REDUCTION OF ^{137}Cs UPTAKE BY FOREST BERRIES IN BELARUSIAN FIELD EXPERIMENT

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Abstract
The effect of different doses of dolomite powder (DP) and potassium fertilizer (PF) on ^{137}Cs transfer from soddy-podzolic sandy soil into *Vaccinium vitis idaea* and from peat-boggy soil into *Oxycocos palustis* has been analyzed. The experimental plots were located in Bilberry and Ledum Pine forests. Distribution of ^{137}Cs between components of berry plant (leaves, stems, roots, fruits) has been determined. The transfer factor of radionuclide in soil – plant system and compositions of soil solution in root-inhabited layer have been studied. It was found that for *Oxycocos palustis* the ^{137}Cs transfer factor is approximately double in comparison with that for *Vaccinium vitis idaea*. It can be caused by the higher content of biologically available ^{137}Cs forms in root-inhabited layer of peat-boggy soil (~ 33%) in comparison to the corresponding layer of soddy-podzolic sandy one (~ 16%). The maximum reduction of ^{137}Cs soil-plant transfer was observed at plots treated with dolomite powder in dose 6 t/ha and potassium fertilizer in dose 0.14 t of K_2O /ha. It was shown that the effect of dolomite powder is defined mainly by the reduction in soil acidity and the effect of potassium fertilizer – by increasing in K/Cs ratio in soil solution of root-inhabited soil layer.

Introduction
The behaviour of radiocaesium in the environment has been extensively studied after the Chernobyl catastrophe for better understanding how it became available for animals and people (1, 2). However, despite of many investigations and implementations of any countermeasures, the problems with the radionuclide soil – plant transfer exist for many years. So, in recent radioecological research the attention was also given to the possibilities to reduce ^{137}Cs transfer into the food chains by application of different countermeasures (3). As a result of Chernobyl catastrophe up to 20% of Belarusian forests have been contaminated by radionuclides. The radiocaesium transfer into the forest berries is a sensitive radionuclide pathway to human diet. The general aim of present study was to investigate the behaviour of radiocaesium in Chernobyl-affected forests of Belarus and to test in practice ability of potassium fertilizer and dolomite powder to reduce radiocaesium transfer from soil to the forest berries. It is based on field experiments and laboratory investigations. Comparison between behaviour of ^{137}Cs in two contrasting types of forest soils before and after their treatments by dolomite powder and potassium fertilizer has been carried out.

Objects and Methods
The study area is located in the South-East of Belarus (Gomel region, 52°36' north latitude, 31°13' east longitude). In two types of forests (Bilberry and Ledum Pine of natural origin), the effect of 3 doses of dolomite powder (3.0, 4.5, 6.0 t/ha) and 2 doses of potassium fertilizer (0.070 and 0.14 t of K_20/ha) on the soil-plant transfer has been investigated. Six experimental plots (25 m^2 each of them) were selected within natural berries plantations. The treatment by dolomite powder was carried out in autumn and by potassium fertilizer — in spring. Before the treatment the studied forestlands did not undergo any cultivation. The soil and vegetation samples were subjected to special preparations before analysis: soils were dried, sieved, carefully homogenized; vegetation probes were divided into leaves, stems, roots and air-dried, then cut into small pieces (2-5 mm). The plant samples were preliminary washed by distilled water. Because of the root systems of *Vaccinium vitis idaea* and *Oxycocos palustis* were located in the forest litter, the soil solutions were obtained from water-saturated samples of this soil horizon. The high-speed centrifuge SIGMA -4 -A has been used for separation of pore soil solutions (4). Content of biologically available forms of ^{137}Cs in the soils was

estimated by the method of consequent selective extraction (5). An exchangeable form of ^{137}Cs was extracted by 1M NH_4COOCH_3, easily soluble form — by 1M HCl. Radioactive caesium in samples of soils, soil solutions and plants has been identified by γ-spectrometer ADCAM-300. The agrochemical properties of soil and soils solutions (acidity, content of organic matter, exchangeable calcium, magnesium, mobile potassium and etc.) have been determined using standard analytical methods (6).

Results and Discussion

The total reserves of ^{137}Cs in the soil profiles and characteristics of forest litter are summarized in Table 1. It has been established that the main part of the radionuclide (up to 60%) was accumulated in the forest litter. The acidity (pH_{KCL}), content of exchangeable forms of calcium (Ca_{ex}) and magnesium (Mg_{ex}), cationic exchange capacity (CEC) of peat-boggy soil is higher than those of soddy-podzolic sandy one. Content of mobile potassium (K_{mob}) in the forest litter is higher in sandy soil. In a whole, the studied soils differ significantly in their agrochemical characteristics. Taking into account the same type of fallout and the comparable levels of ^{137}Cs contamination of two soil types, it is possible to analyze the effectiveness of applied countermeasures on the soil-plant transfer in the different environmental conditions.

The reserves of biologically available forms of ^{137}Cs in soils have been estimated as the total content of easily soluble form of radionuclide in the forest litter (quantity of ^{137}Cs in fractions of 1M NH_4COOCH_3 and 1M HCl). It has been established that the portion of corresponding forms of radionuclide in the peat-boggy soil is much higher than that in the soddy-podzolic sandy one (Table 1). Despite of convention of sequential extraction technique it allows us to conclude that the reserve of biologically available forms of ^{137}Cs in the forest litter of organic soil (~ 33%) predominates that in mineral one (~ 16%).

Table1. Soil characteristics, total reserve and content of bioavailable ^{137}Cs in soils

Parameter	Sites investigated	
Forest type	Ledum Pine	Bilberry Pine
Vegetation	*Oxycocos palustis* (cranberry)	*Vaccinium vitis idaea* (red bilberry)
Soil type	Peat-boggy	Soddy-podzolic sandy
$A^{137}Cs$ in soil, kBq/m^2	700 ± 50	690 ± 130
Forest litter		
pH_{KCl}	2.6 ± 0.1	3.5 ± 0.1
OM, %	92 ± 5	85 ± 6
Ca_{ex}, meq/kg	697 ± 70	241 ± 31
Mg_{ex}, meq/kg	179 ± 27	43 ± 0.6
K_{mob}, meq/kg	6.0 ± 0.9	11.9 ± 1.2
CEC, meq/kg	1015 ± 91	765 ± 54
$A^{137}Cs$, % of total content in soil profile	60 ± 7	56 ± 5
Exchangeable form of ^{137}Cs, % of its content in the forest litter	30.6 ± 3.0	9.7 ± 1.0
Easily soluble form of ^{137}Cs, % of its content in the forest litter	32.9 ± 3.5	15.6 ± 2.1

Influence of ameliorants on soil solution properties

A root uptake is the initial step fluxes of radionuclides into the food chain. The soil solution constitutes the pool of radionuclide forms available for root uptake and plays an important role in transfer of radionuclide from soil into plant.

The root systems of red bilberry and cranberry are located in the forest litter and the characteristics of the corresponding soil solutions allow better understanding in the possible reasons of ameliorant effect on ^{137}Cs transfer into the forest berries. It has been shown that under treatment of soils by different doses of ameliorants the composition of soil solutions had been changed. The change in the acidity of soil solutions after dolomite powder treatment and in the ratio between potassium and radioactive caesium concentrations in the soil solutions ([K]/[^{137}Cs]) after potassium fertilizer treatment were the most noticeable and the most important for transfer of ^{137}Cs into the plants. Dolomite powder was effective in decreasing of soil solution acidity, especially within the red bilberry plantation.

Corresponding pH-values were increased from 3.2 (control plot) to 3.8 for cranberry plantation and from 4.4 (control plot) to 7.0 for the red bilberry plantation (Fig. 1).
Potassium fertilization did not change the acidity of soil solutions. It increased the [K]/[^{137}Cs] ratio in the soil solution: from 1.7 (control plot) to 11.5 for the cranberry plantation and from 7.3 (control plot) to 24.2 for the red bilberry one. Peat-boggy soil with smaller reserve of mobile potassium is more sensitive to potassium fertilization. As a result of fertilization the root uptake of radiocaesium is decreased due to increasing in potassium competitive action.

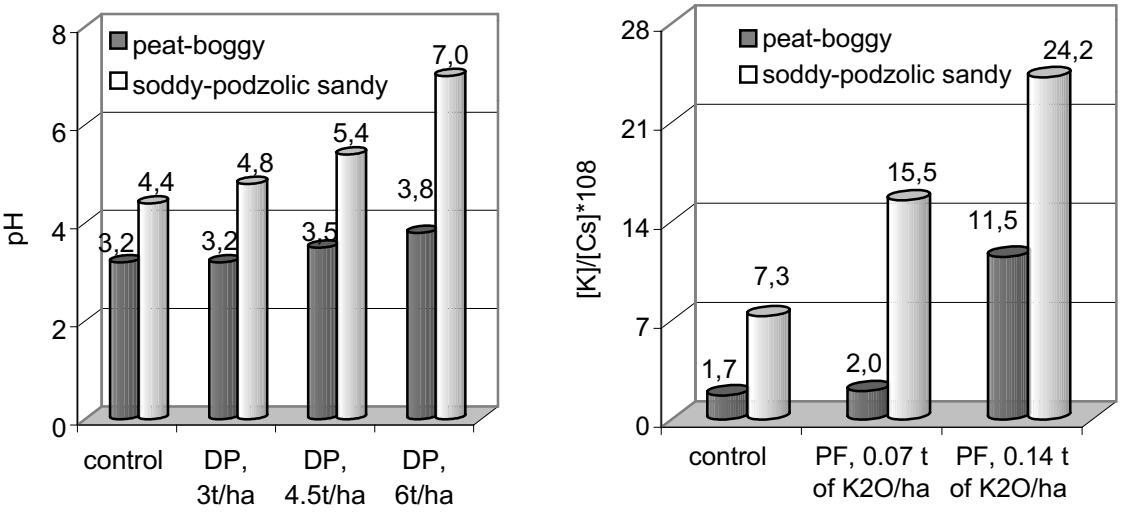

Fig 1. Acidity (pH) and [K]/[Cs] ratio in soil solutions of forest litter of red bilberry and cranberry plots

Influence of ameliorants on ^{137}Cs distribution coefficients in the solid phase – soil solution system
The effects of dolomite powder and potassium fertilizer on distribution coefficient of ^{137}Cs (K_d) in solid phase – interstitial (pore) solution system of the forest litter horizons have been analyzed. The radionuclide distribution coefficient is the ratio between activity concentrations of ^{137}Cs in the solid phase and pore solution of soil in the state of interphase equilibrium. The higher K_d corresponds to the higher ^{137}Cs absorption by solid phase of soil and lower radionuclide mobility in soil. The values of obtained coefficient K_d for plots treated by different doses of ameliorants are presented at Fig 2. It has been shown that at the plots treated by the medium (4.5 t/ha) and the maximum (6.0 t/ha) doses of DP ^{137}Cs migration from the solid phase into the soil solution of root - inhabited layer decreased. The corresponding values of K_d were higher in comparison with that at control plots. The influence of DP on K_d in the forest litter of sandy soil was more effective than that in the forest litter of the peat-boggy soil. Change of distribution coefficient K_d after treatment of both soils by minimum (3.0 t/ha) dose of DP did not exceed experimental error. Potassium fertilization by 0.14 t of K_2O/ha decreased of the value of K_d, but in the case of 0.070 t of K_2O/ha dose the change of K_d did not exceed experimental error.

Influence of ameliorants on soil-plant transfer factor of ^{137}Cs
Distribution of ^{137}Cs between different components of plants for red bilberry and cranberry has been established. Content of ^{137}Cs in the plant organs of *Oxycocos palustis* as well as *Vaccinum vitis-idaea* decreases in the following order: *roots* (30 – 44 kBq/kg) > *leaves* (16 – 29 kBq/kg) > *stem* (14 – 15 kBq/kg) > *beries* (6 – 13 kBq/kg of fresh sample).
The soil – plant transfer factors (T_f) have been used to estimate the biological availability of radionuclide. The ^{137}Cs transfer factor is equal to the ratio of the specific activity of plant (A_p., kBq/kg of fresh mass) to radionuclide reserve in the soil profile (A_s., kBq/m^2). Transfer factors for different components of plants before and after soil treatment by ameliorants have been estimated. The values of T_f for berries as the most important for human diet of local population are presented at Fig. 3. For cranberry the transfer factors of ^{137}Cs are approximately double in comparison with that for red bilberry. One of the reasons of observed difference is conditioned by the higher content of biologically available ^{137}Cs forms in root-inhabited soil layer at the cranberry plantation. Reduction of ^{137}Cs soil –

plant transfer after treatment by dolomite powder and potassium fertilizer has been observed for both soil types.

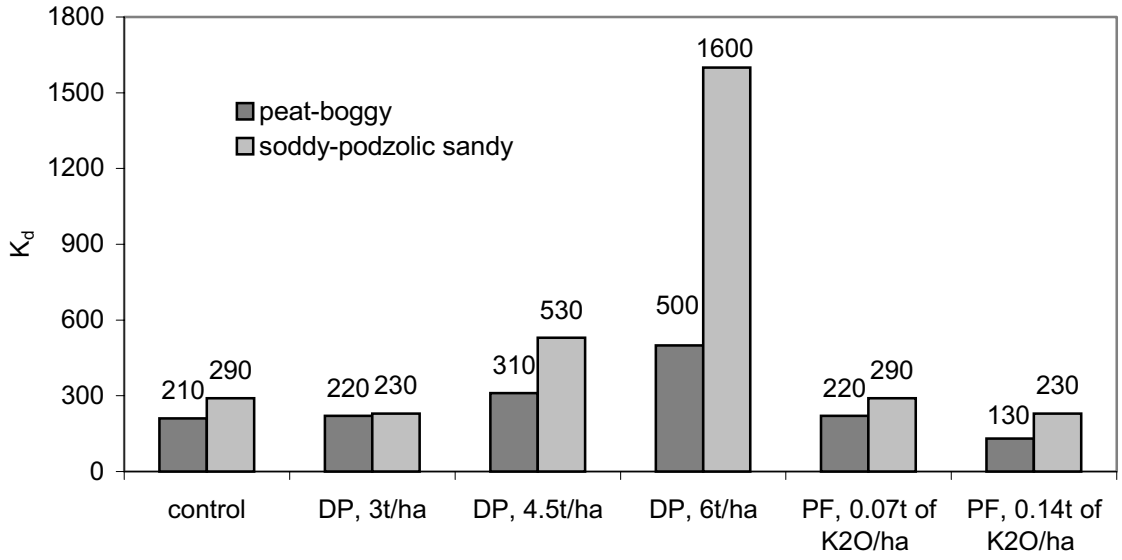

Fig 2. Influence of different doses of dolomite powder and potassium fertilizer on the ^{137}Cs distribution coefficient (K_d) of the forest litter horizon

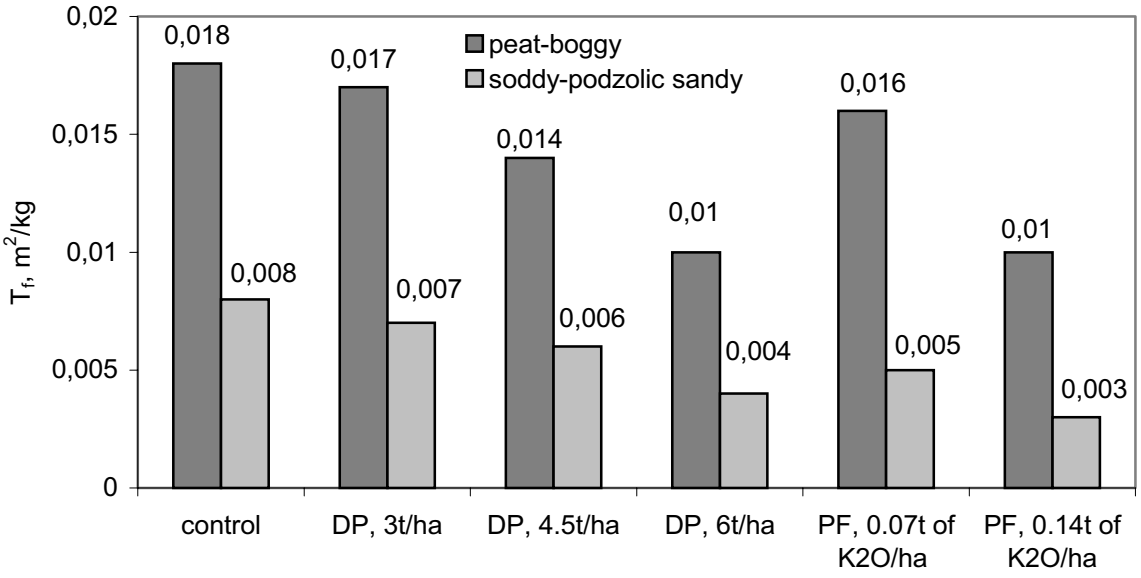

Fig 3. Influence of dolomite powder and potassium fertilizer on ^{137}Cs uptake by forest berries

The observed reduction of caesium transfer into the forest berries after application of ameliorants is caused by change of soil solution composition. Treatment of plot by dolomite powder decreased an acidity of soil solution, sorption of the radionuclide by solid phase of soil increased (the corresponding distribution coefficient in the solid phase – soil solution system became higher). As a result, T_f for berries reduced. Effect of K-fertilization is more complicated. Despite of decrease in the ^{137}Cs absorption by solid phase of soil after application of potassium fertilizer (coefficient K_d has a tendency to decrease), T_f reduced. It means that behaviour of ^{137}Cs in the soil – plant system depends not on the radionuclide concentration in the soil solution, but on its ratio to concentration of competitive chemical analog in solution. In the experimental conditions potassium is the main competitor of caesium during joint uptake of elements by plants.

The effects of applied countermeasures on biological availability of ^{137}Cs for forest berries are summarized in Table 2. The maximum effectiveness of treatment is characteristic for the highest

doses of dolomite powder and potassium fertilizer. At plots treated by maximum doses of ameliorants for both kinds of berries the values of T_f were decreased by a factor of 2 - 3 in comparison with the corresponding T_f at control plots. Maximum positive effect of applied countermeasures on ^{137}Cs soil-forest berry transfer has been revealed for red bilberry at plot treated by 0.14 t of K_2O/ha.

Table 2. Reduction of ^{137}Cs soil-forest berries transfer factor (T_f) after applied countermeasures

Soil	DP, 3 t/ha	DP, 4.5 t/ha	DP, 6t/ha	PF, 0.070 t K_2O/ha	PF, 0.14 t K_2O/ha
Peat boggy (cranberry)	1.1	1.3	1.8	1.1	1.8
Soddy-podzolic (red bilberry)	1.1	1.3	2.0	1.6	2.7

Conclusions

The experimental investigation on application of different doses of dolomite powder and potassium fertilizer in two forest ecosystems reveals:

- the positive effect of countermeasures on reduction of ^{137}Cs content in berries;
- the maximum effects of treatments are characteristic for the doses 6 t/ha of dolomite powder and 0.14 t of K_2O/ha of potassium fertilizer;
- at plots treated by maximum doses of ameliorants for both kinds of berries the transfer factor of ^{137}Cs has been decreased by a factor of 2 – 3 in comparison with that at untreated plots;
- the effect of dolomite powder is mainly defined by reduction in acidity of soil solution, but the effect of potassium fertilizer — by increasing in [K]/[Cs] ratio in soil solutions of root-inhabited layer.

References

1. S. Ehlken, G. Kirchner, Environmental processes affecting plant root uptake of radioactive trace elements and variability of transfer factor data: a review, J. Environ. Radioactivity, **58**, p. 97-112 (2002).
2. S. Lofts, E. Tipping, A. Sanchez, B. Dodd, Modelling the role of humic acid in radiocaesium distribution in a British upland peat soil, J. Environ. Radioactivity, **61**, p. 133-147 (2002).
3. K. Rosen, Field studies on the behaviour of radiocaesium in agricultural environments after the Chernobyl accident, Rapport SLU-REK-78, Sveriges Lantbruksuniversitet, Sweden (1996).
4. S. Ovsiannikova, G. Sokolik, E. Eismont & S. Rubinchik, The Occurrence of ^{137}Cs and ^{90}Sr and their Mobility in Peat Soils of Belorussia, International Peat Journal, **8**, p. 32-41 (1998).
5. F. Pavlotskaya, Migration of radionuclides of global fallouts in soils, Atomizdat, Moscow (1974), (in Russian).
6. Agrochemical methods of investigation of soils, Nauka, Moscow (1975), (in Russian).

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