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Migration and Accumulation of Artificial Radionuclides in the System Water-Soil-Plants Depending on Polymers Applying

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***Abstract*—**The possibility of radionuclides-related contamination of lands at agricultural holdings defines the necessity to apply special protective measures in plant growing. The aim of researches is to elucidate the influence of polymers applying on biological migration of man-made anthropogenic radionuclides ^{90}Sr and ^{137}Cs in the system water - soil – plant. The tests are being carried out under field conditions with and without application of polymers in root-inhabited media in more radioecological tension zone (with the radius of 7 km from the Armenian Nuclear Power Plant). The polymers on the base of K^+, Ca^{++}, K^++Ca^{++} ions were tested. Productivity of pepper depending on the presence and type of polymer material, content of artificial radionuclides in waters, soil and plant material has been determined. The character of different polymers influence on the artificial radionuclides migration and accumulation in the system water-soil-plant and accumulation in the plants has been cleared up.

***Keywords*—**accumulation of artificial radionuclides, pepper, polymer, water-soil-plant system

I. Introduction

THE possibility of radionuclides-related contamination of lands at agricultural holdings defines the necessity to apply special protective measures in plant growing. Soils possess high adsorptive capacity towards radionuclides (RN) and present themselves the initial units of RN migration into agricultural produce. Nowadays the sources of soil contamination embrace nuclear tests, radiation accidents and incidents, as well as operation of nuclear power plants (NPP) [1]-[5]. The presence of a functioning NPP and the prospects to expand nuclear engineering elevates the possibility of radionuclides-caused soil contamination in Armenia as well. Therefore, constant supervision and remediation of contaminated soils is urgent for Armenia, likewise any country throughout the world that it is a country with the limited area for agricultural crop production.

One of the important aspects of the problem of contaminated soils remediation is elaboration of protective actions aimed at reduction of biological mobility of RN in a system *water – soil – plant*. The agricultural radioecology has acquired significant experimental materials on modes decreasing the transfer of RN from soils to plants [6]-[11]. Amongst the man-made RN ^{137}Cs and ^{90}Sr exert long-term after-effects of radionuclide caused contamination: for ^{137}Cs the half-life 30.1 years, while for ^{90}Sr the half-life 28.6 years. The passage of RN, in particular ^{137}Cs and ^{90}Sr, occurs from the soil solution and irrigation water through the root system of plants. Ionic absorption has a specific role in this process of radionuclide transition from the soil into a plant.

The water-expending polymer additives for soil application are highly promising and improve the effectiveness of irrigation-based agriculture, to fight the droughts, soil salination, erosion, processes of desertification, as well as to work out new techniques for plant growing. High-water-expending polymer hydrogels (Superabsorbents) capable of retaining large amounts of water found wide-spread application.

Recently the "Plastpolymer" Institute jointly with the Institute of Hydroponics Problems conducted research on application of high-water-expending polymers for plant production under hydroponic conditions. As known, the water-expending, water-insoluble polymers may be used as a soil modifier to improve water retention. Various systems have been proposed to produce water-expending, water-insoluble polymeric materials [12]-[13].

The aim of this research is to provide new means and procedures for remediation of contaminated soils in zones of radio-ecological tension through regulation of biological migration of man-made anthropogenic RN ^{137}Cs and ^{90}Sr by water-retaining polymers.

The proposed article proposes to achieve to the control of migration of RN in the system *water – soil – plant* due to the counter ions variation in the Superabsorbents.

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II. MATERIALS AND METHODS

The tests are being carried out under field conditions with and without application of polymers in root-inhabited media (RIM) in more radioecological tension zone (with the radius of 7 km of Armenian NPP, v. Taronik). For the investigations, pepper was chosen because it has been cultivated in v. Taronik for ages.

The objectives of investigations are: determination of both quantitative and qualitative productivity of plants depending on the presence (control-without presence of polymer), type of polymer material, water regimen; determination of RN content in a system *water – soil – plant* in the vicinity of the Armenian NPP; determination of migration and accumulation of RN in soil layers in different depth (0-10; 10-20), below- and above-ground parts of plants depending on application of the polymers; revealing the dependence of redistribution of RN in systems water – soil – plant on the type of a polymer material.

The plants were planted with a density of 20plant/m^2 in the experimental field. The polymers on the base of K^+, Ca^{++}, $K^+ + Ca^{++}$ ions, synthesized in the "Plastpolymer" Institute were tested.

The experiments were carried out with the following variants:

1. Control - without polymer, irrigating frequency (IF) once 3-4 days;
2. Soil (RIM) + polymer K^+ (1g/plant), IF once 4-5 days;
3. Soil (RIM) + polymer Ca^{++} (1g/plant), IF once 4-5 days;
4. Soil (RIM) + polymer $K^+ + Ca^{++}$ (1g/plant), IF once 4-5 days.

In whole vegetation period, pepper plants were irrigated: control variant 45 and polymer variants 35 times. 5 harvest of pepper was achieved.

Content of RN was determined by radiochemical methods by means of UMF-1500 device [14].

The content of vitamin C by was determined by titration method [15]. The obtained results submitted to mathematical working out.

III. RESULTS AND DISCUSSION

The results showed (Table I) that for pepper crop it is advisable to apply Ca^{++} and $K^+ + Ca^{++}$ polymers, besides pepper crop, the amount of pepper from unit plant and the mass of a single pepper exceeds the K^+ polymer variant 1.1; 1.2-1.3; 1.2-1.3 times, accordingly. But there is no significant difference from control variant. In the above-ground mass, independently of polymer sort and use, the relation of peppers and leaves+stems was not changed: it was about 4/1 (Fig. 1).

The results of biochemical analysis had shown significant increases (1.7-1.9 times) of vitamin C content in all variants in the end of vegetation period. However, the variants do not differ (Table II).

TABLE I
INDICES OF PEPPER PRODUCTIVITY (FRESH)

Variants	Peppers, g/plant	Amount of peppers, piece/plant	One pepper, g	Leaves+ stems, g/plant	Roots, g/plant
Control-without polymer	273^{a}	19	14.4	71.0	10.4
Soil (RIM) + polymer K^+	217^{ab}	18	12.1	54.4	7.0
Soil (RIM) + polymer Ca^{++}	347^{acd}	22	15.8	89.4	11.9
Soil (RIM) + polymer K^++Ca^{++}	355^{acd}	24	14.8	96.5	11.9

^{abcd}Tukey's Multiple Comparison Test (P<0.05)

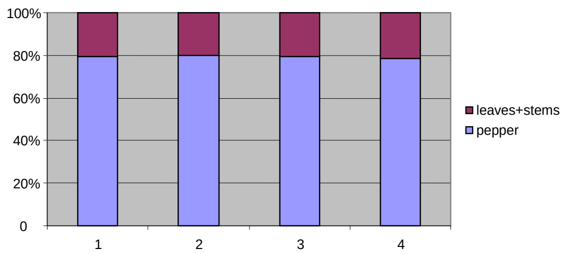

Fig. 1 Ratio of fruits and leaves+stems in the above-ground biomass of pepper

TABLE II
CONTENT OF VITAMIN C IN PEPPERS DEPEND ON THE USE OF POLYMER

Variants	mg% (in July)	mg% (in September)
Control-without polymer	92±2.5	158 ± 4.55
Soil (RIM) + polymer K^+	91±5.0	172 ± 6.01
Soil (RIM) + polymer Ca^{++}	96±6.0	170 ± 4.02
Soil (RIM) + polymer K^++ Ca^{++}	92±5.3	156 ± 4.71

The data of Table III showed that during the vegetation period ^{90}Sr and ^{137}Cs water migration took place with soil vertical slit (from upper 0-10 cm to down 10-20 cm soil layers). So in case of pepper ^{90}Sr and ^{137}Cs content in upper 0-10 cm soil layer in control variant exceeded down 10-20 cm soil layer 1.6 times, and in polymer variants - 1.3-1.5 and 1.1, accordingly.

On the basis of obtained results we can suppose that in case of pepper during the vegetation period ^{90}Sr and ^{137}Cs water migration with soil vertical slit (from upper 0-10 cm to down 10-20 cm soil layer) is more intensive in polymer variants then in control.

TABLE III
CONTENT OF ARTIFICIAL RN IN THE GREY CARBONATE IRRIGABLE SOILS IN THE VICINITY OF THE ARMENIAN NPP AFTER PEPPER CROP HARVEST

Variants	Depth of soil layer, cm	Content of RN, Bq/kg ^{90}Sr	^{137}Cs
Control-without polymer	0-10	11.0±0.29	11.0±0.39
	10-20	6.8±0.06	6.7±0.54
Soil (RIM) + polymer K^+	0-10	13.2±0.31	10.5±0.32
	10-20	8.5±0.14	9.3±0.03
Soil (RIM) + polymer Ca^{++}	0-10	12.6±0.31	12.7±0.04
	10-20	9.7±0.34	10.6±0.29
Soil (RIM) + polymer K^++ Ca^{++}	0-10	12.3±0.14	15.5±0.33
	10-20	9.0±0.49	14.5±0.18

The data of artificial RN content in different organs of pepper at the end of vegetation period were introduced in Tables IV.

It is obvious from Table IV data that the evidence of polymers in soil only had an influence on ^{90}Sr distribution in different organs of pepper. In all variants, pepper organs according to ^{137}Cs content have the following trend: leaves+stems>fruits>roots. According to ^{90}Sr content: in polymer variants - leaves+stems>fruits>roots and in control variant - leaves+stems>roots>fruits.

In pepper fruit the content of ^{90}Sr in control variant exceeded Ca^{++} polymer variant 1.2 times and conceded the same indices of K^+ and $K^+ + Ca^{++}$ polymer variants 1.8 times. In pepper fruit the content of ^{137}Cs conceded K^+ and $K^+ + Ca^{++}$ polymer variants 1.3 and 1.6 times, accordingly.

TABLE IV
CONTENT OF ARTIFICIAL RN IN DIFFERENT ORGANS OF PEPPER, BQ/KG

Organs	Variants	^{90}Sr	^{137}Cs
Fruits	Control-without polymer	3.0±0.07	7.2±0.27
	Soil (RIM) + polymer K^+	4.6±0.23	10.6±0.13
	Soil (RIM) + polymer Ca^{++}	2.4±0.03	8.1±0.23
	Soil (RIM) + polymer K^++Ca^{++}	4.4±0.11	13.3±0.24
Leaves+stems	Control-without polymer	9.3±0.64	13.8±0.19
	Soil (RIM) + polymer K^+	9.5±0.53	16.9±0.2
	Soil (RIM) + polymer Ca^{++}	8.4±0.21	18.3±0.09
	Soil (RIM) + polymer K^++Ca^{++}	10.6±073	19.3±0.19
Roots	Control-without polymer	7.1±0.11	4.9±0.11
	Soil (RIM) + polymer K^+	1.2±0.11	9.3±0.43
	Soil (RIM) + polymer Ca^{++}	1.9±0.04	10.1±0.18
	Soil (RIM) + polymer K^++Ca^{++}	3.0±0.15	11.4±0.11

In all organs of pepper the content of ^{137}Cs exceeded ^{90}Sr in comparison of control roots were we can record the opposite picture: ^{90}Sr exceeded ^{137}Cs 1.4 times. Besides in pepper fruits the content of ^{137}Cs exceeded ^{90}Sr 2.4 times in control variant and in polymer variant 2.3 -3.2 times, in leaves+stems: 1.5 and 1.8-2.3 times, accordingly, in roots of polymer variants 3.8-7.7 times.

Data showed that in pepper roots in control variant the content of ^{90}Sr exceeded ^{137}Cs and in soil in case of evidence of polymer on the contrary, the content ^{137}Cs exceeded ^{90}Sr. Besides the highest exceeding of ^{137}Cs to ^{90}Sr is observed in K^+ polymer variant which is the evidence of K^+ polymer preventing ^{90}Sr absorption by roots.

^{90}Sr and ^{137}Cs Transfer Coefficient (TC, Bq/kg : Bq/m^2) from water into different organs of pepper were introduced in Table V.

TABLE V
TRANSFER COEFFICIENTS OF ARTIFICIAL RN FROM WATER INTO DIFFERENT ORGANS OF PEPPER, TC ^{90}SR / TC ^{137}CS

Variants	Fruits	Leaves+stems	Roots
Control-without polymer	0.02	0.06	0.04
	0.3	0.6	0.2
Soil (RIM) + polymer K^+	0.04	0.08	0.01
	0.6	1.0	0.5
Soil (RIM) + polymer Ca^{++}	0.02	0.07	0.01
	0.5	1.0	0.6
Soil (RIM) + polymer K^++Ca^{++}	0.03	0.09	0.02
	0.8	1.1	0.6

The average data of RN content in pepper and irrigable water as well as irrigable norms accepted for pepper in soil-climate condition of Ararat valley were used for TC calculation. It found out that the migration of ^{137}Cs from irrigable water into different organs of pepper exceeded ^{90}Sr, in addition in polymer variants to a considerable extent. It also found out that the migration of ^{137}Cs from irrigable water into pepper plants in polymer variant exceeded control: in roots – 2.5-3.1, in leaves+stems – 1.6-1.8 and in fruits – 1.4-2.3 times.

The migration of ^{90}Sr from irrigable water into pepper fruits and leaves+stems in polymer variants exceeded control 1.5-2.0 and 1.2-1.5 times accordingly, but in roots on the contrary, the TC of ^{90}Sr is smaller 2.0-4.0 times than in control.

TABLE VI
ACCUMULATION COEFFICIENTS OF RN IN DIFFERENT ORGANS OF PEPPER, AC ^{90}SR / AC ^{137}CS

Variants	Fruits	Leaves+stems	Roots
Control-without polymer	0.3	1.0	0.8
	0.8	1.6	0.5
Soil (RIM) + polymer K^+	0.4	0.9	0.1
	1.1	1.7	0.9
Soil (RIM) + polymer Ca^{++}	0.2	0.7	0.2
	0.7	1.6	0.9
Soil (RIM) + polymer K^+ + Ca^{++}	0.4	1.0	0.3
	0.9	1.8	0.8

It is known that the migration of RN from soil into plants depends on a number of factors: from the quantity of atmospheric precipitations, from biological peculiarities of culture, from agrochemical peculiarities of soil (humus, hydrolytic acidity, K and Ca content in soil).

^{90}Sr and ^{137}Cs Accumulation Coefficient (AC, RN content in plant, Bq/kg : RN content in soil Bq/kg) in different organs of pepper are introduced in Table VI. It must be mentioned that AC also includes the quantity of RN absorbed from air by plant and soil. It found out that AC of ^{137}Cs exceeds AC of ^{90}Sr: in fruits – 2.2-3.5, in leaves+stems – 1.6-2.2 and in roots – 2.7-9.0 times. With the exception of pepper roots in control variant in which AC of ^{90}Sr > AC of ^{137}Cs, that is to say, on the contrary, from soil the absorption of ^{90}Sr by roots was more intensive than ^{137}Cs.

The data of Table VI show that in all variants the AC of ^{90}Sr and ^{137}Cs in leaves+stems exceeds the fruit and root.

The Observed Ratio (OR, ^{137}Cs / ^{90}Sr in plant : ^{137}Cs / ^{90}Sr in soil) is a changeable value and depends on plant species and biological peculiarities. In all variants in soil-plant system OR>1 except soil-root chain link of control variant (Table VII). This confirms that from soil ^{137}Cs absorption by plant was more intensive than ^{90}Sr, in addition to a considerable extent in roots, then in fruits and leaves+stems. In biological leaves+stems-fruits chain link the migration of ^{137}Cs also exceeded ^{90}Sr, as OR>1. In polymer variants, the migration of ^{90}Sr in root-leaves+stems chain link exceeded ^{137}Cs on the contrary, in control variant.

TABLE VII
OBSERVED RATIOS OF ^{137}Cs - ^{90}Sr PAIR IN DIFFERENT ORGANS OF PEPPER

Variants	In soil-plant chain			In biological chain	
	fruits / soil	leaves+stems / soil	roots / soil	fruits / leaves+stems	leaves+stems / roots
1.	2.4	1.5	0.7	1.6	2.1
2.	2.5	2.0	8.5	1.3	0.2
3.	3.4	2.2	5.3	1.5	0.4
4.	2.1	1.3	2.7	1.7	0.5

For pepper between ^{90}Sr AC and OR of ^{137}Cs - ^{90}Sr pair there is inversely proportional coupling: $r = -0.71 \pm 0.22$ but for ^{137}Cs that coupling is directly proportional: $r = 0.58 \pm 0.25$.

The data of Table VIII showed that though in K^+ and K^+ + Ca^{++} polymer variants ^{90}Sr content in pepper fruit is almost the same, however thanks to high yield in K^+ + Ca^{++} polymer variant the output of ^{90}Sr is 1.5 times more in comparison of K^+ polymer variant. In control, K^+ polymer and Ca^{++} polymer variants the output of ^{90}Sr with the pepper fruit is the same and conceded K^+ + Ca^{++} polymer variants.

TABLE VIII
THE OUTPUT OF RN WITH THE DIFFERENT ORGANS AND WHOLE PLANTS OF PEPPER, BQ/KG $\frac{^{90}Sr}{^{137}Cs}$

Variants	Fruits	Leaves+ stems	Roots	Whole plant
Control - without polymer	0.08 0.18	0.15 0.23	0.02 0.01	0,25 0.42
Soil (RIM) + polymer K^+	0.09 0.21	0.12 0.21	0.003 0.02	0.21 0.44
Soil (RIM) + polymer Ca^{++}	0.08 0.26	0.17 0.37	0.006 0.03	0.25 0.66
Soil (RIM) + polymer K^++Ca^{++}	0.14 0.44	0.24 0.44	0.013 0.05	0.39 0.93

The output of ^{137}Cs with the pepper fruit in K^+ + Ca^{++} polymer variant exceeded the same indices of control and K^+ polymer variants 2.4 and 2.1 times, accordingly thanks to high yield and high content of ^{137}Cs in pepper fruit in K^+ + Ca^{++} polymer variant.

The output of ^{137}Cs with the whole plant in control variant exceeded ^{90}Sr 1.7, in polymer variants – 2.1-2.6 times.

IV. CONCLUSION

- The evidence of water retaining polymers in soil RIM gives an opportunity to decrease the expense of irrigating water in about 30% by reason of which decreased the quantity of ^{137}Cs and ^{90}Sr contained in water and entering the soil with water.
- In soil RIM the evidence of Ca^{++} polymer promoted the decrease of ^{90}Sr content in pepper fruit 1.2 times in comparison with control variant.
- Applying of Ca^{++} polymer in soil RIM promoted the decrease of ^{137}Cs in pepper fruit in comparison with K^+ polymer variant 1.3; in K^++Ca^{++} polymer variant - 1.6 times.
- During the vegetation period ^{90}Sr and ^{137}Cs migration with soil vertical slit (from upper 0-10 cm to down 10-20 cm soil layer) is more intensive in polymer variants then in control.
- ^{90}Sr and ^{137}Cs migration from water into different organs of pepper is more intensive in case of polymers applying.
- The content of ^{137}Cs in pepper different organs exceeded ^{90}Sr with the exception of control variant roots where we can record the opposite picture.
- ^{137}Cs migration from soil into different organs of pepper exceeded ^{90}Sr in all variants, with the exception of control variant roots.

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