ISSN 1648–6897
JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
http:/www.vtu.lt/english/editions

2005, Vol XIII, No 3, 97–102

STUDIES OF ^{137}Cs TRANSFER IN SOIL-FERN SYSTEM

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Received 4 Jan 2005; accepted 17 Jun 2005

Abstract. Fern accumulates radionuclides in abundance, including ^{137}Cs. Tranfer of ^{137}Cs and ^{40}K in plants which have different root systems (fern or grass), or have no roots at all (moss) was compared. Samplings were performed in regions contaminated with ^{137}Cs after Chernobyl Nuclear Power Plant (ChNPP) accident in 1994 and 1997–2000. The male fern (*Dryopteris filix-mas*) most prevailing in Lithuania was studied. Fern accumulates ^{137}Cs more effectively than grass or moss. The average ^{137}Cs activity concentration in fern is 180±60 Bq kg^{-1}, and the transfer factor is 0,074 m^2 kg^{-1}. The fern stipe accumulates ^{137}Cs most of all (200±90 Bq kg^{-1}), the transfer factor is 0,087 m^2 kg^{-1}. Accumulation of ^{137}Cs is influenced by the content of K in the soil. ^{137}Cs and ^{40}K activity concentrations in fern are higher than those in the soil what shows that fern accumulates ^{137}Cs better than ^{40}K. Fern can clean the soil because this plant accumulates radionuclides in its stipe rather than roots.

Keywords: ^{137}Cs, ^{40}K, Chernobyl NPP accident, fern, soil, transfer factor.

1. Introduction

In 1986, due to meteorological and synoptic factors after the ChNPP accident, Lithuania occurred directly in the path of polluted air masses coming from Chernobyl. According to airborne measurements from 1987, ^{137}Cs pollution density caused mainly by dry fallout ranged from 7,4×10^2 to 3,0×10^4 Bq m^{-2}. Polluted "spots" ranging from a few square meters to a few square kilometers were found. Southern, south-western and western regions of Lithuania as well as the Curonian Spit were polluted most of all. After the Chernobyl accident ^{137}Cs fallout was mainly accumulated in areas where fallout had been registered previously due to nuclear explosions, near hills, on the outskirts, near lakes, etc [1]. Because of its long half-life and chemical-biochemical similarity with K, ^{137}Cs is one of the most important radionuclides released into the environment, especially after the ChNPP accident, after the short-lived radionuclide decay [2].

^{137}Cs is mostly accumulated in the upper layer of the soil and in litter. It was found that in a 5 cm upper layer in Lithuanian soils an average amount of ^{137}Cs was 85±7 % of the total ^{137}Cs amount in the soil [3]. The transfer rate is the lowest in sandy soils and higher in loam and sandy loam [1]. A significant part of ^{137}Cs was deposited on plants, and a part of ^{137}Cs penetrated from the soil through roots into plants again. Biological availability of ^{137}Cs decreased with time [4, 5].

^{137}Cs transferred to plants participates in the food chain. The soil-to-plant transfer factor is an important parameter widely used to evaluate food chain transfer. However, for a number of long-lived radionuclides it varies by up to three orders of magnitude. This can be explained by chemical, biological, hydrological, physical peculiarities of the soil, or by variety of plant physiological processes [6]. Radionuclide transfer depends on landscape and vegetation, litter and soil as well as on the amount of a radionuclide, its chemical properties and meteorological conditions during the fallout [7].

Cs^+ and K^+ are competing ions. It is known that abundance of K in soil can block the radiocaesium uptake [8–12].

Fern is an interesting radioecological object as a part of the forest ecosystem which is sensitive to radioactive pollution [13–15]. After 10–15 years following the ChNPP accident ^{137}Cs is still localized mainly in litter and in organic soil layers, thus ^{137}Cs activity concentration in forest products is higher than that in agricultural products [6]. There are not many studies on the transfer to fern, though it is found that this plant accumulates radionuclides in abundance [16–18].

The aim of this work is to compare ^{137}Cs transfer in fern, grass and moss which have different root systems (fern or grass) or have no roots at all (moss); as well as to compare ^{137}Cs and ^{40}K accumulation in these plants.

2. Measurement and methods

Samplings were performed in regions more or less contaminated with ^{137}Cs in 1994 and 1997–2000.

The territory of Lithuania was divided into equal square plots with the side of 16 km. Soil was sampled in each of these squares, in a 0–5 cm depth soil layer, in flat open places with an undisturbed structure of the soil, in meadows or glades, not closer than 50 m from trees or shrubbery, and not closer than 100 m from roads. A metal ring with a 14 cm diameter and 5 cm height was driven into the soil, and a soil sample was cut with a shovel. Soil samples were collected together with plant samples from the same sites.

Plants were divided into three groups: fern, grass and moss. In this work male fern (*Dryopteris filix-mas*) most prevailing in Lithuania was studied (Fig 1). Activity concentration of ^{137}Cs and ^{40}K was measured in different parts of fern plants: in pinnae (leaflet), stipes, rhizome and small roots. Samples of grass without roots and moss were also collected, and ^{137}Cs and ^{40}K concentrations were measured.

The samples were transported to the laboratory in plastic bags, dried and weighed, and their density was determined. ^{137}Cs activity was determined using a semiconductor Ge(Li) spectrometer with the registration efficiency of 0,26 % at the energy of 662 keV, in standard cells (1 l volume Marinelli vessel).

The measured activity was converted into activity concentration, Bq kg^{-1}, or (for soil samples) into pollution density, Bq m^{-2}.

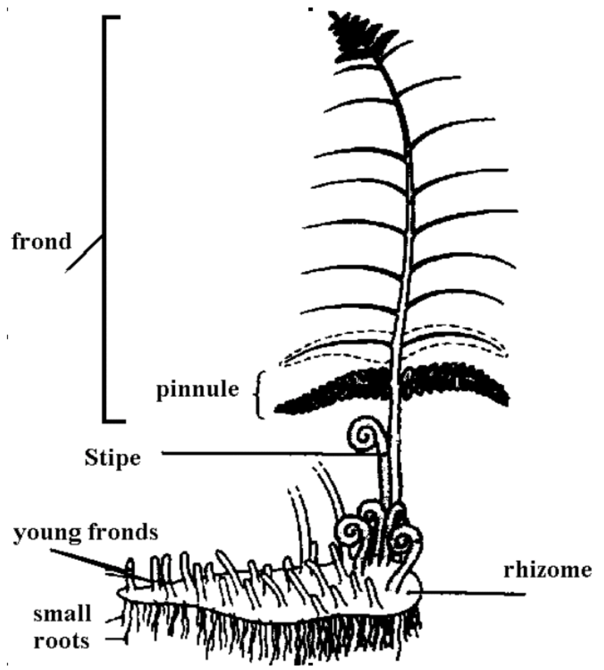

Fig 1. Scheme of fern [19]

3. Results and discussion

The ^{137}Cs uptake from the soil to plants was described using the transfer factor which is defined to be [7, 20, 21] $PK = Q_a/Q_d$, where Q_a is ^{137}Cs activity concentration in plants, Bq kg^{-1} dry weight, Q_d is ^{137}Cs pollution density in a plant-sampling site, Bq m^{-2}. This coefficient is also used for moss, if we assume that radionuclides get into the atmosphere due to resuspension.

Fig 2 shows ^{137}Cs activity concentration of fern, grass and moss. It is obvious that ^{137}Cs activity concentration of fern is significantly higher than that of grass or moss. Its value reached averagely 180±60 Bq kg^{-1}. ^{40}K uptake in fern is also significant, an average concentration is 840±400 Bq kg^{-1}, and the lowest ^{40}K activity concentration is found to be in moss (230±100 Bq kg^{-1}).

The transfer factor in fern is close to that in moss, and this parameter in grass is significantly lower (Fig 3). The transfer factor of moss is the largest, but the ratio of ^{137}Cs activity concentration in moss and in soil does not represent the direct transfer of ^{137}Cs in moss. Mosses assimilate nutrients as well as ^{137}Cs mostly from the air, and only a little part is assimilated from the soil.

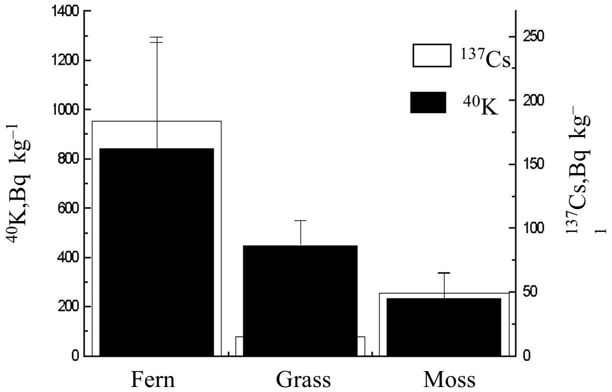

Fig 2. ^{137}Cs and ^{40}K activity concentration in fern, grass and moss

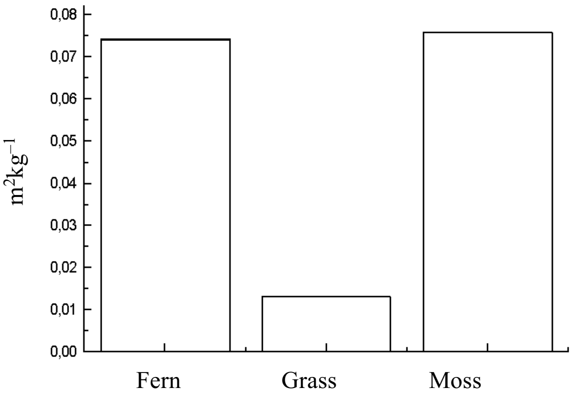

Fig 3. ^{137}Cs transfer factor of fern, grass and moss

^{137}Cs and ^{40}K activity concentration in separate parts of fern were determined. It is found that fern stipes accumulate ^{137}Cs most of all (200±90 Bq kg^{-1}), accumulation in pinnae is less (170±90 Bq kg^{-1}), and it is the least in roots (65±14 Bq kg^{-1}) (Fig 4).

Fig 5 shows that the highest ^{40}K activity concentration is in stipes (1500±800 Bq kg^{-1}), it is lower in rhizome, and the lowest in pinnae (170±90 Bq kg^{-1}).

The dependence of ^{137}Cs and ^{40}K distribution in fern on the sort of soil was studied. Soil samples were divided into three groups according to the composition of the soil: loam, sandy loam and clay (Fig 6). The highest ^{137}Cs activity concentration was found in fern growing in clay, and the lowest – in sandy loam. On the other hand, the highest ^{40}K activity concentration was determined in fern growing in loam or sandy loam, and the lowest – in clay.

^{137}Cs accumulation in plants depends on ^{40}K activity concentration in the soil [7, 9, 17]. The activity concentration of these nuclides in the soil anticorrelate (Fig 7). The ratio of ^{137}Cs and ^{40}K concentration also depends on the composition of the soil, but that is a complex dependence on a number of factors [16].

^{40}K activity concentration in the soil and ^{137}Cs activity concentration in plants anticorrelate too (Fig 8), excluding moss which assimilates ^{137}Cs from the air. Both grass and fern roots have the largest correlation coefficient.

The results of 2000 show that ^{137}Cs concentration in fern was higher than in grass or moss (Fig 9), it reached

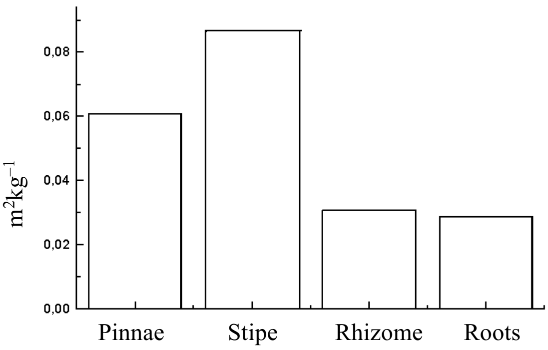

Fig 4. ^{137}Cs transfer factor in separate parts of fern

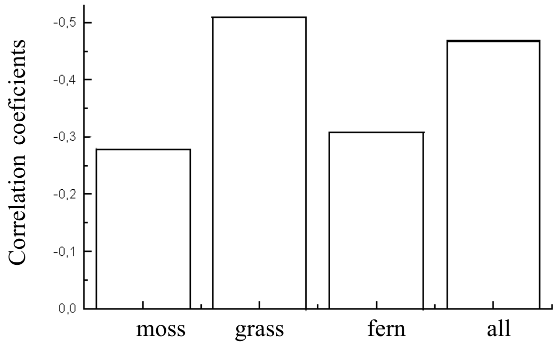

Fig 7. Correlation between ^{137}Cs and ^{40}K activity concentration in the soil under plants

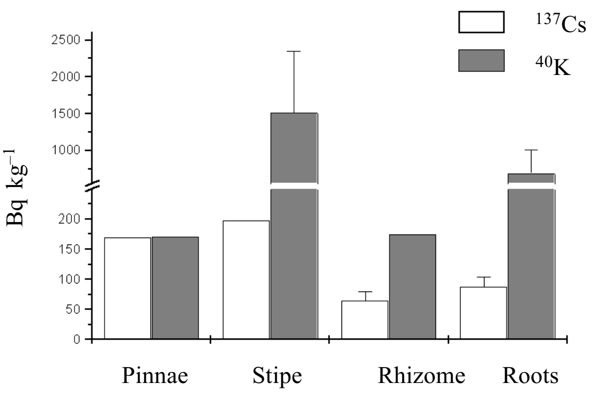

Fig 5. ^{137}Cs and ^{40}K activity concentration in separate parts of fern

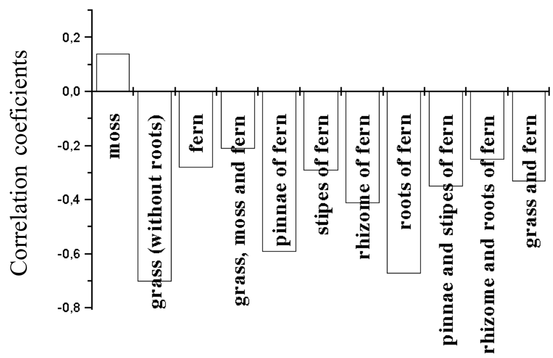

Fig 8. Correlation between ^{137}Cs activity concentration in different plants and their parts and ^{40}K activity concentration in the soil under plants

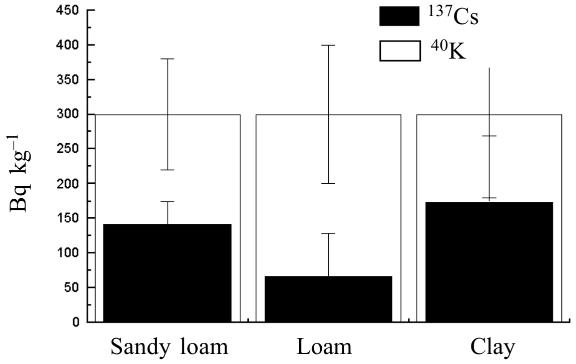

Fig 6. ^{137}Cs and ^{40}K activity concentration in fern depending on the composition of the soil

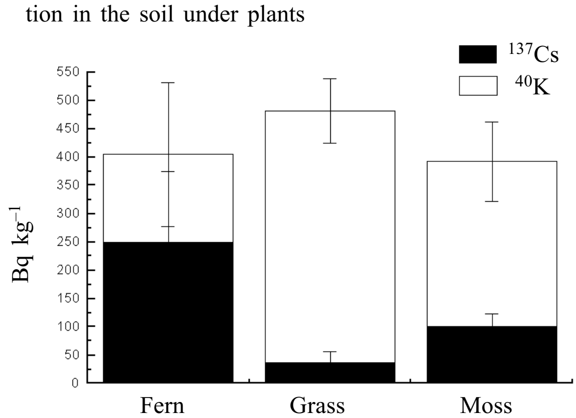

Fig 9. ^{137}Cs and ^{40}K activity concentration in fern, grass, and moss in the whole territory of Lithuania in 2000

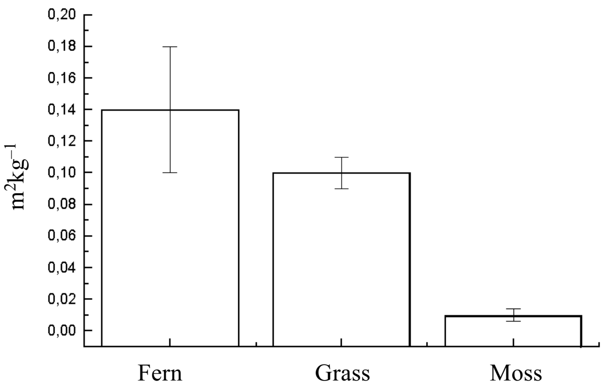

Fig 10. ^{137}Cs transfer factor in fern, grass, and moss in the whole territory of Lithuania in 2000

250±125 Bq kg^{-1}. Furthermore, fern has the highest transfer factor (Fig 10) which is equal to 0,14 m^2 kg^{-1}.

Fig 10 shows that the transfer factor changed during the time after the ChNPP accident. At present the maximum of vertical profile of ^{137}Cs activity in the soil is at a 2–3 cm depth on the average [22], so ^{137}Cs penetrates easily into grass or fern roots. Decrease of ^{137}Cs pollution density influences decrease of its activity in the air due to resuspention, so uptake in moss decreases.

It is determined that ^{137}Cs and ^{40}K activity concentration ratio in the soil is 0,14, 0,03, and 0,66 in sandy loam, loam and clay, respectively. However, this ratio in plants is different: in fern growing in sandy loam it is equal to 0,47, in fern growing in loam it is equal to 0,22, and in fern growing in clay it is equal to 0,95. These values show that fern accumulates ^{137}Cs better than ^{40}K, especially from sandy loam.

According to [21], radionuclide accumulation in plants depends on time: it decreased gradually with time due to radionuclide fixation. Some researchers consider that accumulation depends on time exponentially [23, 24]. The transfer factor depends on radionuclide properties, soil characteristics or even on meteorological conditions [21]. However, increase of the transfer factor can be explained by peculiarity of fern roots. Rhizome spreads near the soil surface (Fig 1), in the layer with a maximum ^{137}Cs activity [22]. ^{137}Cs is available for the plant roots because of its high concentration in the upper soil level and in litter, so high transfer factor values are possible [16]. The highest transfer factor values are observed in coniferous or mixed forests with thick litter or thick humus layer [13, 16].

4. Conclusions

1. Fern accumulates ^{137}Cs more effectively than grass or moss. The average ^{137}Cs activity concentration in fern is 180±60 Bq kg^{-1}, in grass is 16±13 Bq kg^{-1}, and in moss is 51±16 Bq kg^{-1}; and the average transfer factors are 0,074 m^2 kg^{-1}, 0,029 m^2 kg^{-1}, and 0,044 m^2 kg^{-1}, respectively.

2. It has been found that fern stipes accumulate ^{137}Cs most of all (200±90 Bq kg^{-1}), the transfer factor is 0,087 m^2 kg^{-1}.

3. The ^{137}Cs transfer factor in fern increased to 0,140 m^2 kg^{-1} in 2000 in comparison with that in 1994, due to its vertical migration.

4. Fern can clean the soil because this plant accumulates radionuclides in stipe rather than in roots.

5. Maximum negative correlation between ^{137}Cs activity concentration in plants and ^{40}K activity concentration in the soil was found for grass and small roots of fern.

6. It has been found that the ratio of ^{137}Cs and ^{40}K activity concentration in fern is higher than that in the soil. It shows that fern accumulates ^{137}Cs better than ^{40}K, especially from sandy loam.

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^{137}Cs KAUPIMOSI SISTEMOJE DIRVA – PAPARČIAI TYRIMAI

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S a n t r a u k a

Papartis efektyviai akumuliuoja radionuklidus, taip pat ir ^{137}Cs. Šiame darbe palyginami ^{137}Cs ir jo cheminio-biologinio analogo gamtinės kilmės ^{40}K kaupimosi augaluose, turinčiuose skirtingą šaknų sistemą (paparčiai, žolė) ir neturinčiuose šaknų sistemos (samanos) koeficientai. Bandiniai imti 1994 m. ir 1997–2000 m. po Černobylio AE avarijos ^{137}Cs užterštuose Lietuvos regionuose. Tiriamas plačiausiai Lietuvoje paplitęs kelminis papartis (*Dryopteris filix-mas*). Paparčiai kaupia ^{137}Cs efektyviau negu žolės arba samanos, vidutinis ^{137}Cs savitasis aktyvumas juose nustatytas 180±60 Bq×kg^{-1}, kaupimosi koeficientas – 0,074 m^{2}×kg^{-1}. Labiausiai ^{137}Cs susikaupia paparčio stiebe (200±90 Bq×kg^{-1}, kaupimosi koeficientas – 0,087 m^{2}×kg^{-1}). ^{137}Cs kaupimosi augaluose efektyvumui įtakos turi kalio kiekis dirvožemyje. ^{137}Cs ir ^{40}K savitųjų aktyvumų santykis paparčiuose yra didesnis negu šis santykis dirvožemyje, tai rodo, kad paparčiai geriau įsisavina ^{137}Cs nei ^{40}K. Galima teigti, kad paparčiai išvalo iš dirvožemio ^{137}Cs, nes šis cheminis elementas gausiau kaupiasi stiebe negu šaknyse.

Raktažodžiai: ^{137}Cs, ^{40}K, Černobylio AE avarija, papartis, dirvožemis, kaupimosi koeficientas.

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