Transfer Factors of Sr-90 from Corn Grown on Four Soils Typical of Bulgaria

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Abstract

Transfer factors of technogenic radionuclide strontium-90 were studied in vegetation experiment in four soils typical of Bulgaria. The four soil types were – Alluvial meadow (*Fluvisol*), Smolnitsa (*Pellic Vertisol*), Cinnamon forest soil (*Chromic Luvisol*) and Leached chernozem (*Haplic Chernozem*), respectively. The agricultural crop under study was corn.

It was found the content of strontium-90 was the highest in the leaves of the plant, less in the stems and the least in the generative organs of the crop – the grain. The data of the transfer factors obtained for the four soils typical of Bulgaria were comparable with the results cited by other authors for soils specific for temperate environments.

Higher uptake of strontium-90 was observed in corn grown on *Chromic Luvisol* and *Fluvisol* compared to *Pellic Vertisol* and *Haplic Chernozem*, most probably due to the lower content of physical clay, exchangeable calcium and magnesium and humus in the first two soil types.

Keywords: strontium-90, transfer factors, accumulation of radionuclides in plants

Introduction

The nuclear fission product strontium-90 is one of the most hazardous pollutants of the biosphere. One of the pathways the radionuclide enters the food chain is absorption from soil into plants. Therefore it is important to study to what extent different plant species accumulate Sr-90, or the so-called transfer factors of the radionuclide from soil to plant. This would allow to alter the diet of animals and humans at high levels of radioactive soil contamination.

Accumulation of radionuclides in plants depends on a number of factors as the properties of the radionuclide, soil properties as sorption and cation exchange capacity, presence of competing ions, plant properties as rhizosphere effects, etc. (Burger, Lichtscheidl, 2019; Ehlken, Kirchner, 2002). In this regard it was of interest to create a database of transfer factors for different agricultural products grown on soil types characteristic of Bulgaria.

The aim of the present study was to determine the uptake of Sr-90 in corn grown on four soils typical of the country so that, in the case of radioactive contamination of the soil, to

utilize those parts of the plant which would least contribute to the additional dose load of people and animals.

Materials and Methods

The vegetation pot experiment was conducted with soils taken from the experimental fields of ISSAPP "N. Pushkarov" - Tsalapitsa (Plovdiv region), Gorni Lozen (Sofia region), Chelopechene (Sofia region), Gorni Dabnik (Pleven region). The four soil types were – Alluvial Meadow (*Fluvisol*), Smolnitsa (*Pellic Vertisol*), Cinnamon Forest soil (*Chromic Luvisols*) and Leached Chernozem (*Haplic Chernozem*), respectively.

The experiment was carried out in pots of 3.5 kg soil in three replicates and two controls. Nutrients were added to the soil in amounts guaranteeing the normal vegetation of the plants (calcium nitrate - 31 g/kg soil, monopotassium phosphate - 0.07 g/kg, potassium nitrate - 0.14 g/kg and magnesium sulfate - 0.07g /kg).

After 10 days necessary to reach natural humidity and equilibrium in the soil the radioactive isotope in the form of a soluble salt $Sr(NO_3)_2$ in the respective activity and a certain volume of distilled water were introduced in such a way as to simulate conditions of soil contamination by irrigation water during fallout in the event of sudden change in environmental radioactivity. After another 10 days required for the penetration of the radioactive solution into the entire volume of soil, corn (*Zea mays* ssp. *mays*) was sown.

In the end of the vegetation period the plants were harvested and dried at 110°C to air dry weight.

The specific activity of strontium-90 was determined by measuring the activity of the daughter product yttrium-90 according to validated interlaboratory method (Naydenov, et al., 2010). The samples were incinerated at 550°C. Yttrium and strontium carrier were added to the ash samples and they were boiled with 65% nitric acid for 10 min and filtered. Yttrium was extracted from the filtrate three times with tributyl phosphate presaturated with 65% nitric acid. The organic phase was re-extracted with distilled water. Yttrium was precipitated as oxalate from the aqueous extract, filtered and fixed on a plate. The plate was measured for 1 hour in a low background alpha-beta gas flow counter MPC 9300 - manufactured by PIC USA. Calibration was carried out with a standard solution of strontium-90.

To estimate Sr-90 accumulation in plants, the corresponding transfer factors (Tf) – the ratio of the activity in 1 gram of air-dry plant mass to the activity in 1 gram of air-dry soil, were determined (IAEA, 2010).

Threefold repetition of the procedure of Sr-90 determination in the plants from the respective soil was carried out. Standard deviation from the mean was determined. The confidence interval is two-sigma (95%).

Results and Discussion

To study the influence of soil characteristics on the radionuclide plant uptake analyses of soil texture, agrochemical and chemical properties of the soils were carried out according to generally accepted methods, validated in ISSAPP "N. Pushkarov". The results are presented in Tables 1, 2 and 3.

Table 1. *Soil texture in % to air dry state*

№	Soil type	Hygro-scopic moisture, %	Sum >1	1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001	Sum <0.01
1	*Fluvisol*	1.08	0.0	47.0	20.4	8.1	11.3	8.9	4.3	24.5
2	*Pellic Vertisol*	4.06	0.0	18.5	16.9	9.0	10.2	11.0	34.4	55.6
3	*Chromic Luvisol*	2.43	0.0	24.6	20.2	7.1	12.5	10.4	25.2	48.1
4	*Haplic Chernozem*	3.54	0.0	5.1	27.5	12.4	16.2	10.7	28.1	55.0

Table 2. *Agrochemical characteristics of studied soils*

№	Soil type	pH	Σ N $NH_4 + NO_3$	P_2O_5	K_2O	Humus
		H_2O	mg/kg	mg/100g		%
1	*Fluvisol*	5.9	23.0	15.1	19.1	1.00
2	*Pellic Vertisol*	6.1	12.0	4.4	25.6	2.30
3	*Chromic Luvisol*	6.8	33.4	12.6	26.2	1.05
4	*HaplicChernozem*	7.8	44.9	16.1	39.0	2.24

Table 3. *Cation exchange capacity ($T_{8.2}$), strongly acidic (T_{SA}), weakly acidic (T_A) positions of the soil adsorbent, total acidity ($H_{8.2}$) and composition of the most important exchangeable adsorbed cations*

№	Soil type	$T_{8,2}$	T_{SA}	T_A	$H_{8,2}$	Al_{exch}	Ca_{exch}	Mg_{exch}	Base saturation %
		mequ/100g							
1	*Fluvisol*	13.6	-	-	0.0	0.0	11.6	2.0	100.00
2	*Pellic Vertisol*	30.9	27.2	3.6	3.0	0.0	24.8	3.1	90.29
3	*Chromic Luvisol*	21.8	18.7	3.1	2.7	0.0	16.6	2.5	87.61
4	*Haplic Chernozem*	31.3	-	-	0.0	0.0	26.8	4.5	100.00

The obtained results show the soil types under study *Pellic Vertisol* and *Haplic chernozems* are characterized by a heavy sandy clay composition - the content of physical clay is over 50%, of silt - about 30%. This predetermines the high sorption capacity – over 30 Mequ/100g. The soil absorption complex has a high saturation of basic cations - over 90%, of which the exchangeable calcium is between 25 and 27 Mequ/100g. The amount of humus in the two soil types is average – 2 ÷ 3 %.

Chromic Luvisol from the Chelopechene area has a sandy-clay soil texture too, but the degree of saturation with bases and exchangeable calcium in particular, is lower compared to that of the soil types described above. The humus content is low -1.05 %.

Fluvisol is characterized by the lowest sorption capacity, due to the slightly sandy-clay soil texture and the relatively low content of physical clay - 24.5% and silt - 4.3%. The degree of saturation with bases is very high (100%). The humus content is low -1%.

The results of the radiochemical determination of strontium-90 in the different parts of the corn samples are presented in Table 4. The values are averaged from the results of three repetitions of the radiochemical procedure for each part of the plant from the respective soil type. The calculated standard deviation is given in brackets. Fig. 1 shows the percentage distribution of Sr-90 in different parts of the plant. Grain was not obtained on *Chromic Luvisol* and *Haplic Chernozem*.

Table 4. *Activities of strontium-90 in the soil and the organs of corn – Bq/g*

№	Soil type	Sr-90 in soil	Sr-90 in leaves	Sr-90 in stems	Sr-90 in grain
1	*Fluvisol*	0.47	0.72±0.22 (30%)	0.51±0.06 (12%)	0.03 ±0.006 (21%)
2	*Pellic Vertisol*	0.51	0.36±0.09 (24%)	0.32±0.06 (18%)	0.02±0.005 (20%)
3	*Chromic Luvisol*	0.51	1.03±0.32 (31%)	0.66±0.09 (14%)	-
4	*Haplic Chernozem*	0.52	0.65±0.13 (20%)	0.50±0.04 (9%)	-

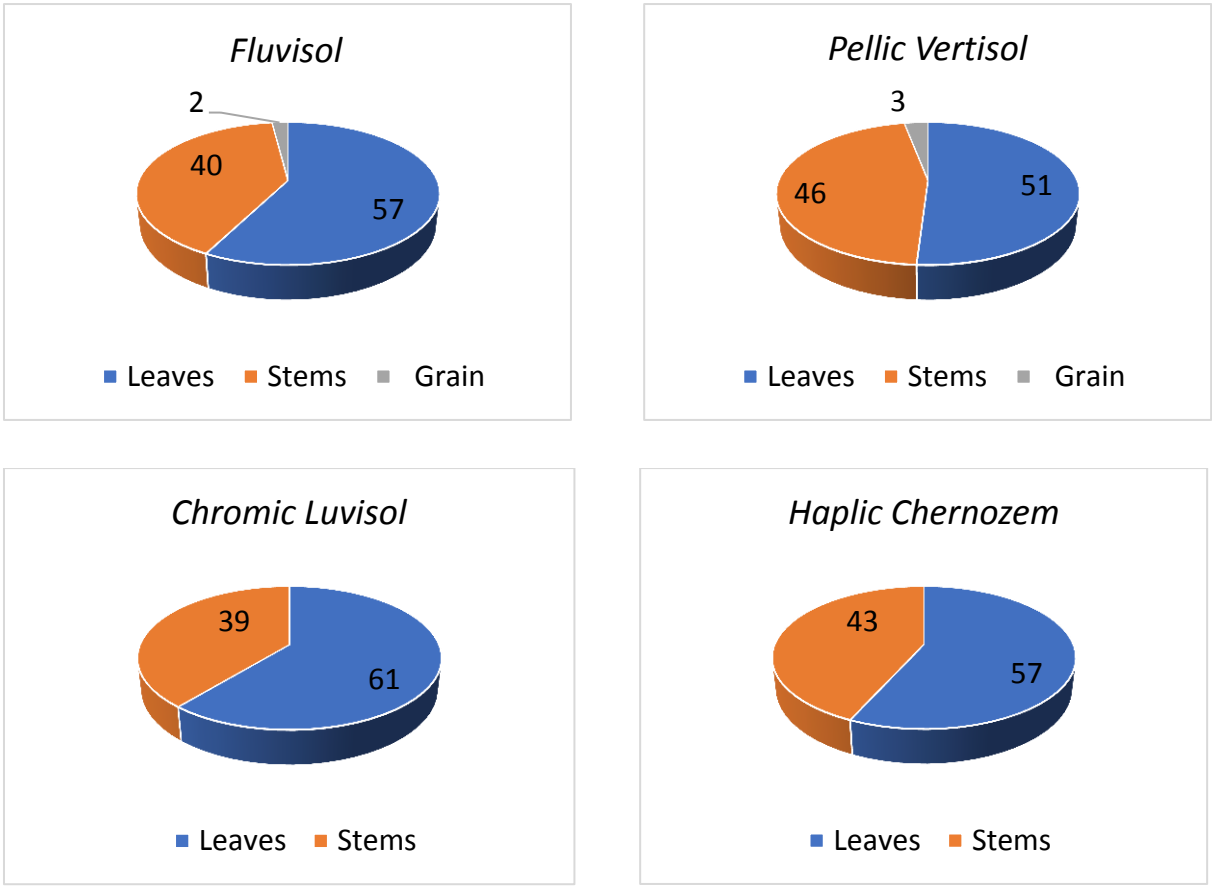


Fig. 1. *Percentage distribution of Sr-90 in different parts of the plant.*

It can be seen from the results the content of strontium-90 is the highest in the leaves of the corn, less in the stems and the least in the grain. As noted by other authors, radionuclides usually accumulate in the leaves and stems and to less extent in the generative organs of the plant (Evans, Dekker, 1962; IAEA, 2009)

The transfer factors (Tf) were determined – the ratio of the specific activity of the radionuclide in 1 gram of air-dry plant and the specific activity in 1 gram of air-dry soil, to evaluate the degree of accumulation of the radionuclide from the respective soil type in the plant. The results are presented in Fig. 2.

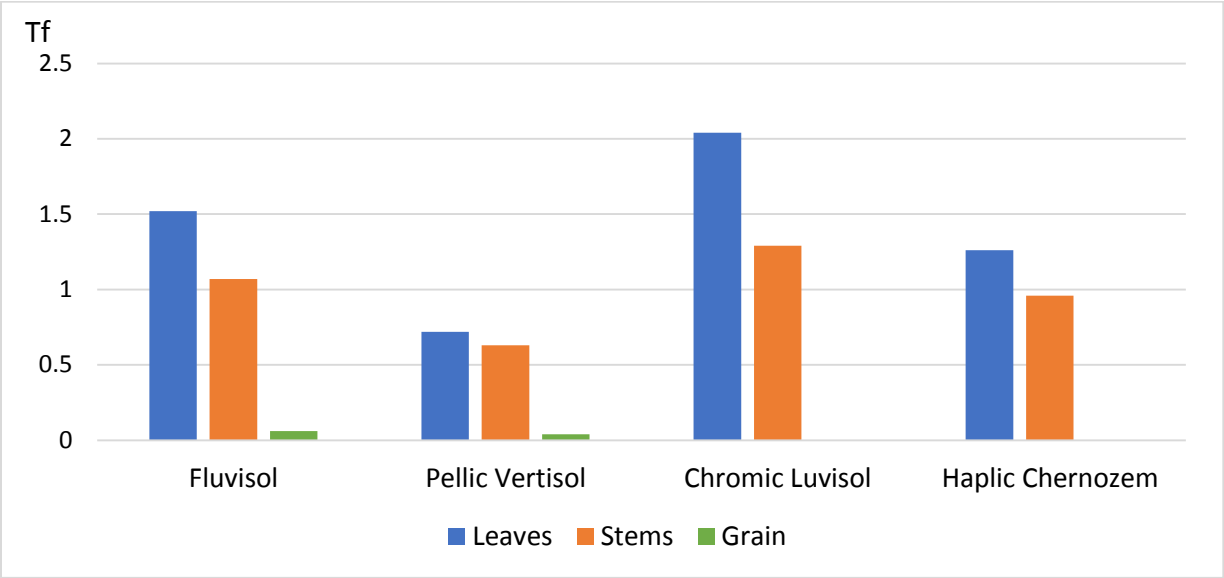


Fig. 2. *Transfer factors of Sr-90 in corn leaves, stems and grain of the soil types under study*

For comparison, transfer factors for Sr-90 in corn derived from summarized data on soil experiments carried out in temperate environments are as follows (IAEA, 2010):

- Grain: sand – 0.04÷2.6 (average 0.52); loam – 0.15÷ 0.86 (average 0.36); clay - 0.002÷0.39 (average 0.069)

- Leaves and stems: sand – 0.12÷3.0 (average 0.82); loam - 0.28÷1.4 (average 0.7); clay – 0.18÷1.1 (average 0.7)

It can be seen the obtained results for the four soils typical of Bulgaria are comparable with the data cited by other authors.

The main factors that influence the migration of radionuclides in soil and their accumulation in plants can be divided into three groups: characteristics of the soil, properties of the radionuclide and physiology of the plant itself.

Sr-90 accumulation in plants is highly influenced by soil texture. The results show the corn uptake of Sr-90 from soil types *Pellic Vertisol* and *Haplic Chernozem*, characterized by a physical clay content of more than 50%, is lower compared to the other two soil types due to the fixation of the radionuclide to the clay particles of the soil complex (Valcke, et al., 1997; Sysoeva, et al., 2005).

From physicochemical characteristics of the soils the content of exchangeable calcium and exchangeable magnesium was found to reduce Sr-90 uptake by plants. In *Pellic Vertisol* and *Haplic Chernozem*, the amount of exchangeable calcium is between 25 and 27 Mequ/100g, and the amount of exchangeable magnesium is 3.1 and 4.5 Mequ/100g compared to Ca_{exch} – 11.6 and 16.6 and Mg_{exch} – 2.0 and 2.5 in Fluvisol and Chromic Luvisol, respectively. The content Ca_{exch} and Mg_{exch} leads to reduction of radionuclide bioavailability

to plants due to the competition of ions for positions in the soil absorption complex. The higher content of exchangeable calcium and magnesium in soils may block to a great extent the accumulation of the radionuclide by the plant.

Liming of soils is one of the measures for reduction of radiostrontium plant uptake. It increases soil pH and leads to preferential absorption of calcium by plants. (Veresoglu et al., 1996; Tyler and Olson, 2001).

Higher Sr-90 transfer factors were observed in *Fluvisols* and *Chromic Luvisols*, characterized by lower content of the clay component and lower amount of exchangeable calcium and magnesium.

From the agrochemical characteristic of the soils a major factor that was found to be crucial for plant uptake of strontium-90 was the content of humus. Soluble Sr-90 is adsorbed in humus and leads to the formation of colloidal organic compounds such as humic and fulvic acids. Association with fulvic acids leads to the formation of soluble colloids that mobilize the radionuclide in low pH soils, while association with humic acids leads to the formation of stable complexes and reduced transfer of Sr-90 to plants (Burger and Lichtscheidl, 2019).

The correlation between content of humus in the four soil types under study and transfer of Sr-90 to corn plants is presented in Fig. 3. It shows the reduction of radionuclide plant uptake in soils *Pellic Vertisol* and *Haplic Chernozem* charecterised by higher humus content.

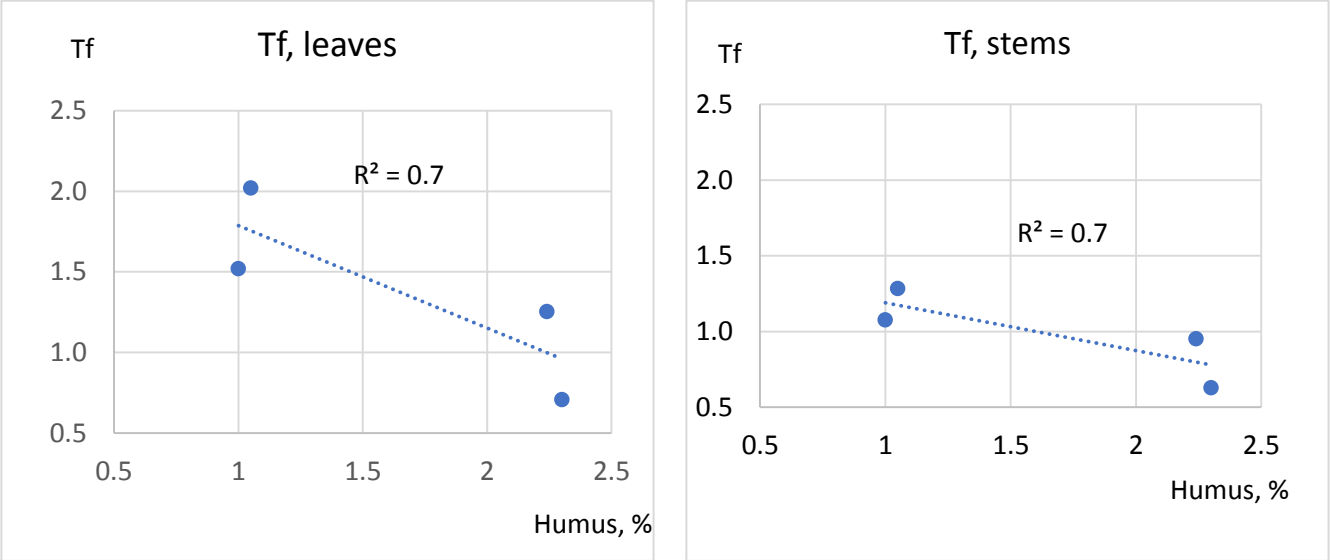


Fig. 3. *Correlation between content of humus in soils and Tf of Sr-90 in corn plants*

Conclusions

The results of the experiment carried out show the absorption of strontium-90 is the highest in the leaves of corn, less in the stems and the least in the generative organs of the plant - the grain. The transfer factors obtained are comparable to those cited by other authors for corn plants grown on soils from the temperate climate zone. Higher uptake of strontium-90 was observed in corn grown on *Chromic Luvisol* and *Fluvisol* compared to *Pellic Vertisol* and *Haplic Chernozem*. The major factors that were found to influence the higher uptake of Sr-90 by plants in the first two soils were the soil texture and the lower content of physical

clay in particular, from the physicochemical characteristics of the soils - the lower amount of exchangeable calcium and magnesium and from agrochemical characteristics the lower content of humus.

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