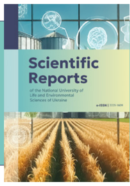
Received 05.11.2024 Revised 30.01.2025 Accepted 27.02.2025

Vol. 21, No. 1
2025



Scientific Reports of the National University of Life and Environmental Sciences of Ukraine

Journal homepage: https://scireports.com.ua/en

UDC 574::539.1.04; 613.648:504.064

DOI: 10.31548/dopovidi/1.2025.132

Root intake of ^{137}Cs in pasture grasses

Sviatoslav Levchuk*

PhD in Biological Sciences, Leading Researcher
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5167-7773

Valerii Kashparov

Doctor of Biological Sciences, Professor, Senior Researcher
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-6460-1049

Valentyna Pavliuchenko

Researcher
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-0986-6444

Abstract. The accumulation of ^{137}Cs in plants can carry risks to animal and human health due to its entry into the body through the food chain. The purpose of the study was to estimate the transition coefficients ^{137}Cs in pasture mixed grasses from the dominant soil types of Ukraine and their dynamics during the growing season. The experiment was conducted on three types of soils, namely: sod-podzolic loam, podzolic chernozem, and typical chernozem. Soils for the experiment were selected in the Kyiv and Zhytomyr oblasts. The density of artificial surface contamination of all soils was the same and amounted to 336 kBq m^{-2}. Radionuclide was applied to the soil surface in a water-soluble form. The plants were grown in a greenhouse in pots with regular watering without fertilisation. The results obtained showed that bioavailability of ^{137}Cs is determined by soil conditions and significantly decreases in the series: sod-podzolic soil > podzolic chernozem > typical chernozem. The obtained average values of the radionuclide transition coefficients to grass for the first mowing ranged from 50 to 4 (Bq·kg^{-1}) /(kBq·m^{-2}) and were maximal for sod-podzolic soil. At the end of the growing season, bioavailability of ^{137}Cs significantly decreased by half for sod-podzolic soil and typical chernozem.

Suggested Citation:

Levchuk, S., Kashparov, V., & Pavliuchenko, V. (2025). Root intake of ^{137}Cs in pasture grasses. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 21(1), 132-141. doi: 10.31548/dopovidi/1.2025.132.

*Corresponding author

No significant changes in the bioavailability of radionuclide were observed on podzolic chernozem. The accumulation coefficients of the stable isotope of caesium (^{133}Cs) are estimated. Compared to the radioactive isotope, stable caesium is characterised by significantly lower bioavailability for plants, but the nature of its dependence on soil conditions is identical to that of ^{137}Cs. Since stable caesium is in the soil in a state of equilibrium, the coefficients of its accumulation by the mixture of grasses did not change during the growing season. The obtained transition parameters, in accordance with soil conditions, can be used in radiological models for conservative estimation of radiation doses of radiation exposure to the population in the first year after radionuclide entry into the environment

Keywords: ^{137}Cs; bioavailability; transition coefficient; caesium; radionuclides; soils, vegetation

Introduction

Technogenic radionuclides enter the environment with emissions from nuclear fuel cycle plants and nuclear power plants (NPPs), with global fallouts after nuclear weapons tests, and as a result of accidents at nuclear facilities. Examples of such major radiation accidents were those at the Chornobyl NPP and the Fukushima Daiichi NPP. In both cases, significant caesium radioisotopes were released into the environment. In addition, now there is a real threat of the use of nuclear weapons on the territory of Ukraine, as a result of which certain territories may be exposed to radioactive contamination. After a certain time following soil contamination (usually in the next growing season), radionuclides begin to enter plants via root, including cultivated plants, which are used for food production. With food, radionuclides enter the human body and irradiate it. One of the radiologically significant technogenic radionuclides is long-lived ^{137}Cs (half-life – 30.08 years), which is a fission product of ^{235}U and ^{239}Pu and is characterised by a high fission yield of about 6%. This radionuclide is characterised by high bioavailability and is one of the main dose-forming radionuclides among fission products. An important way for this radionuclide to enter the human body is the pasture-animals-milk (meat) chain. The main part of internal dose from ^{137}Cs to humans is formed in this way. Given that "fresh" deposition of this radionuclide can be nonequilibrium in the soil environment, information about the dynamics of its bioavailability is extremely important. Some of the radioactive isotopes of caesium are irreversibly absorbed by soil minerals after entering the soil, and their bioavailability decreases over time. This process is called "ageing". It leads to a decrease in the accumulation coefficients of this radionuclide in the soil over time (Park *et al*., 2019).

In the natural environment (earth's crust, clay minerals, etc.), there is only one stable isotope of caesium – ^{133}Cs. The average concentrations of this element are about 1 mg/kg in granites and 4 mg/kg in sedimentary rocks. In soils, the gross concentration of caesium ranges from 0.3 to 25 mg/kg (International Atomic Energy Agency (IAEA), 2009). As for the behaviour in the soil-plant chain, the chemical behaviour of technogenic radioactive isotopes of caesium is considered identical to that of stable caesium. H. Tsukada *et al*. (2023) observed close bioavailability values of stable caesium and a radioactive isotope ^{137}Cs when they enter potatoes from the soil. Stable caesium behaviour analysis is used to understand the long-term behaviour of radiocaesium and its equilibrium distribution in soils. Thus, the naturally occurring stable isotope ^{133}Cs, which is in an equilibrium state in soil, can be a useful analogue for estimating the accumulation rates of its radioactive isotope ^{137}Cs.

V. Kashparov *et al*. (2020) showed that an important factor affecting the plant uptake of radiocaesium is its initial physical and chemical forms in fallout. In the case of the Chornobyl accident, a significant part of radiocaesium in radioactive fallout in the near-accident zone (10 km) was in the composition of fuel particles and was not available for plant assimilation for some time. The dynamics of the bioavailability of radiocaesium and radiostrontium in this area were determined by the superposition of the processes of their adsorption by soil and leaching from fuel particles.

The soil plays an important role in the root uptake of radionuclides by plants. When plants uptake radionuclides from an aqueous solution, radiocaesium is the most biologically available in comparison with other radionuclides ($^{137}Cs > ^{90}Sr > > ^{144}Ce > ^{106}Ru > ^{95}Zr$). According to M. Vanheukelom *et al.* (2023), when growing plants on soil, the bioavailability of ^{90}Sr decreases by about 20 times, whereas ^{137}Cs – by 100-1,000 times. The reason for this is the absorption of radionuclides by the soil. In general, the influence of soil is manifested in a decrease in the bioavailability of radiocaesium with an increase in its content of exchange cations, organic matter, physical clay, montmorillonite minerals, and absorption capacity (Kang & Tazoe, 2024). M. Vinichuk *et al.* (2025) observed higher accumulation rates on sandy loam and organic soils, and lower accumulation rates on soils with a high clay content. In addition, this paper shows that the bioavailability of caesium for grasses in the first few years after deposition rapidly decreased with subsequent plateau release.

The bioavailability of caesium and radiocaesium is affected by the presence of other chemical elements in the soil, especially potassium. The average concentration of potassium in the soil solution is about 10^{-3} m/l, whereas the concentration of activity ^{137}Cs in a soil solution of 1 Bq/l approximately corresponds to its concentration of $2 \cdot 10^{-15}$. M. Syaifudin *et al.* (2023) showed that an increase in the concentration of potassium available to plants in the soil leads to a decrease in the intake of caesium into plants.

According to the latest study by Ukrainian researchers, despite almost forty years after the Chornobyl accident, a significant part of the territory of Ukraine remains radioactively contaminated (Kyrylchuk & Palamarchuk, 2022), and radionuclides enter agricultural products (Snitynskyi *et al.*, 2023). Studies aimed at radiological safety of the population remain relevant. In general, as numerous studies show, the accumulation of caesium by plants is characterised by great variability, which is mainly determined by local soil and climatic conditions. Experimental parameters that consider these local features on a national scale are needed to reduce the uncertainty of predictive estimates. In Ukraine, there are currently no data on the accumulation of ^{137}Cs by grasses in the first growing season after its release into the environment.

The purpose of the study was to estimate the transfer coefficients of ^{137}Cs in pasture mixed grasses from the dominant soil types of Ukraine and their dynamics during the growing season.

Materials and Methods

Scheme of a vegetative experiment. The assessment was carried out in a laboratory experiment simulating "fresh" radionuclide deposition in soluble form before the beginning of the growing season. The study was conducted according to the Convention on Biological Diversity (1992). To investigate the accumulation of ^{137}Cs by a mixture of perennial grasses (ryegrass 60%), 4-litre plastic pots filled with air-dry soil were used. Soil moisture was increased to 60% of their field moisture capacity by adding the appropriate amount of water. The experiment used three types of soils that were selected in Zhytomyr and Kyiv oblasts, namely: sod-podzolic loam; ordinary chernozem; and podzolic chernozem. For each soil type, the experiment included three parallels and a control (without radionuclide application). Grass sowing was carried out on 12.04.2024 with the recommended seeding rate of 3.5 g m^{-2}. After sowing, 9.51 kBq (336 kBq m^{-2}) of ^{137}Cs was applied to the soil surface in each pot. An aqueous solution (50 ml) of radionuclide was evenly distributed over the soil surface using a dispenser. During the experiment, three grass mowing operations were performed. The grass was cut at a height of 1 cm above the ground. The resulting grass samples were dried at 105°C to a constant mass and homogenised using a laboratory mill. The obtained samples were transferred to sealed plastic vials for storage and subsequent measurement of ^{137}Cs activity and concentrations of stable caesium.

Analytical methods. Specific activity of ^{137}Cs in pre-prepared soil and vegetation samples was measured on gamma-ray spectrometers with semiconductor (GEM-30185, "EG & ORTEC", USA) and scintillation detectors (SEG-01, "AKP", Ukraine). The measurements were carried out in polypropylene containers with a volume of 100 cm^3 and in Marinelli vessels with a volume of 1,000 cm^3. The spectrometers were calibrated using certified secondary radionuclide standards in accordance with the requirements of the standardised method (ASTM E181-10, 2010). Specific activity of ^{137}Cs and the concentration of its stable isotope in grass and soil samples were calculated for absolute dry weight.

The concentration of stable caesium in grass and soil samples was determined on a NexIon 2000b inductively coupled plasma mass spectrometer (PerkinElmer, USA). The samples were prepared using the Ethos Up microwave decomposition system (Milestone, USA).

Agrochemical properties of soils were determined by standardised methods (DSTU 4405:2005, 2005; DSTU 7863:2015, 2015; ISO 10390:2021, 2021; ISO/TS 22171:2023, 2023) using appropriate equipment.

To determine the quantitative parameters of the dependence of the transfer of radionuclide from soils to a mixture of grasses on soil properties, the the aggregated transfer factor (T_{ag}) was used. T_{ag} defined as the ratio of the mass specific activity of ^{137}Cs in grass (Bq·kg^{-1}, dry weight) to the density of the soil radionuclide contamination (kBq·m^{-2}) on which it was grown. For the stable isotope, the concentration ratio (CR), defined as ^{133}Cs concentration in the grass (mg·kg^{-1}, dry weight) divided by that in the soil (mg·kg^{-1}, dry weight) on which it was grown, was used.

Results and Discussion

Before the experiment, the main agrochemical properties of soils and their contamination with ^{137}Cs were determined. The ^{137}Cs contamination was formed as a result of nuclear weapons tests and the Chornobyl accident. Soils are characterised by a low level of radioactive contamination (Table 1). Radioactive contamination of chernozems was close to the level of global fallout. Such contamination levels will not affect the experiment, since the introduced activity exceeds them by 2 orders of magnitude. In general, in terms of nutrient supply, sod-podzolic soil is classified as low, podzolic chernozem is close to the middle class, and typical chernozem is to middle class (Table 1). The content of mobile potassium, which affects the accumulation of ^{137}Cs in plants, in this series varies from 70 to 220 mg kg^{-1}.

Table 1. *Main agrochemical characteristics of soils and their contamination density with ^{137}Cs (for horizon 0-10 cm)*

Soil type	^{137}Cs, kBq m^{-2}	pH (H_2O)	pH (KCl)	LOI*,%	Exchange K, mg kg^{-1}	Exchange Ca, mg kg^{-1}	Alkaline hydr. nitrogen, mg kg^{-1}	Mobile phosphorus, mg kg^{-1}
sod-podzolic gleyed	6.4±1.9	6.6	5.6	2.7	70	420	66	30
podzolic chernozem	1.6±0.5	5.7	4.5	5.9	104	1620	94	99
typical chernozem	0.7±0.2	7.8	7.1	7.1	222	2,250	95	167

Note: * – Loss on Ignition
Source: compiled by the authors

The radionuclide specific activity in samples of grass grown on sod-podzolic soil was the highest and 10 times higher than in grass grown on typical chernozem. Grass contamination on podzolic chernozem was twice as high as grass contamination on typical chernozem. The maximum standard deviations between parallels were about 10%. Over time, there was a significant decrease in accumulation of ^{137}Cs in perennial grasses (Table 2). During the growing season, the specific activity of radionuclide decreased in grass grown on sod-podzolic soil and typical chernozem by about 2 times. No significant decrease was observed for podzolic chernozem.

Table 2. *Specific activity of ^{137}Cs in grass samples (for completely dry weight)*

Soil type	Repeatability	^{137}Cs, Bq kg^{-1}		
		Cutting 29.05.24	Cutting 16.07.24	Cutting 01.09.24
sod-podzolic gleyed	control	29 ± 17	24 ± 15	33 ± 16
	1	15,390 ± 920	15,040 ± 750	8,400 ± 750
	2	17,050 ± 1,200	13,610 ± 820	7,070 ± 710
	3	18,040 ± 1,260	11,900 ± 830	7,150 ± 720
	Mean ± SD	**16,830 ± 1,340**	**13,520 ± 1,570**	**7,540 ± 750**
podzolic chernozem	control	<4	<5	<4
	1	2,940 ± 270	4,290 ± 390	2,950 ± 470
	2	3,000 ± 270	3,880 ± 310	3,450 ± 520
	3	2,860 ± 140	4,710 ± 380	5,300 ± 850
	Mean ± SD	**2,930 ± 70**	**4,290 ± 420**	**3,900 ± 1,240**
typical chernozem	control	28 ± 16	18 ± 8	21 ± 9
	1	1,650 ± 130	1,420 ± 140	730 ± 90
	2	1,250 ± 150	910 ± 90	810 ± 160
	3	1,540 ± 150	760 ± 40	650 ± 110
	Mean ± SD	**1,480 ± 210**	**1,030 ± 340**	**730 ± 110**

Source: compiled by the authors

The results showed a significant difference in accumulation of ^{137}Cs in perennial grasses from different soils (Fig. 1). The highest values of aggregated transfer factors were obtained for the first mowing on sod-podzolic soil. This soil is characterised by the lowest content of exchangeable potassium, organic matter (Table 1), and the dispersed composition is dominated by coarse fractions of physical sand. Such characteristics are favourable for high bioavailability of caesium (Sinchenko, 2021). The value of the average T_{ag} value for sod-podzolic soil was 50 (Bq kg^{-1})/(kBq m^{-2}) and exceeded the value obtained in 1987 for the sown grasses hay by averaging a large array of data, by ten times (Ukrainian Institute of Agricultural Radiology (UIAR), 1998). Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments (International Atomic Energy Agency (IAEA), 2010) recommends using a concentration ratio of 0.084 to estimate the transfer of radiocaesium from sandy soil to grasses, which is approximately equal to a T_{ag} of 0.750 (Bq kg^{-1})/(kBq m^{-2}). This recommended value is significantly lower than the parameters obtained, and its use for forecasting may lead to an underestimated evaluation of the radionuclide uptake by vegetation. The average value of the ^{137}Cs aggregated transfer factor for the grass obtained for typical chernozem in the first mowing was at the level of 4 (Bq kg^{-1})/(kBq m^{-2}), which also differs by an order of magnitude from the data of 1987 (Ukrainian Institute of Agricultural Radiology (UIAR), 1998). Y. Khomutinin *et al.* (2022) presented current results on the accumulation of ^{137}Cs in pasture vegetation in natural meadows (meadow-swamp soils). In such landscapes, this radionuclide is still characterised by high bioavailability (T_{ag} 5 (Bq kg^{-1})/(kBq m^{-2})). But even this value of the transition coefficient is significantly lower than those obtained in the experiment for sod-podzolic soil.

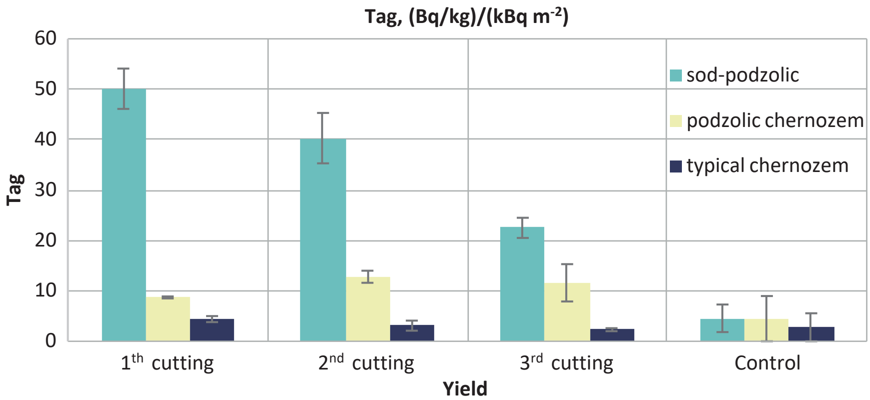


***Figure 1.** Dynamics of ^{137}Cs intake into a mixture of grasses from different soils in a laboratory experiment during the growing season*

Note: surface contamination of the soil after sowing grass (336±34 kBq m^{-2})

Source: compiled by the authors

During the growing season, T_{ag} values for sod-podzolic soil and typical chernozem significantly decreased by half. The results of the experiment for podzolic chernozem showed that the average T_{ag} value in the first cutting for podzolic chernozem was 9 ± 4 (Bq kg^{-1})/(kBq m^{-2}) and in the future, its decrease was not observed (Fig. 1). This behaviour of ^{137}Cs in the soil-plant chain may be related to the acidity index of this soil (Table 1). T_{ag} values were also calculated for the control variants. They characterise the bioavailability of the radionuclide (its ageing), which has been in the soil for about 40 years. Unfortunately, these values are characterised by great uncertainty, as grass contamination was very low for all soils. But even this information indicates that the process of absorption of fresh deposition occurs quite slowly (Fig. 1), especially for soils of light mechanical composition. M. Vinichuk *et al.* (2025) assessed the dynamics of ^{137}Cs transfer coefficients from different soils in Sweden to natural and cultivated grasses. According to the researchers, in loamy soils, T_{ag} values decreased from units to plateaus below 0.01 (Bq kg^{-1})/(kBq m^{-2}) approximately 3-5 years after radioactive fallout, whereas in soils with an intermediate clay content, this process took approximately 12-15 years. These data correlate well with the results obtained.

The concentration of the stable isotope of caesium ^{133}Cs was also determined in soil and grass samples. The gross concentration of ^{133}Cs was the lowest (0.6 mg kg^{-1}) in sod-podzolic soil, and in podzolic chernozem – the highest (2.2 mg kg^{-1}). Stable element transfer parameters are usually used when radionuclide data are not available. For example, if it is necessary to determine the values of transport parameters in areas of low radionuclide contamination, where radionuclide concentrations in food or wildlife are beyond detection. C.L. Barnett *et al.* (2020) conducted a study in this area and showed that the intake of ^{137}Cs and stable Cs in plants are characterised by a good correlation, but has some differences. A number of studies have shown that the ^{137}Cs accumulation coefficients were several times higher than for stable ^{133}Cs, despite a fairly long presence of ^{137}Cs in the soil (Guillén *et al.*, 2022). Stable Cs is mainly retained in primary and clay minerals, so the coefficient of its accumulation by plants may be lower than that of ^{137}Cs, which is of man-made origin. To correctly compare the bioavailability of radioactive and stable caesium, it is necessary to use not their gross concentrations in the soil, but the concentrations of their exchange forms. H. Tsukada *et al.* (2023) proposed an approach based on the following relations for estimating accumulation parameters: $^{137}Cs/Cs$ in the exchange fraction of soil and concentrations of stable Cs in plants and showed that the approach allows more accurately predicting the concentration of ^{137}Cs activity in cultures compared to methods based on accumulation coefficients. The main disadvantage of this method is that it cannot be used with a low level of soil contamination with ^{137}Cs. Using the concentrations of this isotope in grass samples and the corresponding values of soil concentrations, its bioavailability was estimated (Fig. 2).

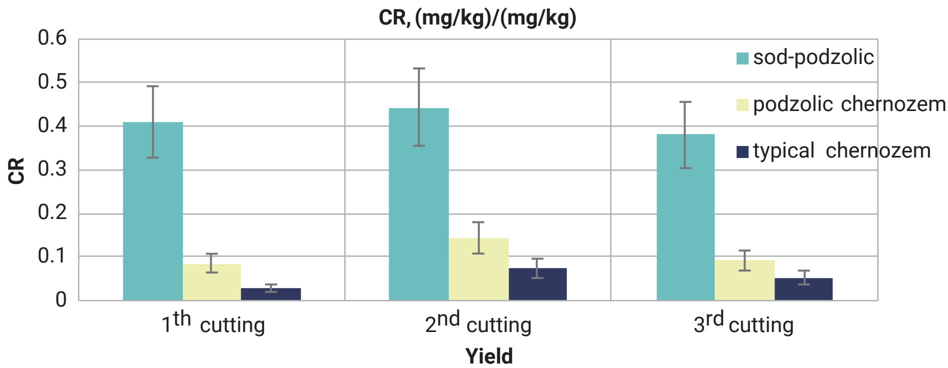


***Figure 2.** Dynamics of ^{133}Cs (stable) intake into a mixture of grasses from different soils in a laboratory experiment during the growing season*

Source: compiled by the authors

In this case, the concentration of ^{133}Cs acid-soluble forms in soils was used to calculate the concentration ratios . The concentration ratios correlate with the aggregated transfer factors for the radioactive isotope depending on soil type – for sod-podzolic soil, they are maximal, and for typical chernozem, they are minimal. The finding does not contradict the studies by C.L. Barnett *et al.* (2020) and J. Guillén *et al.* (2022). The parameters obtained at the end of the growing season for the transfer of radiocaesium from soils to grasses are more than 10 times higher those obtained for its stable isotope. Moreover, such differences were observed for all soils (Fig. 1, 2). Since stable caesium is in the soils in a state of equilibrium, the values of the concentration ratios do not change significantly during the experiment (Fig. 2). It was these data that were necessary to confirm the absence of external factors during the experiment that could affect the bioavailability of caesium.

The results of the experiment on the bioavailability of caesium reflect the features of the behaviour of this element in the soil-plant chain in relation to the dominant soils of Ukraine. Numerical values of transfer factors can be used for conservative assessment of ^{137}Cs contamination of pasture vegetation, and, accordingly, contamination of livestock products in the first year after radionuclide enters the environment.

Conclusions

Experiments have shown that the bioavailability of ^{137}Cs and its stable isotope is determined by soil properties and fall significantly in the following series: sod-podzolic soil > podzolic chernozem > typical chernozem. Differences in the accumulation of ^{137}Cs by a mixture of perennial grasses between contrasting soils under experimental conditions reached one order of magnitude. The data obtained showed that during the growing season, the bioavailability of ^{137}Cs in sod-podzolic soil and typical chernozem significantly decreased by half. The values of aggregated transfer factors of ^{137}Cs for the grass mixture at the end of the growing season significantly exceeded the corresponding parameters recommended by the International Atomic Energy Agency for predictive estimates of radionuclide contamination of vegetation. This finding confirms the fact that the bioavailability of ^{137}Cs depends on its residence time in the soil. The use of the radionuclide transfer parameters, which were obtained in the distant period after a radiation accident, for predictive estimates of plant contamination in the first vegetation period will lead to underestimated results.

For more information on the behaviour of caesium in the soil-plant chain, the accumulation rates of the stable isotope caesium in perennial grasses were estimated. The gross concentration of this trace element in soils varied in the range of 0.6-2.2 mg/kg. Compared to the radioactive isotope, stable caesium was characterised by significantly lower bioavailability for plants, which did not significantly change during the growing season. This confirms that stable caesium is in a certain equilibrium state in the soil. A strong linear relationship was observed between the parameters of vegetation accumulation of stable and radioactive caesium isotopes, but the proportionality coefficient was different from one.

Research on studying the dynamics of radionuclide intake from fresh radioactive fallout into pasture vegetation will continue with the extension of the observation period to 2-3 vegetation periods. In addition to ^{137}Cs, the experiment is planned to include another long-lived and radiologically significant radionuclide ^{90}Sr.

Acknowledgements

The study was supported by the National University of Life and Environmental Sciences of Ukraine, the Ministry of Education and Science of Ukraine (Project No. 110/7-pr-2024).

Conflict of Interest

None.

References

[1] ASTM E181-10. (2010) *Standard test methods for detector calibration and analysis of radionuclides (ASTM E181-10)*. Retrieved from https://www.astm.org/e0181-10.html.

[2] Barnett, C.L., Beresford, N.A., Wood, M.D., Izquierdo, M., Walker, L.A., & Fawkes, R. (2020). Element and radionuclide concentrations in soils and wildlife from forests in north-eastern England with a focus on species representative of the ICRP's Reference Animals and Plants. *Earth System Science Data*, 12(4), 3021-3038. doi: 10.5194/essd-12-3021-2020.

[3] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[4] DSTU 4405:2005. (2005). *Soil quality. Determination of mobile phosphorus and potassium compounds by Kirsanov's method modified by NRC ISSAR*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=60252.

[5] DSTU 7863:2015. (2015). *Soil quality. Determination of readily hydrolyzable nitrogen by Kornfield's method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62745.

[6] Guillén, J., Beresford, N., Baigazinov, Z., Salas, A., & Kunduzbaeva, A. (2022). Can stable elements (Cs and Sr) be used as proxies for the estimation of radionuclide soil-plant transfer factors? *Environmental Pollution*, 299, article number 118897. doi: 10.1016/j.envpol.2022.118897.

[7] International Atomic Energy Agency (IAEA). (2009). *Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments*. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/te_1616_web.pdf.

[8] International Atomic Energy Agency (IAEA). (2010). *Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. Technical Reports series No. 472*. Retrieved from https://surl.li/dyalgx.

[9] ISO/TS 22171:2023. (2023). *Soil quality – determination of potential cation exchange capacity (CEC) and exchangeable cations buffered at pH 7, using a molar ammonium acetate solution*. Retrieved from https://www.iso.org/standard/80891.html.

[10] ISO-10390:2021. (2021). *Soil, treated biowaste and sludge – determination of pH*. Retrieved from https://www.iso.org/standard/75243.html.

[11] Kang, D., & Tazoe, H. (2024). Impacts of soil type and drought stress on growth and cesium accumulation in Napier grass. *Environmental Geochemistry and Health*, 46(7), article number 235. doi: 10.1007/s10653-024-02023-1.

[12] Kashparov, V., Salbu, B., Simonucci, C., Levchuk, S., Reinoso-Maset, E., Lind, O., Maloshtan, I., Protsak, V., Courbet, C., & Nguyen, H. (2020). Validation of a fuel particle dissolution model with samples from the Red Forest within the Chernobyl exclusion zone. *Journal of Environmental Radioactivity*, 223-1224, article number 106387. doi: 10.1016/j.jenvrad.2020.106387.

[13] Khomutinin, Y., Kosarchuk, O., Polishchuk, S., Lazarev, M., Levchuk, S., & Pavliuchenko, V. (2022). Assessment of the possibility of a return to the original use of pastures and hayfields abandoned after the Chornobyl accident. *Nuclear Physics and Atomic Energy*, 23(1), 47-56. doi: 10.15407/jnpae2022.01.047.

[14] Kyrylchuk, A., & Palamarchuk, R. (2022). Dynamics of 137Cs and 90Sr content in the soil cover of agricultural lands in Zhytomyr region. *Agroecological Journal*, 4, 84-92. doi: 10.33730/2077-4893.4.2022.273254.

[15] Park, S.-M., Alessi, D.S., & Baek, K. (2019). Selective adsorption and irreversible fixation behavior of cesium onto 2:1 layered clay mineral: A mini review. *Journal of Hazardous Materials*, 369, 569-576. doi: 10.1016/j.jhazmat.2019.02.061.

[16] Sinchenko, V. (2021). Methodological aspects of beta-spectrometric method of control over radiation safety of agricultural and fishing products. *Ecological Safety and Balanced Use of Resources*, 12(1), 60-72. doi: 10.31471/2415-3184-2021-1(23)-60-72.

[17] Snitynskyi, V., Razanov, S., Hnativ, P., Bakhmat, O., Kutsenko, M., & Kolisnyk, O. (2023). Phytoremediation of 137Cs contaminated sod-podzolic soil in Northern Polissia white sweet clover (*Melilotus albus*). *International Journal of Environmental Studies*, 81(1), 223-229. doi: 10.1080/00207233.2023.2270305.

[18] Syaifudin, M., Suzuki, M., Maruyama, H., Kubo, K., Watanabe, T., & Shinano, T. (2023). Potassium applications reduced cesium uptake and altered strontium translocation in soybean plants. *Soil Science & Plant Nutrition*, 69(2), 88-98. doi: 10.1080/00380768.2023.2166776.

[19] Tsukada, H., Takeda, A., Takahashi, T., Fukutani, S., Akashi, M., Takahashi, J., Uematsu, S., Chyzhevskyi, I., Kirieiev, S., Kashparov, V., & Zheleznyak, M. (2023). Transfer of 137Cs and 90Sr from soil-to-potato: Interpretation of the association from global fallout in Aomori to accidental release in Fukushima and Chornobyl. *The Science of the Total Environment*, 899, article number 165467. doi: 10.1016/j.scitotenv.2023.165467.

[20] Ukrainian Institute of Agricultural Radiology (UIAR). (1998). *Management of agriculture in the conditions of radioactive contamination of the territory of Ukraine due to the accident at the Chornobyl NPP for 1999-2002. (Methodological recommendations)*.Kyiv: UIAR.

[21] Vanheukelom, M., Sweeck, L., Van Hees, M., Weyns, N., Van Orshoven, J., & Smolders, E. (2023). Quantitative clay mineralogy predicts radiocesium bioavailability to ryegrass grown on reconstituted soils. *The Science of the Total Environment*, 873, article number 162372. doi: 10.1016/j.scitotenv.2023.162372.

[22] Vinichuk, M., Simonsson, M., Larsson, M., & Rosén, K. (2025). Long-term transfer of 137Cs in sensitive agricultural environments after the Chornobyl fallout in Sweden. *Journal of Environmental Radioactivity*, 282, article number 107621. doi: 10.1016/j.jenvrad.2025.107621.

Кореневе надходження ^{137}Cs у пасовищні трави

Святослав Левчук
Кандидат біологічних наук, провідний науковий співробітник
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-5167-7773
Валерій Кашпаров
Доктор біологічних наук, головний науковий співробітник
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-6460-1049
Валентина Павлюченко
Науковий співробітник
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-0986-6444

Анотація. Накопичення ^{137}Cs у рослинах може нести ризики для здоров›я тварин і людей через його надходження в організм по харчовому ланцюжку. Метою роботи була оцінка коефіцієнтів переходу ^{137}Cs у пасовищне різнотрав'ям з домінуючих типів ґрунтів України та їх динаміки на протязі вегетаційного періоду. Експеримент проводився на трьох типах ґрунтів, а саме: дерново-підзолистому суглинистому, чорноземі опідзоленому та чорноземі типовому. Ґрунти для експерименту відбирались в Київській та Житомирській областях. Щільність штучного поверхневого забруднення усіх ґрунтів була однаковою і склала 336 кБк м$^{-2}$. Радіонуклід вносився на поверхню ґрунту у водорозчинній формі. Рослини вирощувались в теплиці в горщиках з регулярним поливом без внесення добрив. Отримані результати показали, що біологічна доступність ^{137}Cs визначається ґрунтовими умовами і достовірно спадає в ряду: дерново-підзолистий ґрунт > опідзолений чорнозем > типовий чорнозем. Отримані середні значення коефіцієнтів переходу радіонукліда в траву для першого укосу коливались в межах від 50 до 4 (Бк·кг$^{-1}$)/(кБк·м$^{-2}$) і були максимальними для дерново-підзолистого ґрунту. В кінці вегетаційного періоду біологічна доступність ^{137}Cs достовірно зменшилась в два рази для дерново-підзолистого ґрунту та типового чорнозему. На опідзоленому чорноземі достовірної зміни біологічної доступності радіонукліду не спостерігалось. Оцінено коефіцієнти накопичення стабільного ізотопу цезію (^{133}Cs). У порівнянні з радіоактивним ізотопом стабільний цезій характеризується значно нижчою біологічною доступністю для рослин, але характер її залежності від ґрунтових умов тотожний такій для ^{137}Cs. Оскільки стабільний цезій знаходиться у ґрунті в стані рівноваги коефіцієнти його накопичення сумішшю трав протягом вегетаційного періоду не змінювались. Отримані параметри переходу, відповідно до ґрунтових умов, можуть використовуватись в радіологічних моделях для консервативної оцінки радіаційних доз опромінення населення в перший рік після надходження радіонукліду в оточуюче середовище

Ключові слова: ^{137}Cs; біологічна доступність; коефіцієнт переходу; цезій, радіонукліди; ґрунти; рослинність