which in 2011 decreased from 7 points to 1 point in the variant with the highest dose of nitrogen fertilizers (150 kg/ha per year), which caused a decrease in the weight of one ear of grain to 1. 48 vs. 1.75 g in the version without fertilizers, weight of 1000 grains up to 37 g vs. 45 g. The highest grain yield of winter wheat was obtained in the variant with a one-time application of nitrogen fertilizers in the spring at a dose of 50 kg/ha d.r. against 6.80 t/ha in the $N_{150}P_{100}K_{100}$ *variant. The yield of grain in foci of root rot development ranges from 2.51 to 2.58 t/ha. The development of root rots also reduces grain quality indicators. For example, the protein content decreases to 8.1–8.5 % against 12.5–14.3 % against the background of less development of the disease, and the gluten content accordingly decreases to 15–15.6% against 25.2–34.4 %.*

Conclusions*. In the conditions of the Right Bank Forest-Steppe of Ukraine, on podzolized chernozem, in order to obtain a sustainable winter wheat crop, nitrogen fertilizers must be applied in a dose of N50 in top dressing on a background of P50K50: it ensures the least loss of grain from root rot.*

Key words*: soft winter wheat, root rot, grain quality, yield, plant growth indicators.*

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THE CONTENT OF RADIOACTIVE ELEMENTS IN THE SOIL AND SOFT WINTER WHEAT GRAIN UNDER A LONG-TERM USE OF FERTILIZERS IN THE FIELD CROP ROTATION

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У статті наведено результати формування вмісту радіоактивних елементів у різних шарах ґрунтового профілю, в зерні пшениці м’якої озимої за тривалого внесення мінеральних добрив після різних рослинних попередників (конюшина, горох, кукурудза на силос). Встановлено, що при тривалому насиченні сівозміни $N_{90}P_{90}K_{90}$ *та* $N_{135}P_{135}K_{135}$ *підвищується активність досліджуваних радіоактивних елементів у ґрунті та зерні пшениці м’якої озимої незалежно від попередника. У шарах ґрунту на глибині 20–40 і 40–60 см цей показник був значно нижчим порівняно з шаром 0–20 см.*

Ключові слова*: пшениця м’яка озима, радіоактивні елементи, радіоактивна активність, попередник, добрива.*

Introduction and analysis of recent research. The application of fertilizers has rather active influence on the soil. The presence of various toxic impurities, unsatisfactory quality, as well as possible violations of the application technology can lead to significant negative consequences. Failure to adhere to scientifically grounded application measures of fertilizers, imperfect methods of their introduction may have a negative impact on individual components of the biosphere, on the state of the environment and on a man [1, 2]. The level of radionuclide accumulation is inversely proportional to the soil fertility level: the higher the fertility is, the lower is the soil resistance to radionuclide contamination [3].

In the literature there is practically no data on the radioactivity levels of potassium fertilisers. It is known that 1g of potassium accounts for 29.6 Bq of ^{40}K. Radioactive potassium (^{40}K) has a half-life of 1.2×10^{9} years. It is characterized by a beta-negative decay type with the energy of 1.32 MeV (88.4 %) and partial gamma radiation (K-capture) with the energy of 1.46 MeV (11.6 %) [4]. The content of ^{40}K in the soil can vary within a wide range (100–750 Bq/kg). Potassium isotopes are usually found in soil in a strongly bound form and have a low rate of transition to plants. In nature potassium exists in the form of three isotopes ^{39}K (93.1 %), ^{41}K (6.9 %) and radioactive ^{40}K (0.012 %). Radiation of ^{40}K makes up only 12 % in the general background of natural sources of radiation [5].

The most dangerous radionuclides are ^{137}Cs and ^{90}Sr due to their active inclusion in the circulation of a trophic chain. The migration of these radionuclides in the soil-plant system leads to their accumulation in plant products. To reduce the transition of ^{137}Cs into plant products, it is necessary to apply mineral (especially potassium) and organic fertilizers and to carry out the liming of soils [6, 7]. The analysis of the specific activity of ^{137}Cs and ^{90}Sr in the vegetative mass of buckwheat has shown that the level of their concentration is influenced by the soil acidity and fertilizer system. Thus, there is a decrease of the specific activity of ^{137}Cs in winter wheat grain by 18-30% in variants with organic-mineral fertilizer system. This is mainly due to its binding with organic substance [8].

The aim of the research was to investigate the degree of nuclide pollution of a podzolized chernozem under a long-term land use in order to determine the transformation of radionuclides in winter wheat grain.

Material and methods. The research was carried out on the experimental field of Uman National University of Horticulture in the stationary experiment of the Department of Agrochemistry and Soil Science. The experiment was launched in 1964, and it is based on a 10-field crop rotation extended in time and space (spring barley + meadow clover, meadow clover, winter wheat, sugar beet, corn, peas, winter wheat, silage corn, winter wheat, sugar beet). The object of the research was a podzolized clay-loam black soil of the experimental field. Mineral fertilizer system was used ($N_{45} P_{45} K_{45}$; $N_{90} P_{90} K_{90}$; $N_{135} P_{135} K_{135}$). Fertilizer rates were applied in the form of ammonium nitrate, granulated superphosphate, mixed potassium salt and potassium chloride. The total area of the plot was 180 m², the experimental plot covered 100 m², the experiment was repeated three times on the same location. Winter wheat variety Favoritka was cultivated. Wheat grain samples were taken at the stage of full maturity.

Before the experiment the soil was under a long-term cultivation under field crops. Soils samples taken before the experiment (1964) had the following parameters: content of physical clay – 66.5 %, base saturation – 95 %, humus content – 3.31 %; content of easily hydrolysable organic nitrogen (according to the Tiurin – Kononova method); mobile compounds of phosphorus and potassium (according to Chirikov method) – 122 and 135 mg/kg respectively; pH_{KCl} – 6.2. Soil was characterized by such indicators at the time of setting up the experiment.

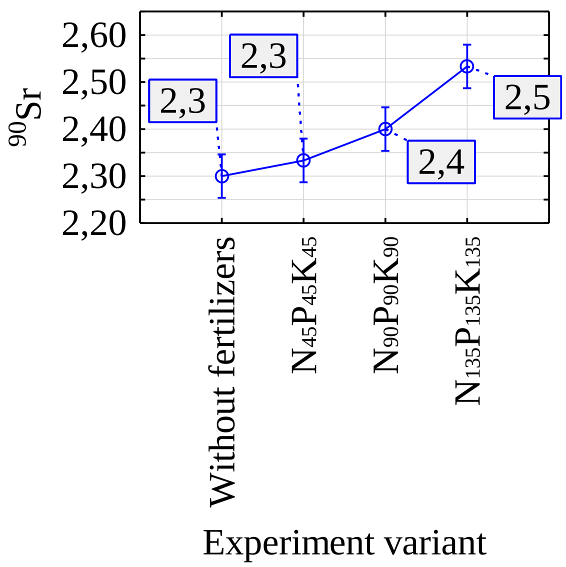
The soil samples were taken by earth boring machine from the layers at the depth of 0–20, 20–40 and 40–60 cm during 2015–2017. The experiment had three repetitions. The method of spectrometric analysis was used to study specific activity of radionuclides (spectrometer – SEG-001, SEB-01-150). Statistical data processing was carried out by using the software Microsoft Excel 2010 and STATISTICA 10.

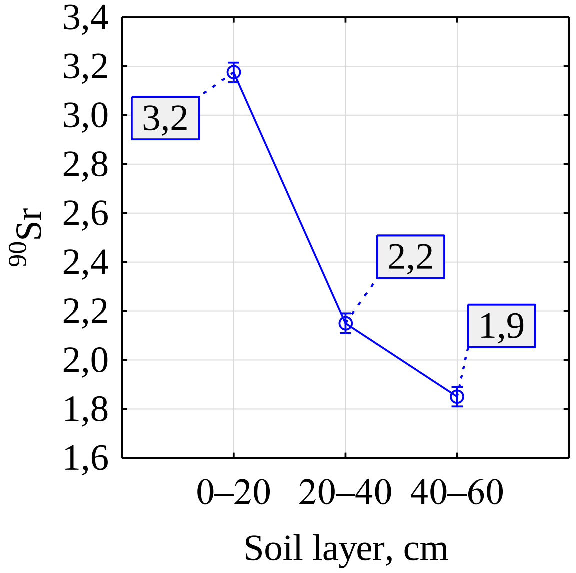
Results. The results of statistical processing indicate the reliability of the obtained findings, since $p \leq 0.05$ (Table 1). The influence of a long-term application of fertilizers in the field crop rotation and the depth of the soil layer influenced the activity of radionuclides.

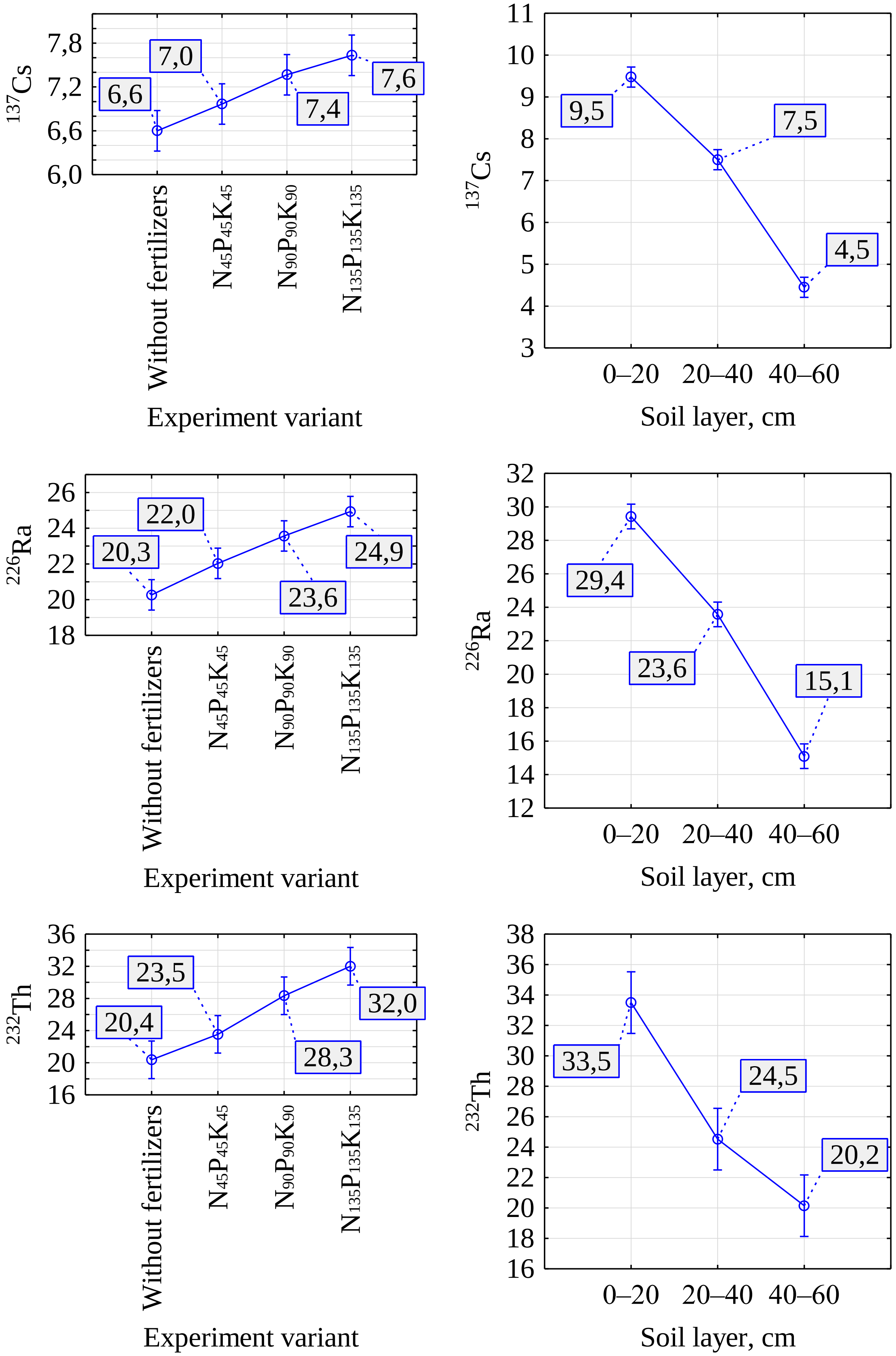
Table 1. Results of statistical processing of soil radioactive activity depending on the fertilization system

Effect	Multivariate Tests of Significance Sigma-restricted parameterization Effective hypothesis decomposition					
	Test	Value	F	Effect	Error	p
Intercept	Wilks	0,000649	11706,58	5	38,0000	0,000000
Experiment variant	Wilks	0,179181	6,07	15	105,3027	0,000000
Soil layer, cm	Wilks	0,000664	287,24	10	76,0000	0,000000

It has been established that a long-term saturation of the crop rotation area with $N_{90}P_{90}K_{90}$ and $N_{135}P_{135}K_{135}$ reliably increases the activity of the studied radioactive elements in the soil under soft winter wheat regardless of the predecessor (Fig. 1).






137Cs
7,8
7,2
6,6
6,0
6,6
7,0
7,4
7,6
Without fertilizers
N45P45K45
N90P90K90
N135P135K135
Experiment variant
137Cs
11
10
9
8
7
6
5
4
3
9,5
7,5
4,5
0–20
20–40
40–60
Soil layer, cm
226Ra
26
24
22
20
18
20,3
22,0
23,6
24,9
Without fertilizers
N45P45K45
N90P90K90
N135P135K135
Experiment variant
226Ra
32
30
28
26
24
22
20
18
16
14
12
29,4
23,6
15,1
0–20
20–40
40–60
Soil layer, cm
232Th
36
32
28
24
20
16
20,4
23,5
28,3
32,0
Without fertilizers
N45P45K45
N90P90K90
N135P135K135
Experiment variant
232Th
38
36
34
32
30
28
26
24
22
20
18
16
33,5
24,5
20,2
0–20
20–40
40–60
Soil layer, cm

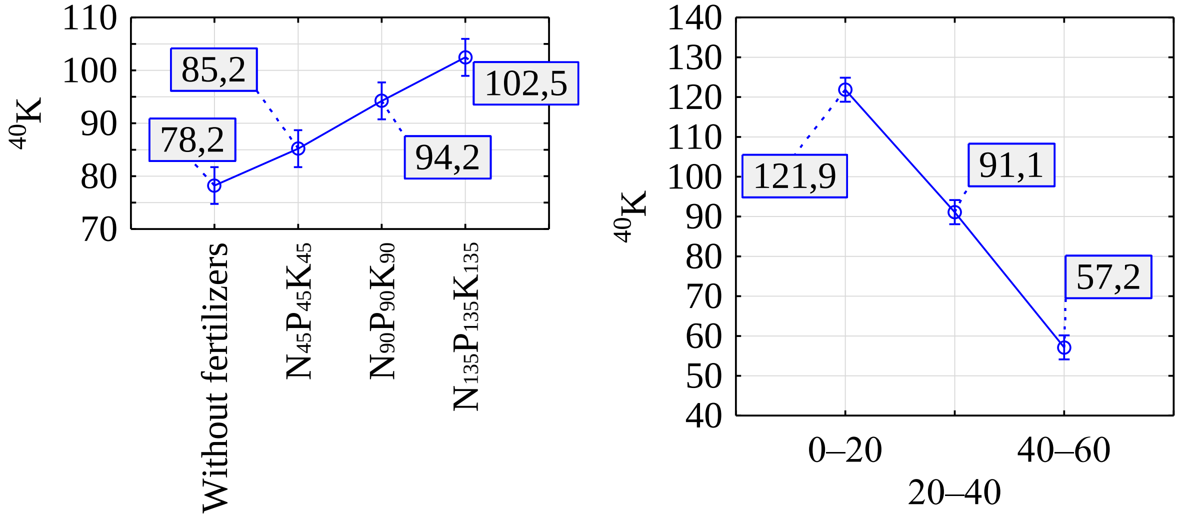


Fig. 1 Activity of radionuclides in the soil depending on the saturation of the field crop rotation with mineral fertilizers

In the soil layers at the depth of 20–40 and 40–60 cm, this indicator was significantly lower compared to the 0–20 cm layer, regardless of the radioactive element. The activity of radioactive elements increased under a long-term use of $N_{45}P_{45}K_{45}$, but it is not valid. The activity of ^{40}K was the highest – 57.2–121.9, and the activity of ^{90}Sr was the lowest – 1.9–3.2 Bq/kg depending on the variant of the experiment. The activity of the rest of the studied radioactive elements varied from 4.5 to 33.5 Bq/kg of the soil, but the radiation was safe for the human health.

As a result of determining the partial coefficient, it has been established that the activity of radioactive elements was most influenced by the depth of the soil profile – 0.97. The application of mineral fertilizers had a smaller effect – 0.46 (Fig. 2).

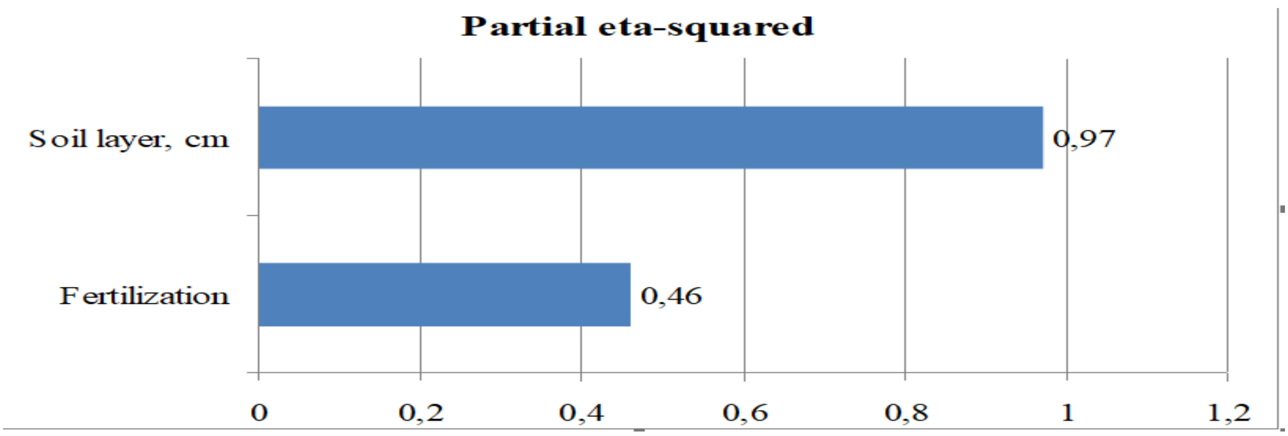


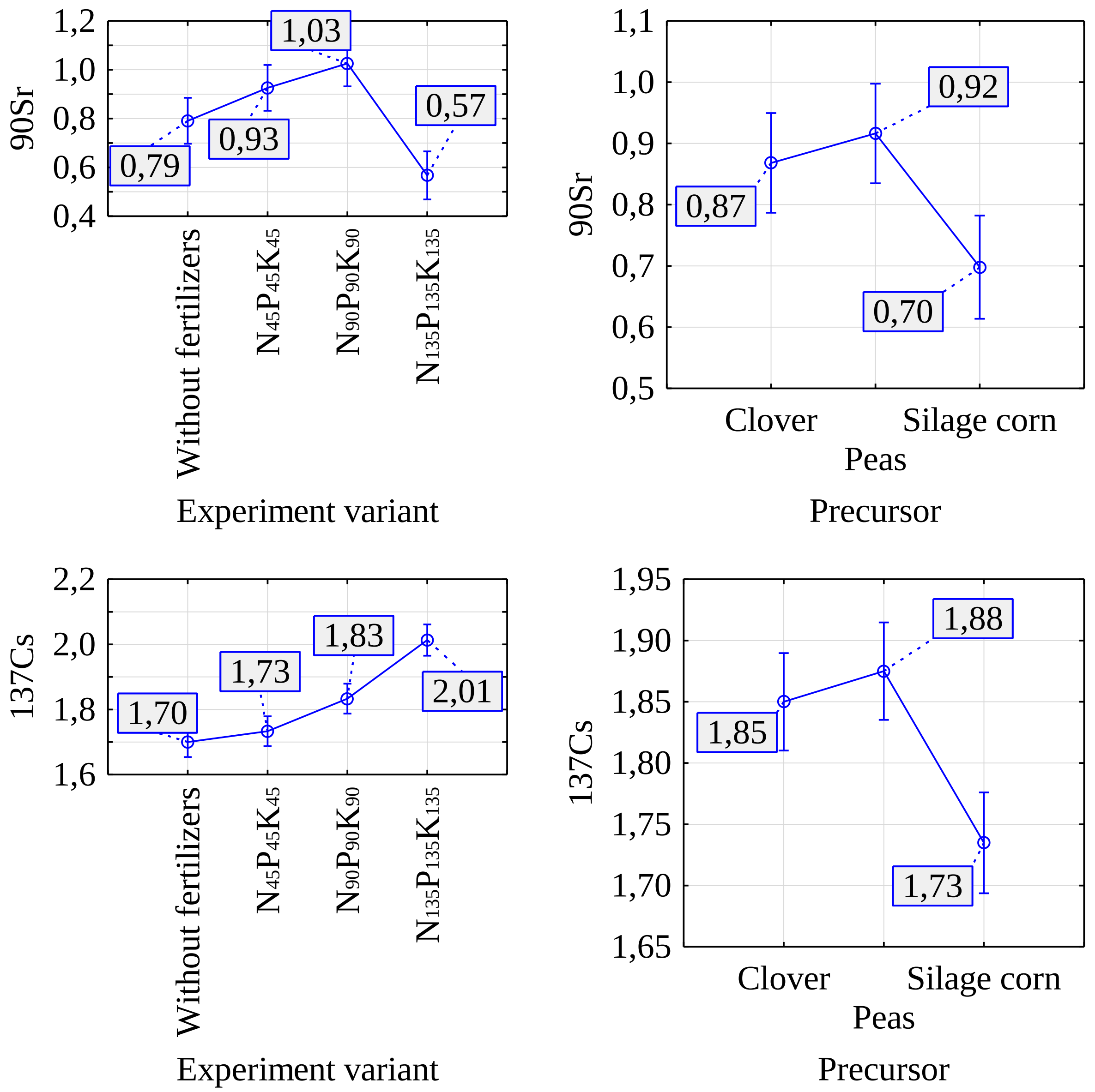
Fig. 2 Partial coefficient of the influence of the soil layer and fertilizer on the activity of radioactive elements

The results of statistical analysis show that a long-term use of mineral fertilizers and the predecessor had a significant effect on the activity of radioactive elements in soft winter wheat grains (Table 2).

Table 2. Results of statistical processing of radioactive activity of soft winter wheat grain depending on the fertilization system and the predecessor

Effect	Multivariate Tests of Significance Sigma-restricted parameterization Effective hypothesis decomposition					
	Test	Value	F	Effect	Error	p
Intercept	Wilks	0,000048	152640,5	5	37,0000	0,00
Experiment variant	Wilks	0,045933	14,0	15	102,5421	0,00
Precursor	Wilks	0,021211	43,4	10	74,0000	0,00

Application of fertilizers in the field crop rotation changes the specific activity of radioisotopes in winter wheat grains (Fig. 3).



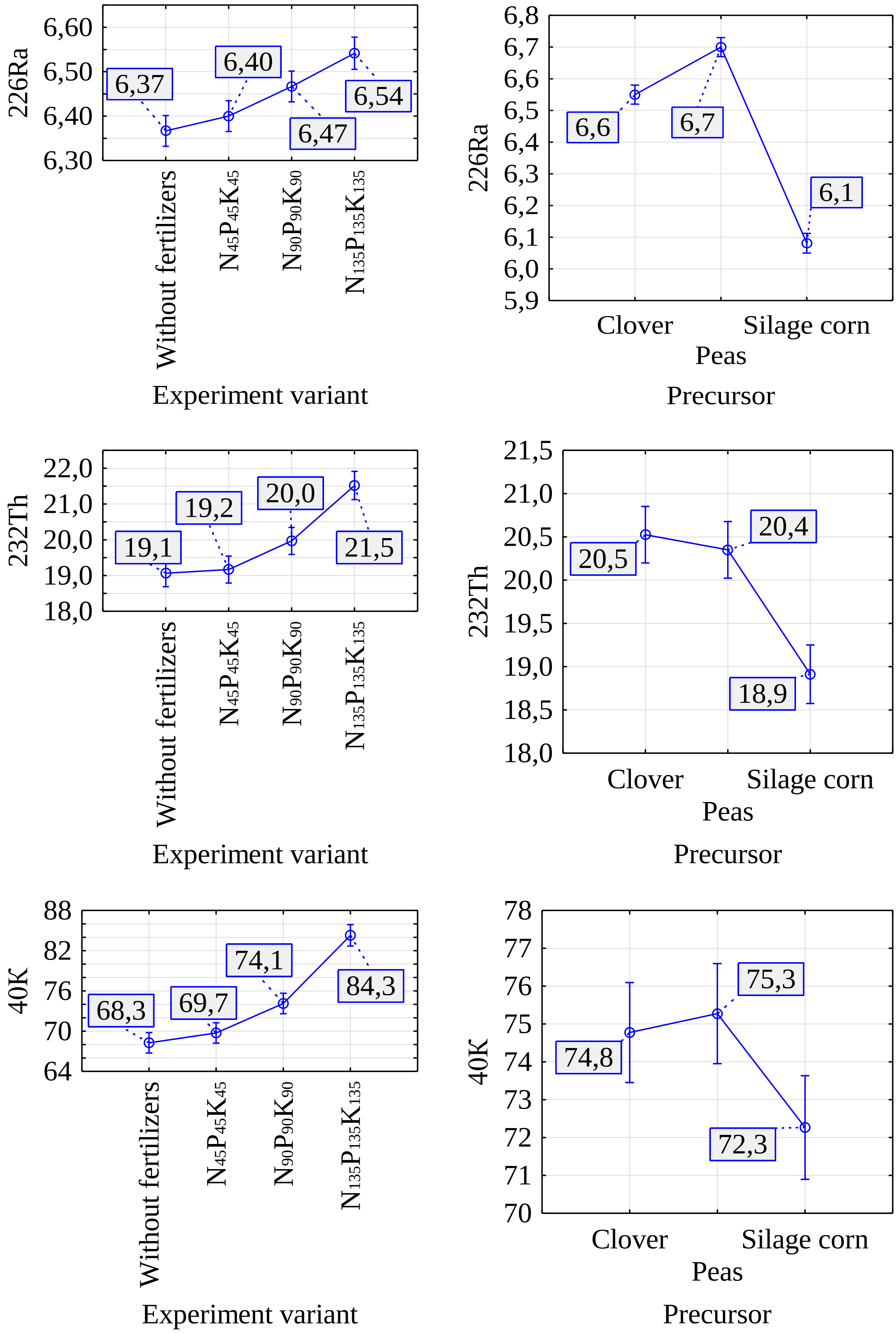


Fig. 3. The activity of radionuclides in soft winter wheat grains depending on the saturation of the field crop rotation with mineral fertilizers and the predecessor

Under the cultivation of wheat after corn for silage it is lower compared to other predecessors (clover and peas). The specific activity of ^{232}Th in winter wheat grain was lower compared to ^{40}K – 18.1–22.8 Bq/kg depending on the fertilizers rates and predecessors. It has also been found that the absorption of ^{232}Th was higher in case of growing wheat after clover and peas (19.6–22.8 Bq/kg of grain) than after corn (18.1–19.8 Bq/kg), which can be explained by the dilution effect at a higher yield.

A long-term application of potassium fertilizers increases the radioactivity of the soil due to the content of ^{40}K and ^{226}Ra. However, the important ecological function of potassium is antagonism in relation to radioactive ^{137}Cs and ^{90}Sr [9]. Many scientists [10, 11] note the significant role of potassium fertilizers in reducing the intensity and migration of radionuclides in the soil-plant system. Potassium inhibits ^{137}Cs transfer into crops of agrocenoses. The greatest effect is achieved with the application of high rates of potassium fertilizers. The specific activity of ^{226}Ra was almost not affected by the investigated components of the agrotechnology of growing winter wheat. Its activity varied within insignificant range – 6.0–6.8 Bq/kg. Radioisotopes ^{90}Sr and ^{137}Cs are easily included in the migration processes of agricultural chains, because their chemical properties are similar to calcium and potassium respectively, which play an important role in the biosphere.

Specific activity of ^{137}Cs and ^{90}Sr in winter wheat grains was the lowest compared to other radionuclides – from 1.7 to 2.1 and from 0.8 to 1.1 Bq/kg respectively depending on the agricultural technology. This shows that a long-term use of fertilizers in the field crop rotation at the indicated rates is safe. At the same time, the specific activity of ^{137}Cs was 40–47 times, and ^{90}Sr was 127–145 times lower than maximum permissible concentration. It has been found that applied potash fertilizers contribute to a significant decrease radiocesium content both in the main and in the non-marketable part of the wheat crop compared to the control. Application of potash fertilizers is an effective and economically justifiable measure to reduce the input of ^{137}Cs and ^{90}Sr into crop production.

As a result of determining the partial coefficient it has been established that the activity of radioactive elements was most influenced by the predesessor – 0.83. Application of mineral fertilizers in the field crop rotation had a smaller effect – 0.64 (Fig. 4).

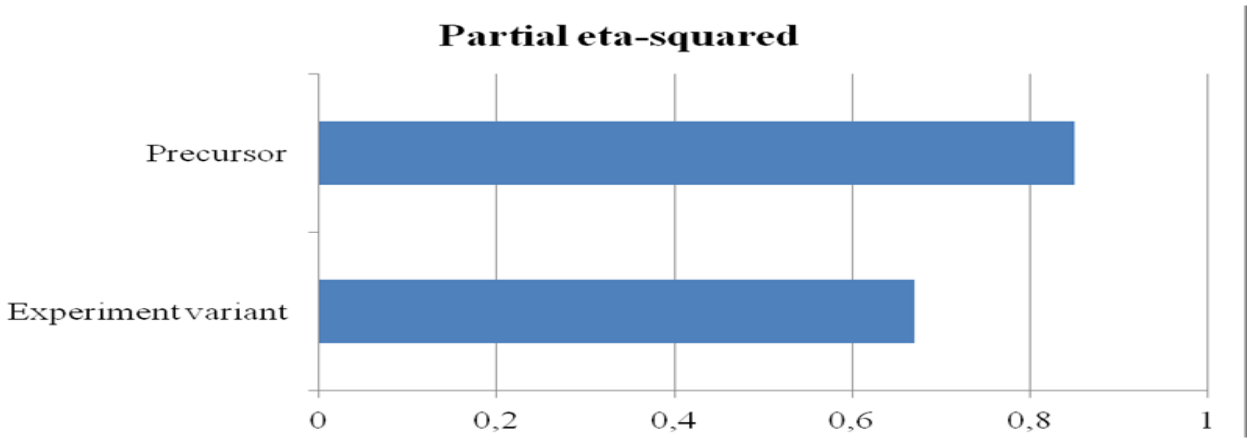


Fig. 4 Partial coefficient of fertilizer and predecessor influence on the activity of radioactive elements in the grain of soft winter wheat

Conclusions. Absorption of radionuclides by podzolized heavy loam black soil prevents their movement along its profile and further penetration into groundwaters. Thus, their specific activity at the depth of 40–60 cm is two times lower than in the soil layer at the depth of 0–20cm. This indicates the fixation of radioisotopes in the upper layers of the soil, which in its turn increases the probability of their getting into plant products. ^{137}Cs is most absorbed by winter wheat plants from the soil, while ^{90}Sr is absorbed much less. Although the absorption of ^{40}K from the soil is significant, it is safe for human health. Contamination of plant products with radionuclides depends on the agrochemical load on the soil. Therefore, the concentration of radionuclides in plants on different soils in different soil and climatic zones at the same level of pollution can be different. A long-term application of potash fertilizers increases the soil radioactivity due to the content of ^{40}K and ^{226}Ra, however, this radiation is safe for human health. In addition, potassium performs an important ecological function. It acts as an antagonist in relation to radioactive ^{137}Cs and ^{90}Sr. Analysis of the specific activity of radionuclides in winter wheat grain shows that a long-term (50 years) use of fertilizers in the field crop rotation in the indicated rates is safe.

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Annotation

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The content of radioactive elements in the soil and soft winter wheat grain under a long-term use of fertilizers in the field crop rotation

Introduction. In agriculture, along with improving yielding capacity and product quality, the studies aimed at preserving and protecting the environment against technogenic pollution should be considered relevant. It is necessary to introduce environmental resource-saving technologies that would ensure the maintenance of clean soil, water and air

Aim. To determine the content of radioactive elements in the soil and grain of soft winter wheat under a long-term use of fertilizers in the field crop rotation.

Methods. Field, laboratory, chemical, statistical, analysis.

Results. Absorption of radionuclides by podzolized heavy loam black soil prevents their movement along its profile and further penetration into groundwaters. Thus, their specific activity at the depth of 40–60 cm is two times lower than in the soil layer at the depth of 0–20cm. This indicates the fixation of radioisotopes in the upper layers of the soil, which in its turn increases the probability of their getting into plant products. ^{137}Cs is most absorbed by winter wheat plants from the soil, while ^{90}Sr is absorbed much less. Although the absorption of ^{40}K from the soil is significant, it is safe for human health. Contamination of plant products with radionuclides depends on the agrochemical load on the soil. Therefore, the concentration of radionuclides in plants on different soils in different soil and climatic zones at the same level of pollution can be different.

Conclusions. A long-term application of potash fertilizers increases the soil radioactivity due to the content of ^{40}K and ^{226}Ra, however, this radiation is safe for human health. In addition, potassium performs an important ecological function. It acts as an antagonist in relation to radioactive ^{137}Cs and ^{90}Sr. Analysis of the specific activity of radionuclides in winter wheat grain shows that a long-term (50 years) use of fertilizers in the field crop rotation in the indicated rates is safe.

Key words: *soft winter wheat, radioactive elements, radioactive activity, predecessor, fertilizers.*