Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2020, 10(3), 208-215, doi: 10.15421/2020_156

ORIGINAL ARTICLE

137 Cs contaminations in wild-growing medicinal plants of *Zhytomyr polissya* forests: A 34 years after Chernobyl accident

I. Davydova[1], A. Panasiuk[1], V. Melnyk[1], L. Davydova[2]

[1]Zhytomyr Polytechnic State University, 103 Chudnivska St, Zhytomyr, 10005, Ukraine
[2]Zhytomyr Ivan Franko State University, 40 Velyka Berdychivska St, Zhytomyr, 10008, Ukraine

**Corresponding author e-mail: davydvairina2@gmail.com*

Received: 06.06.2020. Accepted 11.07.2020

The contamination of ^{137}Cs in wild-growing medicinal plants was studied with regards to the species, type of forest vegetation conditions and soil specific activity of ^{137}Cs in *Zhytomyr polissya* forest phytocenoses (Ukraine). The research was carried out in two plots planted in the most region typical edatopes - fresh and wet subor (Querceto-Pinetum). Species composition of phytocenoses was analyzed and the plants that can be harvested for pharmaceutical industry were identified on these test plots,. The herbal substance samples were tested to determine the specific activity of ^{137}Cs. The studies have shown significant variability in the content of radionuclides due to differences in the level of radioactive contamination in the soil and accumulative capacity of plant species. For European blueberry, the peculiarities of ^{137}Cs accumulation in vegetative and generative organs were studied. Comparison of the content of ^{137}Cs in pants of different edatopes showed more higher intensity of radionuclide accumulation in wet suborbs compared to fresh suborbs. The average values of concentration factors were calculated and their rankings were built according to the intensity of ^{137}Cs accumulation for the plants in each edatope. All studied medicinal plants were divided into four groups according to the contration factor: with weak accumulation, moderate accumulation, strong accumulation, and very strong accumulation. Based on the permissible content of ^{137}Cs in wild-growing medicinal plants (600 Bq/kg), the maximum permissible level of soil contamination with radionuclides was determined for each medicinal plant species.

Keywords: Radiation monitoring; Medicinal plants; Specific activity of ^{137}Cs; Concentration factor; Permissible levels of radionuclide content

Introduction

Large part of the forests of *Zhytomyr polissya* was contaminated with radionuclides after Chernobyl accident in 1986. On the territories of more than 1,140 ha × 10^3, the regulations on the use and harvesting of forestry products have been introduced, and any forestry activity is prohibited on area of 63.9 ha × 10^3, (Krasnov, 2007; Krasnov, 1995). The the forest industry is the leading for the northern part of Ukraine. Traditionally, the inhabitants of the forest Ukrainian regions largely use local timber, wild berries, mushrooms and game that are included in the diet of local residents. Forest plants are used as livestock feed and medicines. Strict regulation and control for the content of radionuclides in non-timber forest products have led to a decrease in industrial volumes of their use in contaminated areas and allow us to assert that the use of the final product that reaches the consumer is completely safe from the point of view of radioecology. However, it is practically impossible to limit the use of forest products by the local population. Even now (34 years after the accident) using or consuming such "gifts of the forest" as mushrooms, berries and medicinal plants, the local population living in territories contaminated with radionuclides receives a significant additional dose load - from 12 to 40% for the entire population and from 50 up to 95% in critical groups of the population (Karachov, 2006; Chobotko et al., 2011). Since the influence of radiation has no visible rapid effects and its action is prolonged in time, the conduct of educational activities among the population is a slow and complicated process. It requires detailed research, study of the problem and presentation of the results in a simple and comprehensible form. Many studies and publications were devoted to the radioactive contamination of mushrooms and berries, but much less attention was paid to the study of the characteristics of the radionuclide accumulation by medicinal plants.

In the first period after the accident, a study of the content of technogenic radionuclides in medicinal plants was carried out in various regions of Ukraine (Hryshchenko et al., 1990). As a result of the research, significant differences in the content of radionuclides were revealed depending on the species of plants and the conditions of their habitat. Russian researchers (Tsvetnova et al., 1990) report that in 1990 in Ukrainian polissya, even within the same ecotope with the same density of soil radionuclide contamination, their content in various types of medicinal plants differs significantly. Belarusian researchers (Yelishevich, Rubanova, 1993) have determined the concentration factors for 120 species of medicinal plants growing in different ecological conditions. The intensity of accumulation of 137Cs from soil by medicinal plants of polissya forests in the main types of forest growth conditions was studied most fully by O.O. Orlov, V.P. Krasnov, S.P. Irklienko, and V.N. Turko (Krasnov et al., 1996). According to their conclusions, taking into account the average values of transition coefficients and their errors, medicinal plants were divided into 5 groups by the intensity of 137Cs accumulation in the raw material. Radioecologists also emphasized the differences in the intensity of 137Cs accumulation in different parts (of medicinal plants), which were obtained from the same plant (Yelishevich, Rubanova, 1993; Krasnov et al., 1996), which requires a differentiated approach to the procurement of medicinal plants. Researchers gave an ecological assessment of the resources of wild-growing medicinal plants (Krasnov et al., 1996) of Ukrainian polissya after the Chernobyl accident and developed recommendations on the possibility of their use depending on the density of radioactive contamination of the soil. However, in subsequent years, the government funding for radiological research was reduced (Krasnov et al., 2016), which led to a reduction in the number of samples tested to determine their levels of radioactive contamination, including samples of wild-growing medicinal plants.

Medicinal plants contaminated with technogenic radionuclides are used as plants for the preparation of various finished medicinal products that must be safe for humans. That is why the issue of standardization of medicinal plants (Sahil et al., 2011) and finished medicinal products of plant origin (Yadav, Dixit, 2008) (including radiological control) is an important issue of our time. Medicinal plants can be used for the preparation of medicinal products of various forms - aqueous (decoctions, infusions), alcohol (tincture, extract). Therefore, researchers study (Antonova, Seditskaya, 1989; Gubin et al., 1999) not only the content of radionuclides in medicinal plants, but also the effect of technological processing of medicinal plants on the content of radionuclides in finished medicinal products.

Since taking medications can pose a radiological risk to public health, a significant amount of scientific research in various countries was devoted to the study of the intake of radionuclides by medicinal plants. Depending on the natural features of the region and medical traditions, some scientists have focused on the study of one plant (Sussaa et al., 2013; Durusoy, Yildirim, 2017) or one radionuclide (Njinga et al., 2015;, Siasou, Willey, 2015), however, most works are devoted to a list of medicinal plants that are most in demand and the content of radionuclides in them of natural and technogenic origin (Chandrashekara, Somashekarappa, 2016;, Desideri et al., 2010). The ultimate goal of such studies is to determine the presence or absence of radiological risk to the health of consumers when using these plants for medicinal purposes. These studies may also contribute to the formulation of regulations concerning radiological health.

Despite a significant number of studies, their results are regional, since for various natural zones differences in the species composition of phytocenoses, ecological growth conditions, and the content of radionuclides in soil cause significant differences in the accumulation of radionuclides by medicinal plants. Therefore, there is a need to conduct such studies for each region separately. In Ukraine, the content of radionuclides in medicinal plants is studied for the western Ukraine (Hrabovskyy et al., 2009) and for the zone of Ukrainian polissya, which are typical as areas of medicinal plants industrial harvesting. V.V. Moisiyenko (2012, 2015) determined the species contamination of 137Cs in wild medicinal plants depending upon the density of soil contamination and type of phytocenoses. The current state of radionuclide contamination in the medicinal plants of Ukrainian forest phytocenoses is studied insufficiently. Considering the fact that the last full-scale research was conducted at the end of the 90s, it becomes extremely important to determine the content of radionuclides in wild medicinal plants of *Zhytomyr polissya* forests.

Methods

Research trial plots were situated in Bazar Forestry State Enterprise "Narodychi Forestry", Zhytomyr region, Ukraine, approximately 70 km from the Chornobyl NPP in the most typical habitat conditions for this region - fresh subor (B2) and wet subor (B3). ^{137}Cs deposition in this area is within 177–395 kBq/m^2 (Davydova et al., 2019).

The main soil in research area was sod-podzolic. The thickness of the organic horizon did not exceed 3-5 cm. Agro-chemical characteristics were determined in accordance with generally accepted methods. Samples were taken by square method to a depth of 15 cm. The analysis of average samples (20 sampling points in each layer) was conducted in certified laboratory of the Zhytomyr Sanitary and Epidemiological Station. Main chemical characteristics of studied soil to the depth of 0-15 cm were as follows: pH of 4.25 ± 0.47, Tot-C 2.96 ± 1.93%, Tot-N 0.12 ± 0.09%, C/N 24.76 ± 2.78, K-AL 7.03 ± 6.36 mg/100 g, Ca-AL 16.82 ± 19.22 mg/100 g, K-HCl 15.63 ± 6.31 mg/100 g, Ca-HCl 22.85 ± 21.70 mg/100g (mean ± SD, n = 14) (Vinichuk et al., 2016).

The research was conducted at two research plots (B2 and B3) in the quarter No 45. The size of the test areas was 100×100 m. The research plots had identical characteristics of the tree storey (pure stands of Scots pine (*Pinus sylvestris* L.) aged 90 years. In addition, they were characterized by high homogeneity of soil and vegetation within the plot.

On the plot No 1 (B2) the forest understorey was represented by oppressed specimens of Scotch pine, common oak (*Quercus robur* L.), and one of European mountain ash (*Sorbus aucuparia* L.). Shrub plants were quite numerous and consisted of a Yellow rhododendron (*Rhododendron luteum Sweet.)*, Labrador tea (*Ledum palustre* L.), alder buckthorn (*Frangula alnus* Mill.) and European dewberry (*Rubus caesius* L.). The basis of grass and shrub layer was blueberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idae* L.), common heather (*Calluna vulgaris* L.), sedge helobius (*Carex limosa* L.) and fibrous tussock-sedge (*C. appropinquata* Schum.).

On the plot No 2 (B3) the forest understorey was not uniform, had a crown closure of up to 0.2-0.3 and was represented mainly by bushes of alder buckthorn and European mountain ash. The grass and subshrub storey was dominated by the purple moor-grass (*Molinia caerulea*), the common club moss (*Lycopódium clavátum*), and common cow-wheat (*Melampyrum pratense*). The moss storey was uniform and dense. It was consisted of green mosses – red-stemmed feathermoss (*Pleurozium schreberi*) and wavy-leaved moss (*Dicranum polysetum*).

The research was conducted in 2018. We studied the intensity of radioactive contamination in various medicinal plants, the patterns of $^{137\text{-}Cs}$ accumulation by medicinal plants in different habitat, the relationship between $^{137\text{-}Cs}$ soil content and medicinal plants.

At the plot No 1 (type of habitat conditions - fresh subor) 12 species of plants were identified, which can be harvested as medicinal plants and are actively used in folk and traditional medicine (Table 1). To determine the content of ^{137}Cs, the appropriate part of the plant was selected, which is used for medical purposes. In particular, in woody plants such medicinal plants as common oak (*Quercus robur* L.) bark and European mountain ash (*Sorbus aucuparia*) berries were studied.

The bark of alder buckthorn (Frangula alnus) was studied among shrub plants. Among subshrubs, the following species and their parts were studied: cowberry (*Vaccinium vitis-idaea* L.), leaves; common heather (*Calluna vulgaris* (L.) Hill.), shoots; European blueberry (*Vaccinium myrtillus* L.), leaves and berries; European raspberry (*Rubus idaeus* L.), leaves.

The largest number of species and their parts in the study group was formed by medicinal plants - herbaceous perennials: motherwort (*Leonurus cardiaca* L.), herb; creeping thyme (*Thymus serpyllum* L.), herb; oregano (*Origanum vulgare* L.), herb; wild strawberry (*Fragaria vesca*), leaves; common Saint John's wort (*Hypericum perforatum* L.), flowering shoot apexes.

On the plot No 2 (type of habitat conditions - wet subor) significantly less species diversity of medicinal plants was found; for example, common oak (*Quercus robur* L.), alder buckthorn (*Frangula alnus*), wild strawberry (*Fragaria vesca*), and creeping cedars (*Lycopodium*), which was not represented among the flora of fresh subor.

Table 1. Research species.

Species	Type of habitat	Plant part	Medicinal products	Medical use
Motherwort (*Leonurus cardiaca* L.)	B2	Herb	Infusion, tincture	Sedative, antihypertensive and neuroleptic agent
Creeping thyme (*Thymus serpyllum* L.)	B2	Herb	Infusion, decoction, tincture	Expectorant, antibacterial, antispasmodic and pain relieving agent; has a calming effect on the central nervous system, stimulates the secretion of gastric juice
Common oak (*Quercus robur* L.)	B2, B3	Bark	Infusion, decoction	Antiseptic, astringent and anti-inflammatory agent
Oregano (*Origanum vulgare* L.)	B2	Herb	Infusion, decoction	Sedative, hemostatic, diuretic, choleretic agent
Alder buckthorn (*Frangula alnus*)	B2, B3	Bark	Infusion, decoction	Laxative, used for chronic constipation and hemorrhoids treatment
Wild strawberry (*Fragaria vesca*)	B2, B3	Leaves	Infusion, decoction	Diaphoretic and diuretic agent
Cowberry (*Vaccinium vitis-idaea* L.)	B2	Leaves	Infusion, decoction	Diuretic and disinfectant agent, has antiseptic and anti-inflammatory effects
Creeping cedars (*Lycopodium*)	B3	Herb	Decoction	Emetic, laxative agent
Common heather (*Calluna vulgaris* (L.) Hill.)	B2	Shoots	Decoction	Antiseptic, hemostatic, astringent and anti-inflammatory agent
European mountain ash (*Sorbus aucuparia*)	B2	Berries	Oil, syrup, juice, decoction, dried berries	Laxative, hemostatic, diuretic, vitamin agent
European blueberry (*Vaccinium myrtillus* L.)	B2	Leaves	Infusion	Antidiabetic agent
		Berries	Tea, compot, kissel	Astringent and bactericidal agent
Common Saint John's wort (*Hypericum perforatum* L.)	B2	Flowering shoot apexes	Infusion, decoction	Astringent, anti-inflammatory and tonic agent
European raspberry (*Rubus idaeus* L.)	B2	Leaves	Infusion	Diaphoretic, has a hemostatic, antitoxic and diuretic effect

To assess the intensity of 137Cs accumulation in medicinal plants, the samples of the appropriate parts from medicinal plants were selected. The collected soil samples were taken directly next to these plant species (5 punctures – 1 sample). Soil and plant samples obtained from woody and shrub species were taken in the projection of their crown. A total of 96 samples were taken using a BP-25-15 drill. The weight of the selected soil sample was 300-400 grams. Packaging, transportation, storage and disposal of radioactive samples of forestry products were carried out in accordance with NRBU-97 ("Radiation Safety Standards of Ukraine"). Each sample was supplied with selection act and passport. The selected samples were tested to determine the content of 137Cs. Sample preparations and measurements were conducted in a specialized radiological laboratory of the Zhytomyr Polytechnic State University. Sample preparations for spectrometric analyzes included sorting, air-drying, grinding and homogenizing, filling and weighing measuring vessels. The determination of the specific activity of 137Cs in the samples was performed by complete scintillation spectrometry system GDM-20 (Gammadata Instrument AB, Sweden), which is based on a 3″x3″ NaI (Tl) detector on a 14-pin PM-tube. Measurement of $^{137\text{-}Cs}$ with spectrometric system was carried out automatically under the control of WinDAS software. The measurement error for each analyzed sample did not exceed 5%. The obtained results were automatically transferred to an electronic database. Radionuclide accumulation in herbal residues is defined in terms of concentration factor (CF), which is calculated as the radionuclide concentration in a plant (Bq kg^{-1}) divided by that in the surrounding soil (Bq kg^{-1}).

The field measurements were processed by STATGRAPHICS and Microsoft Excel software. The data in the tabes are presented like means and standard devations

Results and Discussion

The study of ^{137}Cs accumulation patterns in wild medicinal plants was carried out in fresh and wet subors. Our data demonstrate that the absolute indicators characterizing the radiation situation vary significantly at each station (Tables 2-4). Thus, the specific 137-Cs activity in fresh subor soils ranges from 814 to 2116 Bq/kg . The high coefficient of variation is caused by the mosaic nature of radioactive contamination, presence of areas without forest canopy, different thickness of forest floor, digging ability of wild animals, and impact of human activity.

The significant variability of 137Cs activity in medicinal plants could be explained by the differences in radioactive contamination level in the soil and accumulating capacity of plant species.

Pairwise sampling "soil - medicinal substance" allowed us to exclude the influence of the mosaic effect of radioactive soil contamination on the contamination of plant products. The highest values of the variation coefficient were found for the herb of common St. John's wort (45%) and European raspberry leaves (44%) in fresh subors and for wild strawberry leaves (48%) in wet subors. According to the results of the conducted research, the highest plant species diversity was found in fresh subor. Thirteen samples (12 species of medicinal plants) were taken in total. Our results allow us to conclude that the specific activity of ^{137}Cs in the medicinal plants of one test plot differs significantly – from 353 ± 116.42 Bq/kg in creeping thyme herbs to 2455 ± 998.72 Bq/kg in common heather shoots (Table 2). Thus, the interspecies differences in the average values of the specific activity of ^{137}Cs in this edatope reach 6.95 times.

Table 2. Radioactive contamination in soil and herbal substances of fresh subors.

Herbal substances	Specific activity of 137-Cs in plants, Bq/kg	Specific activity of 137-Cs in soil, Bq/kg	CF*
Common heather, shoots	2455 ± 998.72	1281 ± 516.56	1.95 ± 0.31
Cowberry, leaves	1987 ± 483.20	1437 ± 367.03	1.39 ± 0.08
European blueberry, leaves	1468 ± 188.55	1044.0 ± 146.5	1.46 ± 0.30
European blueberry, berries	1091 ± 331.90	1044.0 ± 146.5	1.00 ± 0.16
Common Saint John's wort, flowering shoot apexes	942 ± 553.42	1903 ± 297.14	0.47 ± 0.21
European raspberry, leaves	902 ± 449.42	2116 ± 383.51	0.41 ± 0.18
Motherwort, herb	833 ± 80.80	892 ± 83.62	0.93 ± 0.03
Alder buckthorn, bark	722 ± 340.07	1372 ± 606.61	0.51 ± 0.04
Wild strawberry, leaves	607 ± 104.23	2006 ± 421.83	0.30 ± 0.09
European mountain ash, berries	553 ± 170.01	1894 ± 377.73	0.29 ± 0.07
Oregano, herb	550 ± 351.10	814 ± 611.14	0.71 ± 0.07
Common oak, bark	390 ± 67.18	1223 ± 156.86	0.50 ± 0.01
Creeping thyme, herb	353 ± 116.42	876 ± 225.06	0.40 ± 0.03

CF – Concentration Factor (see Methods for details).

Taking into account the permissible level (State standards, 1997) of 137Cs content in medicinal plants – 600 Bq/kg, it should be noted that the studied plants mostly could not be harvested and used for medicinal purposes. The only exceptions are common oak bark (390 ± 67.18 Bq/kg) and the herb of creeping thyme (353 ± 116.42 Bq/kg). Despite the fact that the average values of the specific activity of 137Cs for European mountain ash berries (553 ± 170.01 Bq/kg) and oregano herb (550 ± 351.10 Bq/kg) are at an acceptable level, harvesting of this medicinal raw material in the studied area should be abandoned or carried out with caution and the use of radiological control of finished products, since among the taken samples of medicinal plants, there were some, the specific activity of 137-Cs in which exceeded the established norms for medicinal plants. We calculated the average values of CF of 137Cs (Figure 1) and built their ranking according to the intensity of 137Cs accumulation for all medicinal plants in this edatope,.

All plant species can be conditionally divided into four groups by the coefficient of accumulation. The first group included plants that are weak accumulators of 137Cs (AC<0.5). This group is one of the most numerous for this edatope and consists of five medicinal plants. The lowest values of the concentration factor were recorded for European mountain ash (0.29 ± 0.07 Bq/kg). In addition to it, the first group includes the leaves of wild strawberry, herb of creeping thyme, leaves of European raspberry and flowering shoot apexes of common St. John's wort. The interspecies difference between the extreme values of CF for this group is 1.62 times.

The second group consists of common oak bark and alder buckthorn bark, oregano herb, motherwort herb and berries of European blueberry. This group is characterized by a moderate intensity of 137Cs accumulation (0.5<CF<1). The third group is homogeneous both in terms of the type of medicinal raw material (subshrub leaves) and in terms of taxonomy – species of the Vacciniaceae family, which are characterized by a strong accumulation of 137Cs from the soil (1<CF<1.5). The fourth group of medicinal plants includes shoots of heather, which is characterized by a very strong accumulation of 137Cs from the soil.

The features of 137Cs accumulation by various organs and parts of European blueberry were analyzed. The object of research was the bushes of European blueberry plants, which were divided into the following components: berries, leaves, annual shoots, perennial shoots, and roots. Studies have shown (Table 3) that the highest specific activity was found in samples of dried berries of European blueberry (1,091 Bq kg^{-1}) and in samples of leaves (1,468 Bq kg^{-1}). The lowest values were found for annual (898 Bq kg^{-1}) and perennial shoots (941 Bq kg^{-1}) of European blueberries.

A significant variation was found after analysis of the specific activity for each organ of European blueberry. This differentiation is primarily due to a certain mosaic effect of soil conditions for the growth of each individual plant: the moisture content in the soil, the amount of nutrients, the chemical and mechanical composition of the soil. The smallest values of variation were found for the root part of plants and amounted to only 3%. For annual and perennial shoots, these values turned out to be almost the same: 7 and 10% respectively; for leaves – 13%, and for dried berries, the deviation percentage was the largest and amounted to 30%.

Table 3. ^{137}Cs contamination level in vegetative and generative organs of European blueberry and the soil.

Substances	Specific activity of 137Cs, Bq / kg	CF
Dried berries of European blueberry	1091 ± 331.90	1.00 ± 0.16
Annual shoots of European blueberry	898 ± 65.65	0.91 ± 0.16
Perennial shoots of European blueberry	941 ± 97.75	0.93 ± 0.14
Root of European blueberry	973 ± 25.70	0.97 ± 0.14
Leaves of European blueberry	1468 ± 188.55	1.46 ± 0.30
Soil	1044.0 ± 146.5	-

The obtained results suggest that a small variation in the specific activity is observed in those plant organs that contain less moisture and, accordingly, give the smallest scatter of results when dried. Berries, which can contain more or less moisture depending on the growing conditions, when dry give the greatest variation in the specific activity of dried samples. Based on this, we can conclude that in the course of further research it would be advisable to measure not only dried phytomass samples, but also fresh ones. To assess the input of 137Cs from soil into vegetation, the concentration factor was calculated for all phytomass samples. According to the results of calculations, the leaves of European blueberry have the highest concentration factor (1.46), and annual and perennial shoots have the lowest (0.91 and 0.93, respectively).

According to the intensity of ^{137}Cs accumulation, the vegetative and generative organs of European blueberries form a series: Annual shoots < Perennial shoots < Roots < Berries < Leaves. This series is fully consistent with the results obtained by A.Z.

Korotkova (1999). However, we got the AC values which is more lower (20-40%) than the results of previous studies, but the ratio between them did not change. Probably, A.Z. Korotkova were carried out her research in more humid conditions.

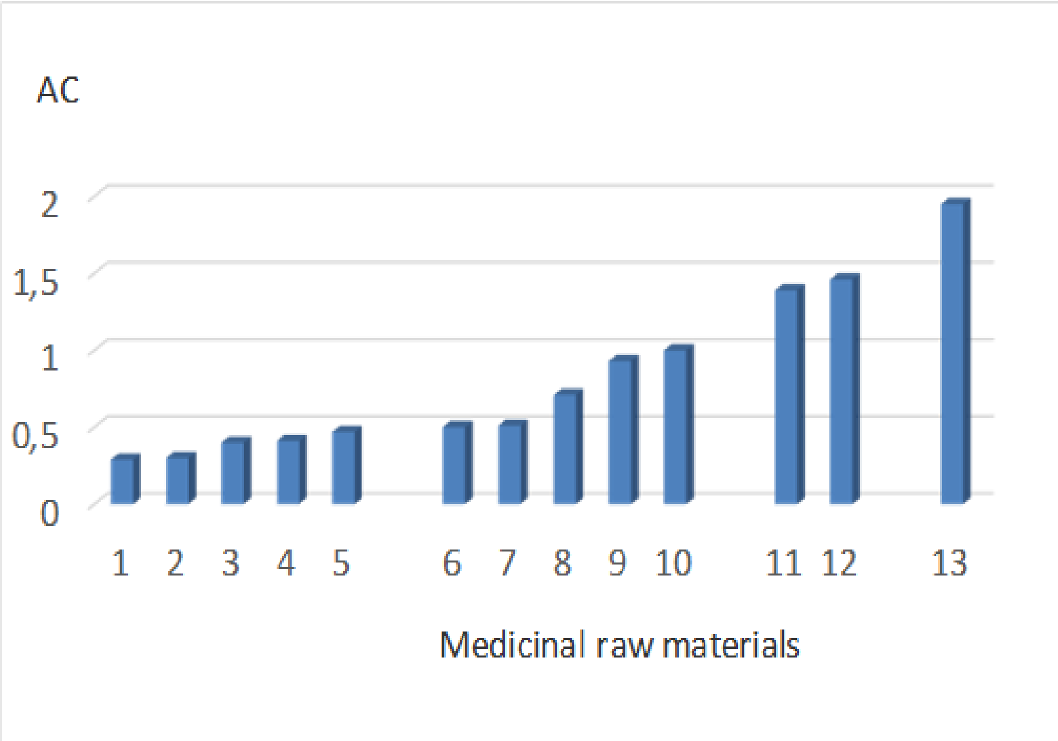

Figure 1. Ranking of herbal substances from fresh subors by the average value of 137-Cs FC.

1. European mountain ash, berries. 2. Wild strawberry, leaves. 3. Creeping thyme, herb. 4. European raspberry, leaves. 5. Common Saint John's wort, flowering shoot apexes. 6. Common oak, bark. 7. Alder buckthorn, bark. 8. Oregano, herb. 9. Motherwort, herb. 10. European blueberry berries. 11. Cowberry, leaves, 12. European blueberry, leaves. 13. Common heather, shoots.

Wet subors proved to be poorer in the species composition of medicinal plants. Only four species of medicinal plants that can be harvested for the pharmaceutical industry were identified at the research site. The test plot was characterized by a significant range of specific activity of 137Cs (Table 4) in the soil (746-3131 Bq/kg) and in medicinal plants (271-2305 Bq/kg). The interspecies differences of the average values of 137Cs specific activity in this edatope reach 8.51 times, which is somewhat bigger than in fresh subors. Such significant variability is primarily caused by a larger range of values of radioactive soil contamination in this research area.

Table 4. Radioactive contamination of soil and herbal substances in wet subors.

Substances	Specific activity of 137Cs in plants, Bq/kg	Specific activity of 137-Cs in soil, Bq/kg	CF
Creeping cedars, herb	2305 ± 338.71	1743 ± 615.08	1.38 ± 0.25
Common oak, bark	1482 ± 23.43	3131 ± 1306	0.53 ± 0.19
Alder buckthorn, bark	898 ± 67.04	1750 ± 473.84	0.55 ± 0.20
Wild strawberry, leaves	271 ± 65.24	746 ± 154.18	0.36 ± 0.11

We found that the only samples from wild strawberry leaves (271 Bq/kg) did not exceed the permissible level of ^{137}Cs content in wet subor, which could be explained by low specific activity of 137Cs in the soil (746 Bq/kg) and species low accumulative properties. The average values of 137Cs CF were calculated for all medicinal plants in this edatope. The ranking of plant species by the intensity of 137Cs accumulation in wet subor generally correspond to the ranking for fresh subor, taking into account the species differences of these phytocenoses: Wild strawberry < Alder buckthorn < Common oak < Creeping cedars

We registered that plant species in wet subors are characterized by a slightly higher intensity of radionuclide accumulation from the soil compared to fresh subors (Figure 2). Thus, the concentration factor for wild strawberry leaves increased by 20%, for common oak bark – by 6% and for alder buckthorn bark – by 8%. These results indicate that the intensity of 137Cs accumulation by the plants with root system located in the upper soil horizons is more dependent on the soil water content copared to the plants with deep root system.

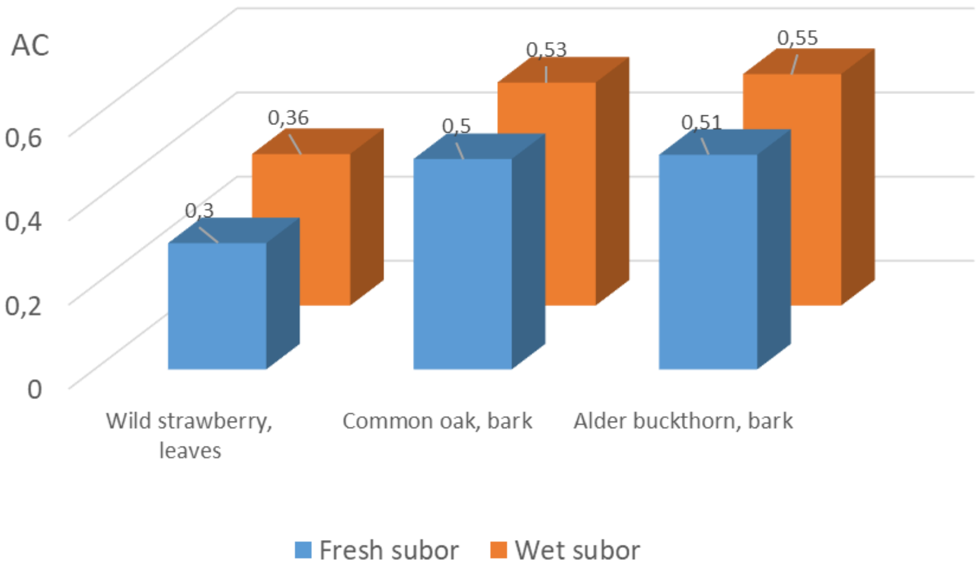

Figure 2. 137-Cs accumulation coeficients in herbal substances of fresh and wet subors.

Despite the higher intensity of radionuclide accumulation in wet subors, all types of medicinal plants that were found in both edatopes were assigned to the same groups according to the average values of AC as in fresh subors (Figure 3). Thus, wild strawberry leaves were included in the group of weak 137-Cs accumulators. The second group (moderate intensity of accumulation) consists of common oak bark and alder buckthorn. Lycopodium, which did not occur in fresh subor, is characterized by a strong accumulation of 137Cs and according to AC (1.38) belongs to the third group (1<AC<1.5). No plants belonging to the group of very strong 137Cs accumulators were found at the research plot.

Since the dependence of 137Cs specific activity in medicinal plants on ^{137}Cs specific activity in the soil under certain environmental conditions is linear, it is legitimate to calculate the expected content of ^{137}Cs in medicinal plants using the generally accepted formula:

$$A_m = CF \times A_s$$

Where, A_m – calculated content of 137-Cs in medicinal plants, Bq/kg; *CF* – concentration factor; A_s – specific activity of 137Cs in soil, Bq/kg.

On the basis of the permissible content of 137Cs in wild-growing medicinal plantss (600 Bq/kg) we can solve the inverse problem – determine the maximum permissible level of soil contamination with radionuclides, at which it is possible to harvest medicinal plants that are normatively pure in terms of radiation:

$$\lim A_m \times CF = \lim A_m$$

Where, lim A_m – permissible content of 137-Cs in medicinal plants (600 Bq/ kg); *CF* – concentration factor; lim A_s – limiting level of 137-Cs specific activity in the soil, at which it is possible to harvest medicinal plants, Bq/kg.

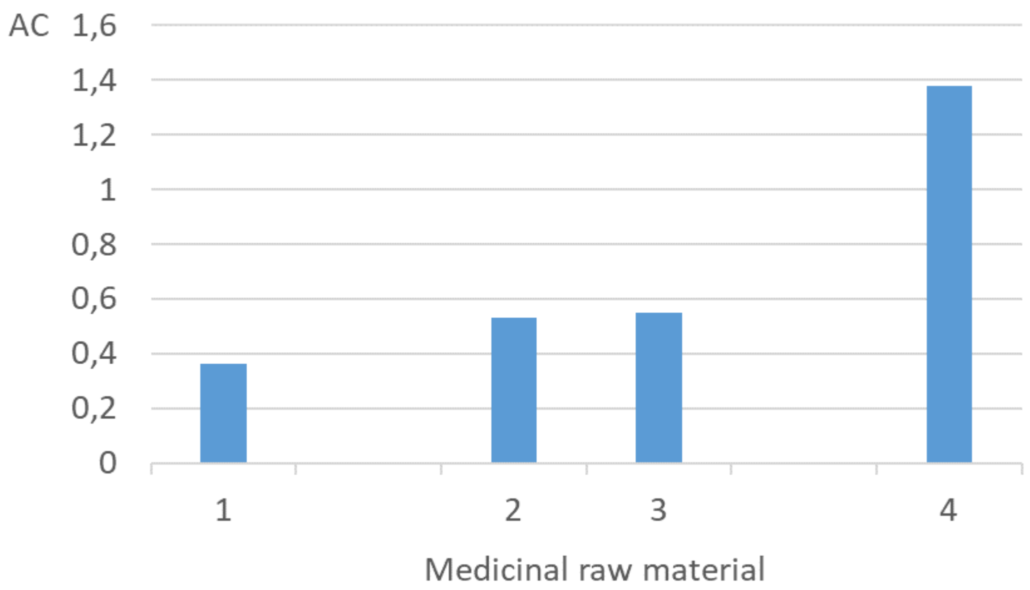

Figure 3. Ranking of herbal substances plants by average value of 137-Cs CF (wet subors).
1. Wild strawberry, leaves. 2. Common oak, bark. 3. Alder buckthorn, bark. 4. Creeping cedars, herb

According to the last formula, we calculated the limiting levels of 137-Cs specific activity in the soil for the harvesting of medicinal plant species (Table 5).

Table 5. Limiting levels of $^{137\text{-}Cs}$ soil specific activity for medicinal herbal substances.

Herbal substances	CF	Maximum level of 137Cs specific activity in the soil for harvesting of medicinal plants
	B2 – fresh subor	
European mountain ash, berries	0.29	2069
Wild strawberry, leaves	0.30	2000
Creeping thyme, herb	0.40	1500
European raspberry, leaves	0.41	1463
Common Saint John's wort, flowering shoot apexes	0.47	1277
Common oak, bark	0.50	1200
Alder buckthorn, bark	0.51	1176
Oregano, herb	0.71	845
Motherwort, herb	0.93	645
European blueberry, berries	1.00	600
Cowberry, leaves	1.39	431
European blueberry, leaves	1.46	411
Common heather, shoots	1.95	307
	B3 – wet subor	
Wild strawberry, leaves	0.36	1667
Common oak, bark	0.53	1132
Alder buckthorn, bark	0.55	1090
Creeping cedars, herb	1.38	435

Thus, our calculations showed that herbal substances, characterized by a weak 137Cs accumulation (European mountain ash berries, Wild strawberry leaves; creeping thyme herb, European raspberry leaves, and flowering shoot apexes of common St. John's wort) in fresh subor (B2) can be harvested with a specific activity of 137-Cs in soil up to 1200 Bq/kg. Herbal substances, which are characterized by a moderate intensity of 137Cs accumulation from the soil (bark of common oak and alder buckthorn, oregano herb, motherwort herb and berries of European blueberry), can be harvested with a specific activity of the radionuclide up to 600 Bq/kg. Harvesting of cowberry and European blueberry leaves is possible at soil contamination levels up to 431 and 411 Bq/kg, respectively. Common heather is a very strong accumulator of 137-Cs and, therefore, can be harvested at 307 Bq/kg of 137-Cs specific activity in the soil. Harvesting of medicinal plants has even more severe conditions for wet subors than for fresh subors, because with growing humidity of edatopes, the intensity of radionuclide accumulation by plant products increases. Thus, the maximum level of specific activity of 137Cs in the soil for harvesting wild strawberry leaves is 1667 Bq/kg, common oak bark – 1132 Bq/kg, alder buckthorn bark – 1090 Bq/kg, and the herb of creeping cedars, which is a strong accumulator of 137Cs – 435 Bq/kg.

Conclusion

The specific activity of 137-Cs in wild-growing medicinal plants of natural forest ecosystems of Ukrainian polissya has been changing and largely depends on species, type of phytocenosis, habitat conditions, and density of territory contamination. Classification of medicinal plants by the intensity of radionuclides contamination from the soil and calculation of average values of AC for herbal substances could be the scientific background for medicinal plants balanced exploitation in radioactive contaminated Ukrainian forests.

References

Antonova, V.A., Seditskaya, Z.L. (1989). Influence of medicine preparation technology on the transition of cesium-137 to liquid medicine form. Gigiyena i sanitariya, 7, 87-88. (in Russian)

Chandrashekara, K., Somashekarappa, H.M. (2016). Estimation of radionuclides concentration and average annual committed effective dose due to ingestion for some selected medicinal plants of South India. Journal of Radiation Research and Applied Sciences, 9, 68-77.

Chobotko, H.M., Raychuk, L.A., Piskovyy, Yu.M., Yaskovets, I.I. (2011). Formation of a dose of internal irradiation of the population of Ukrainian polissya as a result of the consumption of food products of forest origin. Ahroekolohichnyy zhurnal, 1, 37-42. (in Ukrainian)

Davydova, I., Korbut, M., Kreitseva, H., Panasiuk, A., Melnyk, V. (2019). Vertical distribution of 137Cs in forest soil after the ground fires. Ukrainian Journal of Ecology, 9(3), 231-240.

Desideri D., Meli, M.A., Roselli, C. (2010). Natural and artificial radioactivity determination of some medicinal plants. Journal of Environmental Radioactivity, 101(9), 751-756.

Durusoy, A., Yildirim, M. (2017). Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey. Journal of Radiation Research and Applied Sciences, 10, 348-352

Gubin, Yu.I., Dziubak, A.P., Dziubak, S.N. (1999). On the need to develop standards for the content of radionuclides in finished medicine forms. Proceed. 5th National Congress of Pharmacists "Dostizheniya sovremennoy farmatsii i perspektivy yeyo razvitiya v novom tysyacheletii". Kharkov. (in Russian)

Hrabovskyy, V.A., Dzendzeliuk, O.S., Dutsiak, H.Z. (2009). Temporal and seasonal changes in 137Cs content in some plants of Shatsk National Nature Park during 1996-2007. Naukovyy visnyk Volynskoho natsionalnoho universytetu imeni Lesi Ukrainky, 50-55. (in Ukrainian)

Hryshchenko, E.N., Hrodzynskyy, D.M., Moskalenko, V.N. (1990). Radionuclide contamination of plants in various regions of Ukraine after the Chernobyl accident. Abstracts of papers of the international symposium Ekologicheskiye aspekty v farmatsyi (Moscow, 11-16.06.1990). Moscow (in Russian)

Karachov, I.I. (2006) Problems of radioactive contamination of forest food products and internal irradiation of the population. Problemy kharchuvannia, 1, 8-13. (in Ukrainian)

Korotkova, A.Z. (1999). Accumulation of 137Cs by the phytomass of berry plants at different densities of radioactive contamination of the soil. Zdorovye lesa. Lesovodstvo i agrolesomelioratsiya, 9, 16-23. (in Russian)

Krasnov, V.P. (1995). Recommendations for forest management in conditions of radioactive contamination. Kyiv. Agrarna nauka (in Russian).

Krasnov, V.P. (2007). Forest applied radioecology. Zhytomyr. polissya(in Russian)

Krasnov, V.P., Orlov, A.A., Irklienko, S.P. (1996). Cesium-137 contamination of medicinal plants in the forests of Ukrainian Polessye. Rastitelnye resursy, 32(3), 6-43. (in Russian)

Krasnov, V.P., Kurbet, T.V., Davydova, I.V., Sukhovetska, S.V. (2016). The effectiveness of radioecological control of forestry products in Ukrainian polissya in the period remote from the time of the Chernobyl accident. Naukovyy visnyk NLTU Ukrainy, 26(3), 251-257. (in Ukrainian).

Moysienko, V.V. (2012). Ecological state of medicinal plants in the conditions of natural phytocenoses of Zhytomyr region. Visnyk ZhNAEU, 2, 88-95. (in Ukrainian)

Moysienko, V.V. (2015). Radiation monitoring of medicinal plants depending on the density of soil contamination of natural phytocenoses of polissya. Zemlerobstvo, 2, 87-91. (in Ukrainian)

Njinga, R.L., Jonah, S.A., Gomina, M. (2015). Preliminary investigation of naturally occurring radionuclides in some traditional medicinal plants used in Nigeria. Journal of Radiation Research and Applied Sciences, 8, 208-215.

Sahil, K., Sudeep, B., Akanksha, M. (2011). Standardization of medicinal plant materials. International Journal of Research in Ayurveda and Pharmacy, 2(4), 1100-1109.

Siasou, E., Willey, N. (2015). Inter-Taxa Differences in Iodine Uptake by Plants: Implications for Food Quality and Contamination. Agronomy, 5, 537-554.

State hygienic standards. (1997). Permissible levels of 137Cs and 90Sr radionuclides in food and drinking water (DR-97). Approved by the Chief State Sanitary Doctor of Ukraine. Kyiv (in Ukrainian)

Sussaa, F.V., Damattob, S.R., Alencarb, M.M., Mazzillib, B.P., Silvaa, P.S.C. (2013). Natural radioactivity determination in samples of Peperomia pellucida commonly used as a medicinal herb. Journal of Environmental Radioactivity, 116, 148-151.

Tsvetnova, O.B., Shcheglov, A.I., Tshernov, S.A. (1990). Content of radionuclides in medicinal plants of forests exposed to radioactive contamination. Proceed. All-Union Sci. Conf. "Osnovy organizatsyi i vedeniya lesnogo hoziaystva v usloviyah radioactivnogo zagriazneniya". Gomel (in Russian)

Vinichuk, M., Mandro, Y., Rosen, K. (2016). The application of mineral fertilizers in order to restore forest ecosystems contaminated with radionuclide 137Cs. Agroekologichnij zhurnal, 1, 37-43.

Yadav, N.P., Dixit, V.K. (2008). Recent Approaches in herbal drug standardization. International Journal of Integrative Biology, 2(3), 195-203.

Yelishevich, N.V., Rubanova, R.V. (1993). Accumulation of radionuclides by medicinal plants by types of their habitats. Abstracts of papers of the Radiobiological Congress (Kyiv, September 20-25, 1993). Part I. Pushchino (in Russian).

Citation:

Davydova, I., Panasiuk, A., Melnyk, V., Davydova, L. (2020). 137Cs contamination in wild-growing medicinal plants of *Zhytomyr polissya* forests: 34 years after Chernobyl accident. *Ukrainian Journal of Ecology, 10*(3), 208-215.