificial forest plantations have hardly been studied. (Irklienko et al. 2001, Krasnov & Landin 2013, Chorna & Ananieva 2020).

The purpose of our work was to identify the patterns of migration of radionuclides in the abiotic and biotic components of artificial forest ecosystems.

MATERIALS AND METHODS

Samples of natural material were taken in 2020–2021 on the territory of agricultural land near the Maiorka village of Dniprovskyi district (48.264627, 35.165395). It had been observed the field protective forest strip on the border of the dirt road and agricultural land. The main tree species is *Robínia pseudoacacia* L. The height of the trunks is 12-15 m. Ordinary planting of five rows. Distances between trees in rows make 1-3 m, between rows – 2.5 m. Planting width 4.5 m. Closure of crowns – 50 %. Age 60 years. The 60-year-old plantation is an artificially created strip of wood, and the 15-year-old and 5-year-old plantations are the result of natural regeneration of the *Robínia pseudoacacia* plantation. Since the original 60-year-old plantation was created artificially, it is significantly crowded compared to the other two plots that arose by natural seeding. *Robínia pseudoacacia* is an invasive species in the Steppe Ukraine, well acclimatized to local climatic conditions. The tree breed is widely used to create artificial recreational and field-protective plantings. Due to the favorable climate, it can spontaneously spread over vast areas.

Sample plots were selected according to groupings of robinia with a predominance of 60-, 15-, and 5-year-old trees in the age structure. The thickness of the forest litter was 4.0, 2.5, and 1.0 cm, respectively. Soil samples were taken at a depth of 20–25 cm in accordance with standard GSTU 4287:2004 (2005). Totally, 240 samples were analyzed.

The primary preparation of natural material consisted in grinding using a laboratory mill and drying in a dry heat oven to constant weight at a temperature of 105°C. The specific activity of radionuclides was determined in samples weighing 10–20 g on a scintillation spectrometer of gamma radiation SEG-001 "AKP-C" and a spectrometer of beta radiation SEB-01-150 (Ukraine) in Bq/kg of dry weight.

To assess the overall level of radioactivity, which is created in the components of the ecosystem by the main dose-forming radionuclides, and the possible effect on the biota, the integral indicators of the effective specific radioactivity and the absorbed dose rate were calculated.

The integral indicator of the effective specific activity of natural radionuclides in soil and forest litter was calculated using the formula (Radiation Safety Standards of Ukraine-97, 1997):

$$A_{ef} = A_{Ra} + 1.31A_{Th} + 0.085A_{K} \quad (1)$$

To assess the risk of radiation exposure to biota, the absorbed dose rate was calculated using the conversion factors recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation, 2000 (Abba et al. 2018, Abedin et al. 2019, Gad et al. 2019):

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_{K} \quad (2)$$

The intensity of the background radiation was measured using a digital dosimeter-radiometer RKS-01 "STORA" (Ukraine). The power of the natural background radiation in the study area did not exceed the established sanitary and hygienic standards, the value ranged from 0.085 to 0.275 μSv/h.

The obtained numerous data were subjected to mathematical processing by the generally accepted methods of variational statistics for a small sample. Statistical processing was carried out using Statsoft Statistica 10.0. The obtained data of average values are presented in the figures, standard deviations do not exceed 5–7 % that corresponds to the quality control standards of the results of the analysis of internal laboratory control and characterizes them as reliable.

RESULTS AND DISCUSSION

The forests of the Dnipropetrovsk region have no industrial significance, they mainly perform ecological, protective and recreational functions and have an environmental, scientific, historical and cultural purpose. The beneficial properties of forests in the region are extraordinary, since they are able to reduce the negative effects of natural phenomena, protect the soil from erosion, prevent pollution and cleanse the natural environment, contribute to the regulation of water flow, improve the health of the population and its aesthetic education. The forest belt significantly reduces the noise load, which is a problem in large industrial cities, which include the city of Dnipro and its satellites.

According to calculations, the optimal forest cover in the Dnipropetrovsk region should be 8–10 %, currently it is only 5.6 % (in Ukraine this indicator is 15.6 %) (Regional report… 2020).

In the Dnipropetrovsk region, a system of artificial forest plantations has been formed, it consists of large tracts, windbreakers, water protection plantations and areas of restoration plantations within natural forest ecosystems (ravine, floodplain and arena forests). They perform soil protection and water protection, phytomeliorative, recreational functions, increase landscape and species diversity, are reservations of valuable species of plants and animals that are part of ecological corridors and eco-nuclei in the system of the ecological network of Ukraine, have great ecological potential. However, in the modern period, a significant number of them are in an unsatisfactory destructive state, which is due to both natural reasons (age-related crisis state) and anthropogenic impact (deforestation, fire, etc.).

The object of our research was the processes of accumulation and migration of the main dose-forming radionuclides and the forming effective specific radioactivity and absorbed dose rate in artificial forest plantations.

In order to study the features of the migration of ^{226}Ra, ^{232}Th, ^{40}K, ^{137}Cs and ^{90}Sr radioactive isotopes in the biogeocenosis of the sanitary-protective windbreaker, a radioecological analysis was carried out in three components of the ecosystem of artificial forest plantations of *Robinia pseudoacacia*, as soil, forest litter, tree leaves.

The levels of natural and artificial radionuclides in the soil of artificial forest plantations of Robinia pseudoacacia. It was revealed that in the summer period ^{226}Ra concentrations in soil samples varied from 19.8 to 27.2 Bq/kg, and in locations where 60-year-old trunks prevailed, the level of ^{226}Ra in soil was lower by an average of 16.1 % compared to arrays of younger trees (Fig. 1).

The content of ^{232}Th in the soil of the studied points was more uniform. The absolute values of the specific radioactivity of ^{232}Th were found in the range from 29.8 to 35.4 Bq/kg, the average statistical decrease in the places where older trees grew was 8.0 %. The level of ^{40}K in the soil ranged from 32.6 to 41.2 Bq/kg and decreased with an increase in the age of trees by an average of 17.1 %.

In the autumn and winter periods, insignificant increases in the ^{226}Ra content in the soil were found on average by 33 and 11%, while the ^{232}Th content decreased by 45 %. The concentration of ^{40}K in the soil in the winter-autumn period almost doubled to 73.44 and 67.58 Bq/kg. Obviously, a significant increase in the ^{40}K content is associated with its intense input from the above-soil layer. The results obtained are in good agreement with the data of other authors (Abba et al. 2018), who noted that the rate of

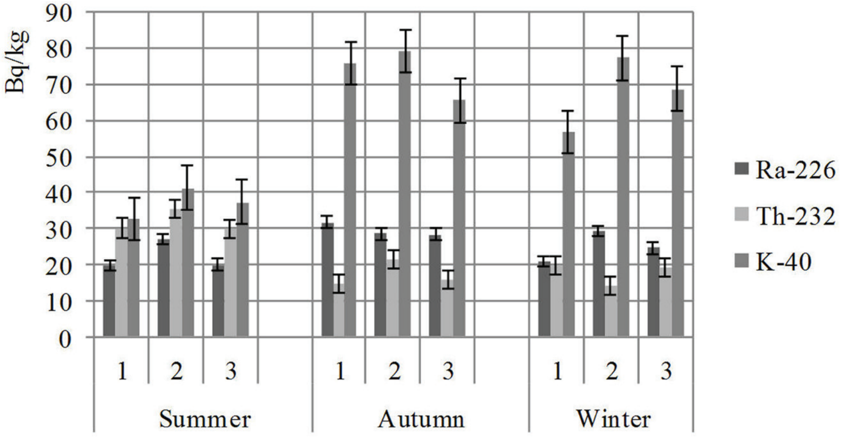

Figure 1. The levels of natural radionuclides (Bq/kg of dry weight) in the soil under artificial forest plantations of *Robinia pseudoacacia*: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

migration of radionuclides depends on the granulometric composition of the soil in the following sequence: $^{40}K > ^{232}Th > ^{226}Ra$.

The values of integral indicators of effective specific radioactivity in soil varied, respectively, from 59.04 to 77.07 Bq/kg in summer and from 51.30 to 54.43 Bq/kg in winter; absorbed dose rate – from 28.69 to 35.67 nGy/h in summer and from 23.81 to 25.67 nGy/h in winter (Table 1).

It should be noted that the values of the integral indicators did not change significantly during the studied seasons of the year, which indicated a redistribution of radioactive elements in the soil layers due to differences in their mobility and migration capacity. The data obtained indicated that the levels of radioactivity in the study area were within the permissible radiation background and did not pose a risk to biological objects.

The measured concentrations of ^{137}Cs and ^{90}Sr artificial radionuclides in the soil layer of the ecosystem of the *Robinia pseudoacacia* artificial forest belt were 20–40 times lower than in natural one (Fig. 2), which is consistent with their small proportion in the chemical composition of the soil. The levels of ^{137}Cs and ^{90}Sr in most cases did not depend in a regular way on the age structure of communities of tree plantations of Robinia pseudoacacia in the study area.

In the autumn-winter period, the concentrations of ^{137}Cs and ^{90}Sr radionuclides in the soil layer

Table 1. Integral indicators of effective specific radioactivity (A) and absorbed dose rate (D) in the soil under artificial forest plantations of *Robinia pseudoacacia.*

Indicator	Sampling point	July	November	February
Effective specific radioactivity (A, Bq/kg)	1	62.0	57.63	51.30
	2	77.07	63.62	54.43
	3	59.04	54.68	55.26
Absorbed dose rate (D, nGy/h)	1	28.69	26.78	23.81
	2	35.67	29.42	25.29
	3	28.8	25.40	25.67

Note: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

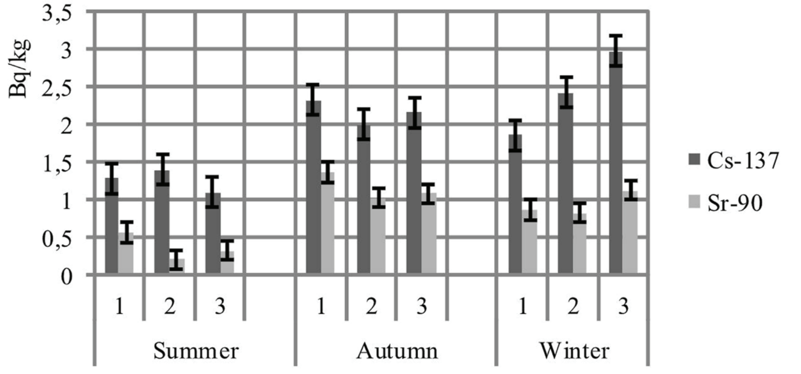

Figure 2. The levels of artificial radionuclides (Bq/kg of dry weight) in the soil under artificial forest plantations of *Robinia pseudoacacia*: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

of the artificial forest belt ecosystem increased by 1.5–2 times, although they did not exceed the permissible norms. The ^{137}Cs content in the soil varied from 1.1 Bq/kg in summer to 2.33 Bq/kg in autumn and 2.97 Bq/kg in winter. Moreover, in the winter period, a uniform increase in the content of ^{137}Cs in the soil was noted in inverse relationship to the age of tree plantations of *Robinia pseudoacacia*.

Concentrations of ^{90}Sr varied from 0.57 Bq/kg in summer to 1.37 Bq/kg in autumn and 1.13 Bq/kg in winter, no dependence on the age structure of woody vegetation was observed.

The levels of natural and artificial radionuclides in the above-soil layer of artificial forest plantations of Robinia pseudoacacia. The above-soil layer of the windbreak consists of dead soil cover and forest litter, which are formed by fallen leaves, grass vegetation and other natural substrates. The processes of destruction and biochemical transformation of plant residues are intensively occurring in the forest litter, therefore it is one of the most important components of the forest group and a structural and functional component that unites the abiotic and biotic parts of the biogeocenosis into an integral system (Tsvetkova & Yakuba 2011).

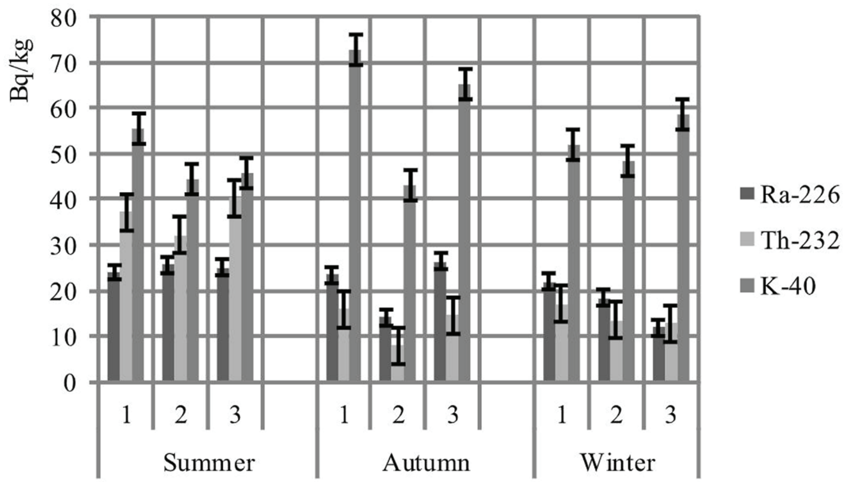

Figure 3. The levels of natural radionuclides (Bq/kg of dry weight) in the above-soil layer of artificial forest plantations of *Robinia pseudoacacia:* 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

The study of the content of radionuclides in the samples of the above-soil layer of the windbreak showed that in the summer period ^{226}Ra concentrations varied from 24.0 to 25.7 Bq/kg, ^{232}Th concentration – from 32.1 to 40.2 Bq/kg, ^{40}K concentration – from 44 4 to 55.3 Bq/kg (Fig. 3).

In the autumn and winter periods, a uniform decrease in the content of natural radionuclides in the forest litter was observed, probably due to their vertical migration into deeper soil layers. It is known that the acidity of the bedding layer affects the development of and vital activity of microorganisms and, as a consequence, the intensity of decomposition processes organic matter and the release of radionuclides into the soil (Yakuba & Gorban 2021). The specific radioactivity absolute values of ^{226}Ra were found in the range from 14.03 to 26.43 Bq/kg in autumn and from 11.87 to 21.97 Bq/kg in winter, the seasonal decrease averaged 14.5 % and 30.2 %, respectively. The ^{232}Th content levels varied from 7.97 to 15.97 Bq/kg in autumn and from 12.80 to 16.97 Bq/kg in winter, the radioactivity of ^{232}Th decreased by an average of 63.5 % in the autumn-winter season.

For ^{226}Ra and ^{232}Th natural radionuclides, a regular decrease in the specific radioactivity in the above-soil layer was noted as the age of tree plantations decreased, the most pronounced was in winter. The levels of ^{40}K in forest litter ranged from 43.0 to 72.67 Bq/kg in autumn and from 48.43 to 58.57 Bq/kg in autumn. An increase in ^{40}K radioactivity by 24.4 % was noted in the autumn period, probably due to its intense influx into the above-soil layer with fallen leaves.

Integral indicators of effective specific radioactivity and absorbed dose rate in the above-soil layer varied depending on the season of the year (Table 2).

The values of the effective specific radioactivity indices varied, respectively, from 71.52 to 81.66 Bq/kg in summer and from 33.62 to 48.60 Bq/kg in winter; absorbed dose rate in forest litter – from 33.11 to 37.79 nGy/h in summer and from 15.65 to 22.56 nGy/h in winter, which also indicates a seasonal decrease in the background radiation due to the migration of dose-forming radionuclides into deeper soil layers.

Concentrations of ^{137}Cs artificial radioisotopes in forest litter varied from 1.2 to 1.32 Bq/kg in summer, from 0.96 to 2.07 Bq/kg in autumn, and from 0.90 to 1.70 Bq/kg in winter. The ^{90}Sr content levels were determined within the range of 0.6–0.12 Bq/kg in summer, 0.61-1.27 Bq/kg in autumn, and 0.58–1.07 Bq/kg in winter (Fig. 4).

Thus, the radioactivity of ^{137}Cs and ^{90}Sr artificial isotopes increased in the autumn-winter period by 22.2 % and 76.7 %, respectively. For ^{90}Sr radionuclides, a regular decrease in the specific radioactivity in the forest litter was determined with a decrease in the age of tree plantations.

Table 2. Integral indicators of effective specific radioactivity (A) and absorbed dose rate (D) in the above-soil layer of artificial forest plantations of *Robinia pseudoacacia.*

Indicator	Sampling point	July	November	February
Effective specific radioactivity (A, Bq/kg)	1	77.43	50.56	48.60
	2	71.52	28.13	40.17
	3	81.66	50.95	33.62
Absorbed dose rate (D, nGy/h)	1	35.87	23.51	22.56
	2	33.11	13.08	18.67
	3	37.79	23.68	15.65

Note: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

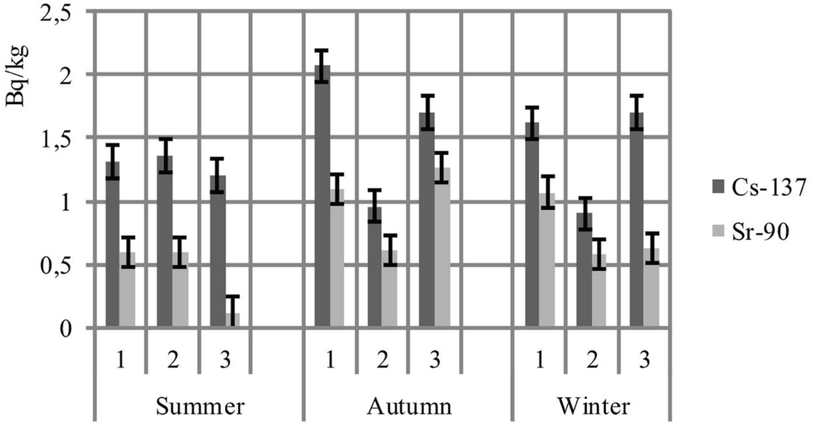

Figure 4. The levels of artificial radionuclides (Bq/kg of dry weight) in the above-soil layer of plantings of *Robinia pseudoacacia*: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

Conducted correlation analysis of the radioactivity concentration in the forest litter and soil layer, resulted in high values of the obtained Pearson coefficients for ^{137}Cs (R=0.64), ^{232}Th (R=0.61) and ^{40}K (R=0.72), that indicates a significant positive relationship between processes of migration and accumulation of radionuclides

The levels of natural and artificial radionuclides in Robinia pseudoacacia leaves in artificial forest plantations. The levels of radioactive elements were determined in the leaf of *Robinia pseudoacacia*, one of the most widespread tree species in the steppe zone for the formation of protective, recreational, decorative, forest reclamation artificial plantations, which is also recommended as biological indicator (Alekseeva 2014). In summer, the concentration of radionuclides in the leaves of trees of different ages varied from 9.8 to 11.3 Bq/kg for ^{226}Ra, from 10.2 to 12.4 Bq/kg for ^{232}Th, and from 12.3 to 16.0 Bq/kg for ^{40}K (Fig. 5).

In autumn, the levels of ^{226}Ra in the Pseudoacacia robinia leaf were determined in the range from 8.67 to 15.5 Bq/kg, ^{232}Th – from 7.4 to 11.13 Bq/kg, ^{40}K – from 16.47 to 27.07 Bq/kg. In the autumn period, an increase in the content of natural radionuclides ^{226}Ra by 18.5% and ^{40}K by 43.2 % was observed in the leaf mass. An inverse relationship was also found between the concentrations of ^{226}Ra and ^{232}Th radionuclides

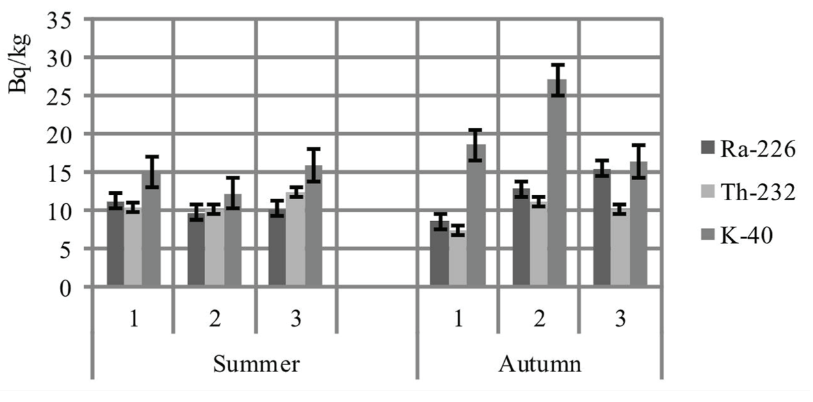

Figure 5. The levels of natural radionuclides (Bq/kg of dry weight) in the leaves of *Robinia pseudoacacia*: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

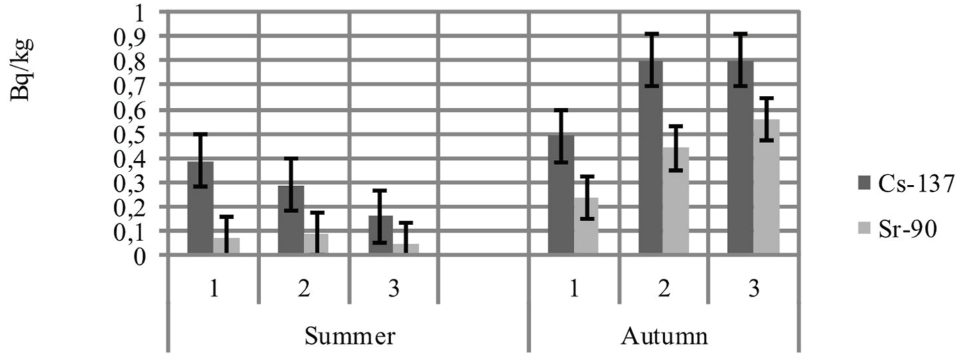

Figure 6. Levels of artificial radionuclides (Bq/kg of dry weight) in the leaves of *Robinia pseudoacacia*: 1– 60-year old trees, 2– 15-year old trees, 3– 5-year old trees.

in the leaf and the age of *Robinia pseudoacacia* trees. Obviously, young trees accumulated radioactive elements at a higher rate due to more intensive processes of conducting solutions and synthesizing organic substances.

The highest concentrations of ^{226}Ra, ^{232}Th, ^{40}K natural terrigenous radionuclides and the value of integral indicators of effective radioactivity and absorbed dose rate were found in the composition of the forest litter, the lowest in the leaf. Perennial woody plants, in contrast to one-two-year-old herbaceous plants, accumulate radionuclides in wood, bark, shoots. And although the main mass of radionuclides is usually concentrated in the leaf, and the smallest in wood, the long-term closed cycle of substances: leaves – forest litter – soil – roots – trunk – leaves can lead to the fact that radionuclides involved in the biological cycle begin to be included in the tissues of plant components, intensively accumulate in their perennial organs, in particular in wood, roots, rhizomes and are excluded from the environment.

Concentrations of ^{137}Cs artificial radionuclides in the foliage of *Robinia pseudoacacia* trees were determined in the range from 0.16 to 0.39 Bq/kg in summer and from 0.49 to 0.80 Bq/kg in autumn. (Fig. 6).

The ^{90}Sr concentration in the leaf varied from 0.05 to 0.09 Bq/kg in the summer season and from 0.24 to 0.56 Bq/kg in the autumn season. Low concentrations of artificial radionuclides in biotic and abiotic components of the ecosystem are associated with their successive “aging” – a decrease in radioactivity because of the ascent of the half-life, removal outside the territory due to solid and liquid surface discharge.

Despite the low levels of the content of ^{137}Cs and ^{90}Sr artificial radionuclides, in autumn their accumulation in the foliage of trees was clearly traced, as a result of which the concentrations of ^{137}Cs and ^{90}Sr increased more than 2 times. In addition, in the autumn period, there was a pattern to an increase in the levels of ^{137}Cs and ^{90}Sr artificial radionuclides and the intensity of their accumulation in the leaf of young *Robinia pseudoacacia* trees.

Thus, the data obtained confirm the significant role of artificial forest plantations in the migration of radioactive elements in the ecosystem.

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CONCLUSIONS

1. The highest concentrations of ^{226}Ra, ^{232}Th, ^{40}K natural radionuclides and the value of integral indicators of effective specific radioactivity and absorbed dose rate were found in forest litter, the lowest in foliage; the values of both integral indicators in the soil and forest litter were within the permissible radiation background and did not pose a risk to biological objects.

2. As the age of the trees increased, the indices of the content of ^{226}Ra, ^{232}Th, ^{40}K natural radionuclides and specific radioactivity decreased in the surface layer of the soil.

3. The values of the indicators of the effective specific radioactivity and the absorbed dose rate in the forest litter decreased during the autumn-winter period, which indicates a seasonal decrease in the radiation background due to the migration of dose-forming radionuclides into deeper soil layers.

4. Changes in the concentrations of ^{137}Cs and ^{90}Sr artificial radioisotopes in the soil and forest litter did not show a regular relationship with the age structure of dendroflora groups, but were probably determined by other factors, such as the rate of their removal from the biological cycle, distance from the source of radioactivity, etc.

5. In the autumn-winter period, the concentrations of ^{137}Cs and ^{90}Sr radionuclides in the soil layer of the artificial forest belt ecosystem increased by 1.5–2 times, although they did not exceed the permissible norms.

6. There was a regularity in relation to the seasonal increase in the levels of ^{137}Cs and ^{90}Sr artificial radionuclides and the intensity of their accumulation in the leaf of predominantly young *Robinia pseudoacacia* trees.

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