EFFECT OF SOIL FACTORS ON MECHANISMS OF RADIONUCLIDE TRANSFER IN A SOIL - PLANT SYSTEM

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Abstract
The radionuclides ^{137}Cs and ^{90}Sr (and other pollutants, e.g. heavy metals), are in an exchangeable part of a soil and in a soil solution. The key stage in the process of radionuclide accumulation in plants is transfer soil solution – root. The modeling approach was used, when nuclide transfer from solution into a seedling roots was studied. The results show, that ^{137}Cs and ^{90}Sr pass into the root by different mechanisms, which differently, respond to a variation of soil factors. So, with low potassium level the high-affinity weakly-selective mechanism of cation transfer is activated, which determines rate and level of monovalent ^{137}Cs accumulation, but does not pass divalent ^{90}Sr. On a normal potassium level the transfer ^{137}Cs into root is carried out by selective potassium and nonselective ionic channels; and their balance determines the level of accumulation. It is shown, that exists both theoretical limit, and the optimum “of potassium therapy” and others agroameliorative measures for each species or variety of plants. ^{90}Sr and Ca transfer into root due to the same pathways – selective and nonselective ionic channels. In ^{90}Sr accumulation the essential role plays its binding in root cell cytoplasm. In this case the “proportional distribution” takes place.

Introduction
The radionuclides cesium and strontium and other pollutants like heavy metals are in a soil as a cations of different valency. They transfer into a root together with soil mineral elements such as potassium, calcium, magnesium and so on. Their bio-available shares include exchangeable and soluble part. The ions of a exchangeable part before to get into the root, should pass in solution, so the key stage of the process of radionuclides accumulation in plant is the transfer soil solution - root, more exactly, the root cells. Just such key stage were under investigation.

The main mechanisms responsible for radionuclides soil-plant transfer are the cation-transportation ones in plasma membrane of a root cells, and they are different for cation of different valency. For monovalent cations such as ^{137}Cs they are so called high-affinity mechanism and low-affinity one, including cation channels (1, 2). The soil factors such as mineral composition, pH, water movement and temperature influence on them. ^{90}Sr enter a root cells through another mechanisms. They are selective to calcium and nonselective cation channels. These mechanisms operate under all soil conditions, and soil factors such as mineral composition, pH, water movement and temperature only modulate them.

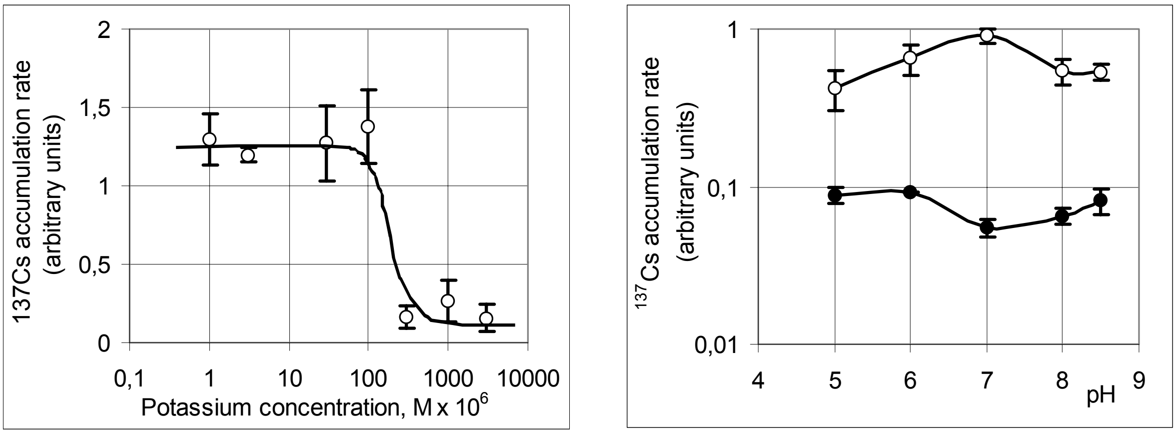
Methods
As a object seedlings of some crops have been used (2, 4). Initially seedlings was grown in a water culture for four-five days, after that they was placed in tested solution with added radionuclide (RN). In the course of experiments the curves of radionuclides accumulation and washing-out in a seedling in time have been obtained. The seedling, placed in solution, containing either ^{137}Cs or ^{90}Sr, in a defined interval of time, were periodically withdrawn from solutions for measuring their accumulated activity by appropriate counters. The value of the RN specific activity in solutions amounted to 10-20 kBq/ml for ^{90}Sr and 50-100 - for ^{137}Cs. The nuclides have been used as CsCl and $SrCl_2$, their concentration being less than 10^{-7} M. This value is higher then in the soil solution, but lower, than the independence thresholds of ion transport through the membrane (1), and the membrane effects of these cation (adsorption on fixed anions of Sr^{2+} and blocking of potassium channels by Cs^+ (3).

So, experimental procedures for Cs, were the following: the seedling, withdrawn from solution for the activity measuring, after rinsing in distillate, were successively held for 2,5 min in two solutions for the

radionuclide ^{137}Cs removal from the AP. For the estimation of its cation-exchanging capacity no soaking has been used before the first measuring, and then above procedure applied.
It is well known, that as a result of decay ^{90}Sr arise ^{90}Y; the both exist simultaneously and penetrate into a cell differently due to their different ion charges. The measurements were conducted using an Al filter to chop 0.99 of Sr radiation and 0.50 - Y, and without the filter - to obtain estimation of Sr content. The seedling activity has been determined immediately upon rinsing, the apoplast capacity has been estimated by the counting rate after the first 5 min of exposure in a labeled solution.]). As a basic solution for growth and test of seedling Knop's medium was used (1,7 KH_2PO_4, 1,8 KCl, 3,1 $Ca(NO_3)_2$, 2,1 $MgSO_4$, 0,077$FeCl_3$)$\times10^{-3}$ M, pH values were adjusted by TRIS and MES buffers.

Results
The time course of nuclides accumulation and washout was about linear for 4-6 hours, and the accumulation rate was determined as a slope of initial linear part of a curves. The soil factors such as mineral composition, pH, water movement and temperature were under investigation. The first of them was potassium concentration. Figure 1A shows the ^{137}Cs accumulation rate under varying of potassium level both growth and test solutions.

Figure 1: ^{137}Cs accumulation rates for seedlings of barley. (A): under varying of potassium level and (B): pH for low (upper) and normal (lower curve) potassium both in the growth and test solutions



We can see, that when potassium concentration decreases, the accumulation rate sharply increases. This is transition from so called low- to high-affinity mechanism of monovalent cation transfer into root cells. The pH value of growth and test medium has a opposite effect depending on potassium level; the opposite reactions of different mechanisms are seen.

The next question was, whether growth mineral conditions, in which the ion transportation mechanisms are formed, have a similar or different effects on radionuclides accumulation. The appropriate data are shown in table 1.

Table 1: Influence of mineral composition of Growth media and Test solutions on ^{137}Cs accumulation rate (arbitrary units) in barley seedling roots

Test solutions / Growth media	(0,1 K, 0,2 Ca, 0,2 Mg) $*10^{-3}$ M	(0,1 K, 4,0 Ca, 4,0 Mg) $*10^{-3}$ M	(0,1 K, 0,2 Ca, 4 Mg, 4 Ba) $*10^{-3}$ M	(4 K, 0,2 Ca, 4,0 Mg) $*10^{-3}$ M	(4,0 K 4,0 Ca 4,0 Mg) $*10^{-3}$ M
Knop's medium (3,5 K, 3,1 Ca, 2,1 Mg)$*10^{-3}$ M	0,19±0,032	0,14±0,011	0,11±0,025	0,07±0,011	0,05±0,009
Knop's medium with low K (0,1 K, 3,1 Ca, 2,1 Mg)$*10^{-3}$ M	0,39±0,044	0,35±0,042	0,53±0,070	0,18±0,021	0,12±0,016
Knop's medium with low Ca (3,5 K, 0,1 Ca, 2,1 Mg)$*10^{-3}$ M	0,26±0,034	0,43±0,057	0,36±0,048	0,25±0,037	0,18±0,0
Knop's medium with low Ca and Mg (3,5 K, 0,1 Ca, 0,1 Mg)$*10^{-3}$ M	0,60±0,052	0,28±0,043	0,32±0,050	0,12±0,018	0,07±0,010
	Low potassium High-affinity cation transportation mechanism			Normal potassium. Selective and nonselective cation channels	

We can see from table 1 that growth mineral conditions, in particular potassium level, are not so efficient, as medium, in which radionuclide accumulation occurs. Really, the rate variations are about three and nine times under similar varying the growth and test media. The lowest accumulation rate was observed for seedlings, grown and tested in full Knop's medium, when cation channels operate. The biggest one is observed for grown medium with high potassium, deficit calcium and magnesium and the same testing solution with low potassium. In this case high-affinity mechanism operates.

Table 2: Influence of temperature on accumulation rate (arbitrary units) on normal and lower potassium levels

Temperature	15 ^{0}C		5 ^{0}C	
Medium	Knop's	Knop's with low K	Knop's	Knop's with low K
Accumulation rate	0,020±0,0031	0,710±0,11	0,097±0,0023	0,093±0,0019

The variations of temperature bring about the great changes of mechanisms activity, in particular on low potassium level. About seven fold decreasing of accumulation rate was observed when the temperature was changed on ten degrees. The temperature coefficient Q_{10} increases from about 2 on high potassium level to 7 on low one.

Table 3: Influence of water influxes varying (addition of polyethylene glycol, PEG) on ^{137}Cs accumulation rate (arbitrary units) in barley seedling roots on high and low potassium levels in medium

Composition of medium	Normal		0,05 M PEG		0,1 M PEG	
	Normal K	Low K	Normal K	Low K	Normal K	Low K
Accumulation rate	0,36±0,041	2,04±0,29	0,21±0,027	1,43±0,18	0,15±0,029	0,15±0,024

Decrease of water influx by means of osmotic pressure enhances by means addition of 0,05 M polyethylene glycol (two-fold reduction of water influx) results in proportional decrease of accumulation rate for the both mechanisms. The further increasing osmotic pressure (addition of 0,1 M PEG) result in dehydration of a root tissues, and it influence especially on high-affinity mechanism.

^{90}Sr enter a root cells through another mechanisms. They are selective to calcium and nonselective cation channels. These mechanisms operate under all soil conditions, and soil factors only modulate them. Firstly the mineral composition of growth media and test solutions on ^{90}Sr accumulation rate in barley seedling roots were investigated. The data are presented in Table 4.

Table 4: Influence of mineral composition of Growth media and Test solutions on ^{90}Sr accumulation rate (arbitrary units) in barley seedling roots

Test solutions / Growth media	(0,1 K, 0,2 Ca, 0,2 Mg) *10^{-3} M	(0,1 K, 4,0 Ca, 0,2 Mg) *10^{-3} M	(4,0 K, 0,2 Ca, 0,2 Mg) *10^{-3} M	4,0 K, 0,2 Ca, 0,2 Mg, 4 Ba) *10^{-3} M
Knop's medium (3,5 K, 3,1 Ca, 2,1 Mg)*10^{-3} M	0,0055±0,0010	0,0015±0,0002	0,0019±0,00032	0,0019±0,00027
Knop's medium with low K (0,1 K, 3,1 Ca, 2,1 Mg)*10^{-3} M	0,0040±0,0009	0,0009±0,0002	0,0012±0,00028	0,0012±0,00030
Knop's medium with low Ca and Mg (3,5 K, 0,1 Ca, 0,1 Mg)*10^{-3} M	0,0052±0,0011	0,0015±0,0003	0,0022±0,00034	0,0016±0,00035

As we can see from Table 4, just as fore cesium, the growth conditions have not an essential effect on accumulation rate of ^{90}Sr. However, contrary to cesium, the accumulation mineral conditions have a little effect as well. Only lowest level of the all mineral elements enhances the accumulation rate.

Table 5: Influence of pH and mineral composition of test solutions on ^{90}Sr accumulation rate (arbitrary units) in barley seedling roots

Knop's medium (3,5 K, 3,1 Ca, 2,1 Mg) 10^{-3} M			Knop's medium with low K (0,1 K, 3,1 Ca, 2,1 Mg) *10^{-3} M			Knop's medium with low Ca and Mg (3,5 K, 0,1 Ca, 0,1 Mg) *10^{-3} M			Knop's medium with low K, Ca and Mg (0,1 K, 0,1 Ca, 0,1 Mg) *10^{-3} M		
PH 4	PH 6	PH 8	PH 4	PH 6	PH 8	PH 4	PH 6	PH 8	PH 4	PH 6	PH 8
0,0025 ±0,00017	0,0037 ±0,00040	0,0021 ±0,00025	0,0021 ±0,00029	0,0028 ±0,00050	0,0010 ±0,00015	0,0019 ±0,00	0,0014 ±0,00021	0,0016 ±0,00026	0,0045 ±0,00064	0,0035 ±0,00055	0,0030 ±0,00060

The data Table 5 show, that pH medium value has not an influence for low calcium and magnesium levels. In all medium variants the lowest accumulation rates was registered under pH eight.

Table 6: Influence of water influxes on ^{90}Sr accumulation rate (arbitrary units) in lupin seedling roots on high and low potassium levels and different pH in medium (0,02 and 0,04 M PEG provide 0,75 and 0,5 normal water influx)

Parameters of medium	Knop's medium		Knop's medium with low K (10^{-4} M)	
	PEG 0,02 M	PEG 0,04 M	PEG 0,02 M	PEG 0,04 M
pH 4,5	0,0003±0,00007	0,00190±0,00037	0,00035±0,00009	0,00085±0,00012
pH 6,5	0,0014±0,00023	0,00150±0,00040	0,00200±0,00035	0,00052±0,00011
pH 7,0	0,0017±0,00035	0,00074±0,00010	0,00100±0,00019	0,00023±0,00007

Like cesium, decrease of water influx reduces accumulation rate of ^{90}Sr, especially for neutral pH seven. Some differences were revealed for seedling of lupine, were pH dependence took place only on low potassium level. In all variants the lower pH, the larger ^{90}Sr accumulation rate, except for extremely acid medium with pH 4,5. .

Discussion

In such a way, there are two mechanisms of ^{137}Cs transfer into roots from soil solution – high- and low-affinity ones. The potassium level switch-over each-other and their activity is differently modulated by calcium, magnesium and pH. The data Table 1 show, that at all growth mineral conditions addition of divalent Ca and Mg have not any essential effect on accumulation rate of high-affinity mechanism, whereas for low-affinity one evident reducing at the same situation take place. It agrees with the fact of potassium channels blocking by calcium (3), but at the same time not great blocking effect suggests the essential share nonselective channels in the total nuclide entrance too.

The presented results show, that RN accumulation by a seedling root realise both selective and unselective pathways. Their relative shares are different for different crops. reveal a weak dependence on mineral conditions of the growth media. Conditions of mineral nutrition influence accumulation of radiocesium uptake by roots, mainly, not through a process of formation of components of the system of ionic transport in ontogenesis.

The obtained data show, that the high- and low-affinity mechanisms are of a different nature: the temperature dependence of accumulation rate is much more stronger on low potassium level, when high-affinity mechanism operates. The water fluxes and temperature have the greatest modulation effects.

The data Table 4 suggest, that divalent ^{90}Sr enter a root by means another than cesium mechanisms – they are calcium-selective and nonselective cation channels. Varying of potassium level in medium produce modulating effect, but in less extent, than for cesium: it means lack of the high-affinity mechanism contribution in ^{90}Sr transfer into root. In this case the potassium effect is determined by its influence on cation channels.

Similarly ^{137}Cs, variations of growth medium have a little effect on ^{90}Sr accumulation rate, whereas both high potassium and calcium levels in test solution decrease it. The potassium effect is due to plasma membrane depolarisation, but as for calcium we can see so called “proportional distribution”, when the relative share of radionuclide outside and inside of the cell is the same. The influence of pH value varying is not great for seedlings of barley, but is essential for representative of legume – seedlings of lupin (Table 5), in particular on low potassium level. Like cesium, decrease of water influx reduces accumulation rate of ^{90}Sr, especially for neutral pH seven.

Conclusions

The results show, that of ^{137}Cs and ^{90}Sr pass into the root by different mechanisms, which differently respond to a variation of soil factors. The obtained results suggest some practical issues. Increase of potassium content in a soil above some level for each crop species stop to give effect. The biggest cesium accumulation rate for cereals would be under insufficiency of mineral elements in a soil, at acid pH-value and surplus of water. These conditions would be the case on peat-bog soils.

Accumulation rate for ^{90}Sr reach its minimum on sufficient level of potassium, calcium and magnesium, neutral pH value and normal water supply. There are the great differences between responses the ^{90}Sr accumulation rate of different crop species – for example cereals and legumes – on variation of some soil factors.

The obtained results make possible to propose one of the direction of reducing radionuclides accumulation by the plants under normal potassium supply without disturbing their mineral nutrition: it is increasing the share of the unselective pathway by means of both using special agrochemical measures and choosing of the corresponding species of the agricultural plants. Developed approach make possible to elaborate the appropriate tests.

Acknowledgements
This work was supported by Belarussian Foundation of Fundamental Research, grant № 105 B00M.

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