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INTENSITY OF ^{137}CS TRANSITION INTO NECTAR-POLLINATING PLANTS AND BEEKEEPING PRODUCTS DURING RECLAMATION OF RADIOACTIVELY CONTAMINATED SOILS

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ABSTRACT

The article presents investigations of transition ^{137}Cs to agricultural crops (sunflower) and beekeeping products (honey, bee pollen) for reclamation of radioactively contaminated soils. It is proved that the quality of beekeeping products depends from the ecological condition of nectar-pollinating lands. As a result of the 1986 accident at the Chernobyl nuclear power plant, nectar-pollinating lands were subjected to high man-caused impact, in particular, some areas of Polissya. It caused a certain accumulation of ^{137}Cs and ^{90}Sr in beekeeping products. The authors studied the effect of reclamation of contaminated soils, in particular, in the Narodytskyi district of Zhytomyr region of Ukraine with ^{137}Cs up to 5 Ci/m^2 with different acidity on the intensity of accumulation of this radionuclide in honey and bee pollen produced by bees from nectar and sunflower pollen. It was found that the specific activity of ^{137}Cs in honey and bee pollen produced by bees from nectar and pollen of sunflower grown on agricultural land with a content of this radionuclide in soils from 2824 Bq/kg to 2665 Bq/kg, not exceeding DR-2006 200 Bq/kg. Reclamation of radioactively contaminated soils with hydrolytic acidity from 1.6 mg to 2.4 mg-eq/100 g of soil, in particular, the application of defication mud in them at a rate of 4 t/ha to 6 t/ha reduced the specific activity and accumulation coefficient of ^{137}Cs in vegetative mass of sunflower, honey and bee pollen, made by bees from nectar and pollen of this plant.

Keywords: sunflower, soil, honey, bee pollination, vegetative mass, nectar, pollen, specific activity of ^{137}Cs.

INTRODUCTION

Nectar-pollinating plants play an important role in the existence of the honey bee. Nectar and pollen are a source of food for bees and raw materials for their products, including honey, perga, wax, royal jelly, homogenate of drone larvae and others (Nicolson, 2011).

The nectar-pollinating base of Ukraine includes about 900 species of plants. Among this number of nectar pollinators, about 472 species occupy the main honey plants, which include aster, legumes, rosales, labiatae, crucifers (Razanov et al., 2019).

Among the main species of nectar pollinators in Polissya of Ukraine it is necessary to distinguish plants of forest parks, agricultural lands and natural meadows. In particular, the main representatives of nectar-pollinating plants of forest parks of Polissya include linden, maple, acacia; agricultural lands - sunflower, rapeseed and winter rape, buckwheat; natural meadows - dandelion, thyme, white clover, blueweed, clover and others (Ibatullin et al., 2020) .

Analysis of the state of nectar-pollinating lands in Polissya of Ukraine shows that among the plants of field crop rotation a promising and powerful source of nectar and pollen is sunflower, which is grown in Ukraine as the main oil crop. In addition, it also provides the beekeeping industry with nectar and pollen, ie raw materials for the production of carbohydrate and protein feed of bees and their products (Nedashkivskyi et al., 2019).

Sunflower belongs to the family Compositae. The duration of its flowering is up to 25 days, and the flowering period - from the second decade of July to the first decade of August. This crop currently occupies the largest sown area among agricultural nectar-pollinating crops in Ukraine, which makes it possible to provide bees in sufficient quantities with both food and raw materials for the production of marketable products (Mazur et al., 2020; Palamarchuk et al., 2021; Rudska, 2021).

Due to the widespread use of beekeeping products as a highly effective food raw material for treatment and prevention, the demand for it is growing rapidly in our country and around the world. At the same time, the requirements for the quality and safety of this product are increasing.

It is known that the quality of beekeeping products depends on the ecological condition of nectar-pollinating lands, which in Ukraine are generally characterized as favorable for the production of high quality beekeeping products, except for some areas that are under high man-made load. It is known that nectar-pollinating lands suffered the highest man-caused load, in particular, some territories of Polissya as a result of the 1986 accident at the Chernobyl nuclear power plant, which caused a certain accumulation of ^{137}Cs and ^{90}Sr in beekeeping products. At the same time, there were cases of exceeding the permissible levels (DR-1991) for the content of ^{137}Cs in honey and pollen in areas where the content of this isotope in the soil was higher than 5 Ci/km^2. Sometimes there were cases of excess (DR-1991) in beekeeping and ^{137}Cs content in soils above 1 Ci/km^2, especially in bee pollen (pollen) (Dutov et al., 2015; Razanov et al., 2021).

According to the Law of Ukraine "On the Legal Regime of the Territory Contaminated by Radioactive Contamination as a Result of the Chornobyl Accident", the territories, in particular, and agricultural lands where nectar pollinators grow are divided into certain zones:

1. The zone of unconditional resettlement of inhabitants occupies areas with a density of ^{137}Cs soil contamination of 15.0 Ci/km^2 and above, and ^{90}Sr - above 3.0 Ci/km^2.
2. The zone of guaranteed voluntary resettlement of the population includes territories with the level of soil pollution ^{137}Cs from 5.0 to 15.0 Ci/km^2, and ^{90}Sr - from 0.15 Ci/km^2 to 3.0 Ci/km^2.
3. The zone of enhanced radiological control includes areas with ^{137}Cs content in the soil from 1.0 to 5.0 Ci/km^2, and ^{90}Sr - from 0.005 Ci/km^2 to 0.01 Ci/km^2 (Law of Ukraine, 1991).

It has been proven that radionuclides that are in soluble soils can migrate into vegetation, reducing their quality and safety. The rate at which ^{137}Cs and ^{90}Sr move into vegetation depends on a number of factors, including soil type, mineral composition, soil pH, organic matter content, and botanical origin (Frissel et al., 2002; Ji-gen Lu et al., 2006).

Different intensities of radionuclide accumulation both by nectar pollinators and by beekeeping products made from nectar and pollen of these plants were also established. In particular, it was found that the intensive accumulation of ^{137}Cs is characterized by such nectar-pollinating plants as thyme, creeping clover, heather, raspberry and others. Honey and pollen produced by bees from the nectar and pollen of these plants were characterized by a higher content of ^{137}Cs compared to other nectar pollinators (Razanov et al., 2020).

Peat and peat-swamp soils, which are part of the Polissya ecosystem of Ukraine, are characterized by low sorption properties, on which the transition of ^{137}Cs and ^{90}Sr to vegetation depends. It was also found that on wet soils the migration of ^{137}Cs and ^{90}Sr into vegetation is higher compared to soils of moderate moisture (Razanov et al., 2020).

In addition, it should be noted that the activity of movement from soils to plants ^{137}Cs and ^{90}Sr is their pH. Thus, on soils with high pH of the environment (4.5 - 5.0 units) there is a higher transition of ^{137}Cs and ^{90}Sr in plants compared to pH 6.0 - 7.0 units (Pryster, 1997).

The danger of ^{137}Cs for the human body, as well as the high demand for bee products, its widespread use for therapeutic and prophylactic purposes among the population, there is a need to control and seek measures to reduce this toxicant in bee products.
One of the measures to increase the safety of beekeeping products, in particular, to reduce ^{137}Cs in it is to prevent the movement of this element in the soil system - nectar pollinators. Chemical reclamation of agricultural lands, which involves liming of soils with high acidity, has a certain effect on the reduction of ^{137}Cs in plants (Camps et al., 2004).

The application of calcium into the soil in the form of lime or defication mud (waste from sugar factories) leads to the neutralization of the acidity of the soil solution, the displacement of hydrogen ions from the soil complex and its saturation with calcium (Goulding, 2016).
It was found that the application of lime into the soil in an equivalent dose depending on their hydrolytic acidity reduces the transition of ^{137}Cs in crop products up to 2.5 times (Pryster, 1997). The study of ^{137}Cs transition to vegetation in the territory of Polissya of Ukraine was carried out mainly on agricultural crops zoned in these territories (oats, barley, rye, wheat, vetch, peas, corn).

Thirty years after the Chernobyl accident due to climate change, in particular due to rising ambient temperatures, the structural composition of crops has changed somewhat (Bondar, 2020). Thus, recently in the territory of Polissya of Ukraine there is a tendency to increase the area of agricultural land for growing sunflower, which was mainly cultivated until 2000, mainly in the southern steppes of Ukraine. Today, sunflower in the Polissya area is one of the main nectar pollinators among crops (Dikhtiar, 2018).
Due to the high toxicity of ^{137}Cs and the reduction of permissible levels, there is a need to monitor the receipt of this isotope in nectar pollinators and bee products.

Based on this, we monitored the accumulation of ^{137}Cs in beekeeping products and studied the impact of chemical reclamation (application of calcium into the soil as a defication mud) on its transfer to agricultural nectar-pollinating plants (sunflower) to further predict the entry of this radionuclide into the production of radionuclides, pollen).

MATERIALS AND METHODS

The effectiveness of reducing the migration of ^{137}Cs into agricultural nectar pollinators (sunflower) was carried out in the Narodytsky district of Zhytomyr region, Ukraine.
The research program provided for the study of the specific activity of ^{137}Cs in the soils of agricultural nectar-pollinating lands and in vegetation (vegetative mass) at different stages of their development (stem growth, budding, flowering) for the application of defication mud into soils. Reclamation of soils included the application of defication mud in them.
Defication mud -is the I-class sugar production waste with a content of 60% (Fares et al., 2016). Sunflower cultivation, honey production and bee pollination were carried out in the conditions of four agricultural lands, the distance from each of which was from 8 to 12 km.
The studies were performed on sod-podzolic soils with a contamination density of ^{137}Cs up to 5 Ci/km^2 and an acidity of 1.6 mg to 2.4 mg-eq/100 g of soil.
In the conditions of agricultural lands № 1 (control) sunflower was grown on soils with ^{137}Cs content - 3640 Bq/kg with hydrolytic acidity of 2.4 mg-eq/100 g of soil without defecation mud.
On agricultural lands №2 (experimental) sunflower was grown on soils with ^{137}Cs content - 3665 Bq/kg and hydrolytic acidity of 2.4 mg-eq/100 g of soil with application of defication mud at the rate of 6 t/ha.
In the conditions of agricultural lands №3 (control) sunflower cultivation was carried out on soils with ^{137}Cs content of 2824 Bq/kg with hydrolytic acidity of 1.6 mg-eq/100 g of soil without defication mud.
On agricultural lands №4 (experimental) sunflower cultivation was carried out on soils with ^{137}Cs content 2837 Bq/kg and hydrolytic acidity 1.6 mg-eq/100 g of soil with the application of defication mud at the rate of 4 t/ha.
The specific activity of ^{137}Cs in soils and vegetative mass of agricultural nectar pollinators was determined using the method of expressive radiometric analysis by gamma radiation of volume and specific activity of Cs radionuclides in water, soil and livestock and crop products.

Soil selection for radiological analysis was performed by envelope method from each field where sunflower was grown.

Selection of vegetative mass of sunflower was carried out by mowing it on an area of 1 m^2 on 8 sites of each field in different phases of its growth: stem growth (20 days), budding (5 days), flowering (10 days).
The botanical origin of sunflower honey and bee pollen was determined by pollen analysis and the shape of their grains.

The accumulation coefficient of ^{137}Cs in different phases of sunflower development and in beekeeping products (honey, bee pollen) was determined by the formula:

$$C_{Accumulation} = \frac{137Cs\ content\ in\ raw\ materials}{137Cs\ content\ in\ soil}$$

RESULTS AND DISCUSSION

Analysis of the results of studies to study the intensity of ^{137}Cs accumulation in the vegetative mass of sunflower (Table 1) showed that the application of defication mud in the soil helps to reduce the accumulation of this radionuclide in the plant.

Thus, in the phase of sunflower vegetation (stem growth) the specific activity of ^{137}Cs during the application of defication mud in soils with hydrolytic acidity of 2.4 mg decreased by 2.19 times, and the accumulation coefficient by 2.26 times. In the budding phase, the specific activity of ^{137}Cs in the vegetative mass of sunflower decreased by 1.99 times, and the accumulation coefficient by 2.04 times. Whereas in the sunflower flowering phase the specific activity of ^{137}Cs and the coefficient of accumulation in the vegetative mass decreased by 2.3 times and 2.4 times, respectively.

Table 1. The intensity of the accumulation of ^{137}Cs in the vegetative mass of sunflower for the application of defication mud into the soil

Development phase	Indexes	Agricultural land			
		№1 (without application of defication mud)	№2 (with application of defication mud)	№3 (without application of defication mud)	№4 (with application of defication mud)
Stem growth	Specific activity of ^{137}Cs in soil, Bq kg	3640±3.2	3665±7.8	2824±1.9	2837±2.7
	The specific activity of ^{137}Cs in the plant, Bq/kg	191.4±4.7	87.1±1.2	152.1±1.8	81.7±0.7
	Accumulation coefficient	0.052	0.023	0.053	0.028
Budding	Specific activity of ^{137}Cs in soil, Bq/kg	3640±1.2	3665±7.8	2824±4.1	2837±2.7
	The specific activity of ^{137}Cs in the plant, Bq/kg	157.2±1.4	78.8±0.8	143.5±2.1	73.7±1.3
	Accumulation coefficient	0.043	0.021	0.050	0.033
Flowering	Specific activity of ^{137}Cs in soil, Bq/kg	3640±3.2	3665±7.8	2824±4.1	2837±2.7
	The specific activity of ^{137}Cs in the plant Bq/kg	150.3±2.7	65.1±0.6	128±3.4	59.8±2.7
	Accumulation coefficient	0.041	0.017	0.045	0.021

A similar trend was observed for the application of defication mud in soils with a hydrolytic acidity of 1.6 mg.
In particular, when defication mud were applied into soils with hydrolytic acidity of 1.6 mg in the vegetative mass of sunflower in the stem growth phase, the specific activity of ^{137}Cs was 1.86 times lower and the accumulation coefficient was 1.89 times. Whereas in the budding and flowering phase of sunflower, the specific activity of ^{137}Cs during the application of defication mud into the soil was 1.94 times and 1.92 times lower, and the accumulation coefficient was 2.14 and 2.14 times, respectively, compared to the variant without fertilizer.

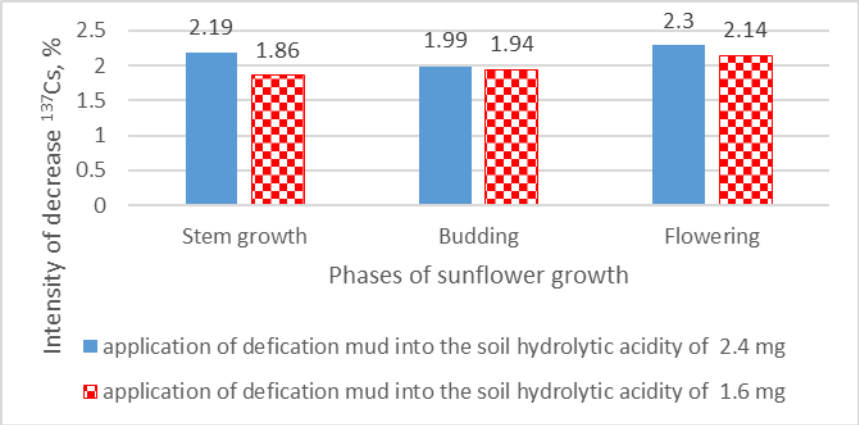

Figure 1. Comparative assessment of ^{137}Cs reduction in the vegetative mass of sunflower for the application of defication mud in soils of different acidity

Characterizing the effectiveness of reducing ^{137}Cs in the vegetative mass of sunflower (Fig. 1), it should be noted that the highest result was achieved by making defication mud in soils with hydrolytic acidity of 2.4 mg compared to soils with hydrolytic acidity of 1.6 mg.
In particular, the rate of decrease in ^{137}Cs in the vegetative mass of sunflower in the growth phase (stem growth, budding, flowering) for the application of defication mud in soils with hydrolytic acidity of 2.4 mg was higher by 0.33 percentage points (pp), 0.05 pp and 0.16 pp respectively compared to the hydrolytic acidity of 1.6 mg.

Table 2. The intensity of the accumulation ^{137}Cs in beekeeping products made from nectar and pollen of sunflower for the application of defication mud into the soil

Agricultural lands and research options	Beekeeping products					
	Honey			Bee pollen		
	Specific activity in soil ^{137}Cs, Bq/kg	The specific activity of ^{137}Cs in honey Bq/kg	C accumulation	Specific activity in soil ^{137}Cs, Bq/kg	The specific activity of ^{137}Cs in bee pollen Bq/kg	C accumulation
№1 – without application of defication mud (control)	3640±5.1	32.3±0.7	0.008	3640±5.1	81.5±1.2	0.022
№2 – with application of defication mud (experimental)	3665±2.1	17.2±0.34	0.004	3665±2.1	27.2±0.74	0.007
№3 – without application of defication mud (control)	2824±1.4	30.4±0.95	0.01	2824±1.4	70.3±2.1	0.024
№4 – with application of defication mud (experimental)	2837±1.5	18.1±1.5	0.006	2837±1.5	28.1±1.7	0.009

We have found out changes in the intake of ^{137}Cs in beekeeping products during liming of acid soils of agricultural lands for growing sunflower, the nectar and pollen of which are raw materials for the production of honey by bees and bee pollen (Table 2).

Thus, the specific activity and accumulation coefficient of ^{137}Cs in honey produced by bees from sunflower nectar during its cultivation when making defication mud in soils with hydrolytic acidity of 2.4 mg, was lower by 1.87 times and 2.0 times compared to the option without making defication mud.

When defication mud were introduced into soils with hydrolytic acidity of 1.6 mg, the specific activity of ^{137}Cs in honey produced by bees from sunflower nectar was 1.68 times lower and the accumulation coefficient was 1.66 times lower than in the non-defication mudive version.

A similar tendency to decrease the specific activity and accumulation coefficient of ^{137}Cs was observed in bee pollen produced by bees from sunflower pollen for defecation in acidic soils of agricultural lands.

In particular, when the defication mud was introduced into soils with hydrolytic acidity of 2.4 mg, the specific activity of ^{137}Cs in bee pollen made by bees from sunflower pollen was 3.0 times lower and the accumulation coefficient was 3.1 times lower than in the non-defication mudive version. .

When defication mud were introduced into soils with a hydrolytic acidity of 1.6 mg, the specific activity of ^{137}Cs in bee pollination was 2.5 times lower, and the accumulation coefficient was 2.6 times lower than in the variant without defecation.

In addition, it should be noted that the specific activity of ^{137}Cs in honey and bee pollen for the application of defication mud in soils with hydrolytic acidity of 2.4 mg was lower than DR-2000 g 11.6 times and 7.3 times, respectively, whereas in the version without these defication mud were 6.2 and 2.4 times higher in the soil.

The specific activity of ^{137}Cs in honey and bee pollen produced by bees from the nectar of sunflower pollen when growing it for defecation in soils with hydrolytic acidity of 1.6 mg was 11.0 times lower than DR-2000 and 7.1 times, respectively, while in the version without introducing defication mud into the soil (control), these figures were between 6.5 and 2.8 times.

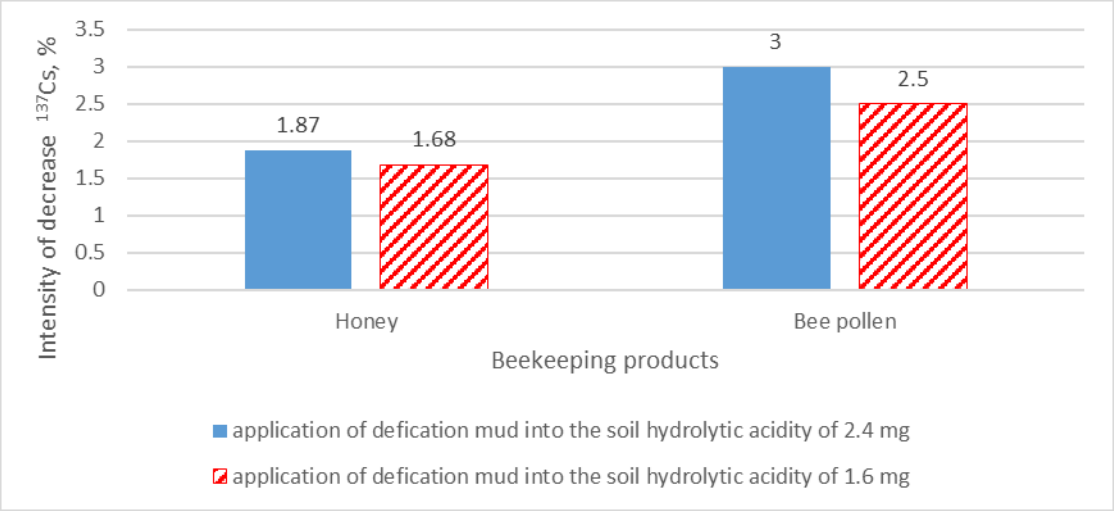

Figure 2. Comparative assessment of the reduction of ^{137}Cs movement in beekeeping products for the application of defication mud in soils of different acidity

There was also a higher efficiency of ^{137}Cs reduction in beekeeping products with the application of defication mud in soils with hydrolytic acidity of 2.4 mg-eq/100 g compared to hydrolytic acidity of 1.6 mg-eq/100 g (Fig. 2).

Thus, the application of defication mud into soils with hydrolytic acidity of 2.4 mg showed a decrease in ^{137}Cs in honey by 0.19 percentage points, and in bee pollination by 0.5 percentage points compared with hydrolytic acidity of 1.6 mg.

Thus, the results of research revealed that reclamation of agricultural nectar pollinators (application into the soil of defication mud) reduces the accumulation of ^{137}Cs in the vegetative mass of sunflower, honey and bee pollen produced by bees from nectar and pollen.

CONCLUSION

- The specific activity of ^{137}Cs in honey and bee pollen produced by bees from nectar and pollen of sunflower grown on agricultural land with the content of this radionuclide in soils from 2824 Bq/kg to 2665 Bq/kg, did not exceed 200 DR, 2006 Bq/kg.
- Reclamation of radioactively contaminated soils with hydrolytic acidity from 1.6 mg to 2.4 mg-eq/100 g of soil, in particular, the application of defication mud in them at a rate of 4 t/ha to 6 t/ha reduced the specific activity and accumulation rate ^{137}Cs in the vegetative mass of sunflower, honey and bee pollen, made by bees from the nectar and pollen of this plant.
- Higher efficiency of reduction of specific activity and accumulation coefficient of ^{137}Cs in honey and bee pollen produced from nectar and pollen of sunflower was characterized by defecation mud application in soils with hydrolytic acidity of 2.4 mg-eq/100 g of soil compared to 1.6 mg-eq/100 g of soil.

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