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Radio-Ecological Substantiation Of Applying Mineral Fertilizers In The Field Fodder Production On Radioactively Contaminated Territories.

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ABSTRACT

Livestock production is largely determined by the quality of fodder, especially by the protein content. Alfalfa variable (medicago x varia) is a legume from which you can produce fodder with a protein content in accordance with the zootechnical norm, especially when it is cultivated in the crops mixed with cereal grasses. In the south-western regions of Central Russia, another relevant problem of fodder production is growing grasses in the conditions of radioactive contamination. The intake of radionuclides into the yield is reduced by using potassium fertilizers, as potassium ions have an advantage over caesium ions in the process of adsorption by the root systems of plants. In 2011-014 we studied the influence of the phosphorous-potassium fertilizer in the field on the alfalfa formation in pure and mixed crops (with smooth brome and timothy grass) on the background of radioactive contamination. It was determined that the highest yield with the crop being mowed twice is characteristic of the alfalfa-brome mix (yield of dry matter – 11.1 t/ha), and in order to obtain fodder virtually free from caesium-137 in all variants of the experiment, the phosphorus-potassium fertilizer is introduced at a dose of $P_{60}K_{210}$.

Keywords: variable alfalfa, smooth brome, timothy grass, mixed crops, radioactive contamination, caesium-137, phosphorus-potassium fertilizer, productivity.

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INTRODUCTION

The accident at the Chernobyl nuclear power plant with its consequences, which affect all spheres of the economy directly or indirectly, has set a number of problems for science and practice to overcome its consequences. The existence of the whole region appeared to be linked with the problem of land use, contaminated with long lived radionuclides [1-3].

Extensive contamination of agricultural land and a long period of decay of radionuclides necessitated the development and implementation of new theoretical approaches and recommendations to conduct specialized farming systems, which on the one hand, provide extended reproduction of soil fertility, better crop productivity, production of agricultural products in accordance with the veterinary and sanitary requirements and regulations, on the other – ensure the environmentally safe operation of agricultural production [4-6].

In modern conditions, field fodder production is crucial to building a strong fodder base for livestock. The most valuable raw material for the preparation of high quality voluminous fodder-grass is mainly leguminous perennial herbs in a form of a monoculture or in a mixture with cereal herbs [7, 8].

Many researchers say that in comparison with the monocultural crops of leguminous or cereal grasses, mixtures use the soil and climatic potential better and more efficiently, are more resistant to diseases and weeds. Legume-grass mixtures are more productive, give fodder with a good protein and energy balance at low cost [9-12]. At the same time, the productivity of mixed crops is maximized only if the components of the mixture are chosen correctly by floristic and varietal composition, taking into account their compatibility both in terms of the development and seeding rates, which eliminate oppression of the leguminous component.

In the Bryansk region, over 1756.7 thous. Ha of farmland were subject to radioactive contamination, 491.4 thous. Ha of which are natural grasslands. One of the main problems of agricultural production on the territories contaminated with radionuclides is to produce fodder, which contains the minimum amount of radionuclides and meets the requirements of environmental protection legislation. The reduction of radionuclide content in the fodder is the most important factor contributing to the decline in radionuclides consumed by animals and then by a man with animal products and thus the dose reduction of internal exposure of the population in the contaminated areas [13, 14].

Adding potassium fertilizers is an effective technique to increase the productivity of agricultural land and reduce the amount of radionuclides absorbed into the harvest. The effectiveness of potassium fertilizers is due to the antagonism between caesium ions and potassium ions for the amount of crops, especially on sod-podzolic sandy and sabulous soils, which are potassium depleted [15-17].

Production of agricultural products, which correspond to the health and hygiene standards, on technogenically-contaminated lands is impossible without the development of scientific bases of the fertilizer system, in which potassium plays the most important role [18-20].

Despite many studies in the field of radioecology, currently, the issues of influence of a combination of various mineral fertilizers and their doses on the yield and the degree of radionuclides transfer into fodder perennial grasses and further by the trophic chain to animals and humans, are poorly understood. It is necessary to develop a complex of agrochemical measures to ensure the highest possible yield from natural fodder grassland standard, which are "clean" from caesium-137, according to the sanitary regulations, for specific soil and climatic conditions of the radioactively contaminated zone. Therefore, the research on mineral nutrition levels, aimed at increasing productivity and obtaining fodder, which is clear of caesium, according to the standards, is an actual scientific and practical task.

The goal of research

Radioecological substantiation of the mineral fertilizers use for leguminous and bluegrass crops as a monoculture and as mixed crops under the conditions of radioactive contamination of the environment.

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METHODS OF RESEARCH

The studies were carried out at the experimental field of the Bryansk State Agrarian University in 2011–2014. Soil of the experimental plot is sod-podzolic, moderately cultivated. Thickness of the arable layer is 20-22 cm; the content of humus in the soil is 1.5-1.7%. The content of mobile phosphorus and exchangeable potassium (according to Kirsanov) is 155-180 and 80-20 mg per 1 kg of soil, respectively, pH_{KCl} 5.5-5.8. The density of soil contamination with cesium-137 in average amounts to 237 kBq/m^2.

Number of the experiment replications is three; the placement of variants is systematic. The area of the record plot amounted to 30 m^2. The following varieties were sown: alfalfa variable (*Medicago varia* Mart.) of the Sarga variety, timothy grass (*Phleum pratense* L.) of the Marusinskaya variety–297, smooth brome (*Bromopsis inermis*) of the Morshansky variety 760. The sowing of perennial grasses was coverless. With the use for 2 mowings, for the first time alfalfa was mowed in the budding phase – in the beginning of flowering, cereal grasses – in the booting phase – in the beginning of ear emergence. The studies were conducted by conventional methods [21].

During the years of studies, meteorological conditions differed significantly from the average long-term data by both the temperature regime, and the amount of precipitation and its distribution over the decades and months of the vegetation period. The year of 2012 was the most favourable by the moisture conditions and temperature regime of the vegetation period. The vegetation periods of 2011, 2013 and 2014 were less favourable for perennial grasses and were characterized as arid in the second half of vegetation.

The content of caesium-137 in soil and hay of perennial grasses was determined in the paired samples of plants and soil, taken from the plots 1 m^2. Measurements were performed on the USC "Gamma Plus" (universal spectrometric complex) with the "Progress 2000" software [22].

The specific activity of caesium-137 in milk and meat was calculated by the equilibrium coefficient of radionuclide transfer from the daily diet into animal products (with the daily consumption of 5 kg of hay). The value of internal radiation dose received with milk and meat was calculated according to the methodological guidelines [23]. Consumption of milk and dairy products in the milk equivalent per year is 200.8 litres, meat – 31.4 kg according to the law of the Bryansk region of 08.06.2001 No. 45-Z (ed. of 12.10.2001) "On the consumer basket in the Bryansk region ".

RESULTS AND DISCUSSION

In the control variant in monocultural crops, variable alfalfa exceeded smooth brome and timothy grass by the yield and overall productivity. Yields of alfalfa hay increased significantly with the introduction of phosphorous-potassium fertilizers in gradually increasing doses, reaching a maximum value with the introduction of the fertilizer in the dose of $P_{60}K_{210}$. The yield of bluegrass hay on the background of increasing doses of the phosphorous-potassium fertilizer turned out to be lower than the yield of alfalfa, as it was significantly limited by mineral nitrogen. Since alfalfa satisfies its need for mineral nitrogen at the account of symbiotic nitrogen fixation (Table. 1).

The highest yield of hay in the experiment was obtained in the mixed crops of alfalfa with bluegrasses, where the leading role in the formation of the harvest attributed to alfalfa. When comparing the productivity levels of mixed crops, the alfalfa-brome grass mixture demonstrated the higher yield.

The rate of return of 1 kg of mineral fertilizers with the increase in the yield of perennial grasses is essentially the main indicator of their effectiveness. It gives an opportunity to assess different doses of phosphorous-potassium fertilizers most fully.

The introduction of potassium fertilizers at a K_{120} dose on the background of phosphorous (P_{60}) fertilizers during alfalfa cultivation allows obtaining 6 kg of hay per 1 kg of introduced phosphorous-potassium fertilizers. Further increase of potassium fertilizers dose per 30 kg of active ingredient increases the rate of return by 1.5 times, per 60 kg of active ingredient – by 2.5 times, per 90 kg – by 3.0 times.

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Table 1: Efficiency of mineral fertilizers using perennial agrophytocenosis

Variant		Alfalfa variable	Smooth brome	Timothy grass	Alfalfa + smooth brome	Alfalfa + timothy grass
The yield of hay, t/ha (for a total of two mowings)						
Control		5.56	3.95	3.4	7.26	5.39
Background – P_{60}	K_{120}	6.64	4.4	4.17	8.23	6.27
	K_{150}	7.51	4.89	4.61	9	6.97
	K_{180}	9.21	5.24	5.13	9.89	7.88
	K_{210}	10.36	5.73	5.61	11.1	10.66
Increase in yield, t/ha						
Control		-	-	-	-	-
Background – P_{60}	K_{120}	1.08	0.45	0.77	0.97	0.88
	K_{150}	1.95	0.94	1.21	1.74	1.58
	K_{180}	3.65	1.29	1.73	2.63	2.49
	K_{210}	4.80	1.78	2.21	3.84	5.27
Rate of return of mineral fertilizers with the increase in yield, kg/kg rate active ingredient						
Control		-	-	-	-	-
Background – P_{60}	K_{120}	6.00	2.50	4.28	5.39	4.89
	K_{150}	9.29	4.48	5.76	8.29	7.52
	K_{180}	15.21	5.38	7.21	10.96	10.38
	K_{210}	17.78	6.59	8.19	14.22	19.52

The rate of return of 1 kg of phosphorous-potassium fertilizers, used under the Poaceae grasses and reaches 8.19 kg at its maximum.

The biggest rate of return is detected in mixed crops of alfalfa and timothy grass – 19.52 kg with applied phosphorous-potassium fertilizers at a $P_{60}K_{210}$ dose, higher rate of return in comparison with the $P_{60}K_{120}$ dose by 4 times.

When a territory is radioactively contaminated, the most important quality indicator of produced fodder is the content of radionuclides in it; this content should not exceed the accepted norms. For the content of ^{137}Cs in the hay of perennial grasses, the norm is < 400 Bq/kg. [24].

The content of 137Cs in the hay of perennial grasses without fertilizers ranged from 291 to 386 Bq/kg, depending on the floristic composition of grass stand, as in our experiment we obtained the following rating of grasses, according to the tolerance to radiation contamination: legumes legume-bluegrass mixtures and bluegrasses. The hay produced in the experiment corresponds to the veterinary and sanitary quality requirements (Table 2).

Introduction of phosphorous-potassium fertilizers at a dose of $P_{60}K_{120}$ decreased the content of ^{137}Cs in the hay by 1.4-2.2 times in comparison with the control variant depending on the floristic composition of grass stand. The use of increasing doses of potassium fertilizers reduces the specific activity of hay at a maximum from 40 to 103 Bq/kg, depending on the floristic composition of grass stand.

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Table 2: Radio-ecological assessment of mineral fertilizers use for the cultivation of perennial grasses for hay (average for 2010 -2014)

Variant		Alfalfa variable	Smooth brome	Timothy grass	Alfalfa + smooth brome	Alfalfa + timothy grass
Specific activity of 137Cs in hay, Bq/kg (the average for two mowings)						
Control		386	256	239	315	291
Background – P_{60}	K_{120}	246	136	107	197	207
	K_{150}	192	94	141	133	111
	K_{180}	142	77	83	91	75
	K_{210}	103	55	69	80	40
Yield of ^{137}Cs with the harvest, kBq/ha						
Control		2146	1011	813	2287	1568
Background – P_{60}	K_{120}	1633	598	446	1621	1298
	K_{150}	1442	460	650	1197	774
	K_{180}	1308	403	426	900	591
	K_{210}	1067	315	387	888	426
N-fold reduction						
Control		-	-	-	-	-
Background – P_{60}	K_{120}	1.6	1.9	2.2	1.6	1.4
	K_{150}	2.0	2.7	1.7	2.4	2.6
	K_{180}	2.7	3.3	2.9	3.5	3.9
	K_{210}	3.7	4.7	3.5	3.9	7.3
Specific activity of ^{137}Cs in milk, Bq/l						
Control		19	13	12	16	15
Background – P_{60}	K_{120}	12	7	5	10	10
	K_{150}	10	5	7	7	6
	K_{180}	7	4	4	5	4
	K_{210}	5	3	3	4	2
Specific activity of ^{137}Cs in meat, Bq/l						
Control		77	51	48	63	58
Background – P_{60}	K_{120}	49	27	21	39	41
	K_{150}	38	19	28	27	22
	K_{180}	28	15	17	18	15
	K_{210}	21	11	14	16	8

The biggest yield of ^{137}Cs with the harvest from the soil was detected in the control variant; increased doses of phosphorous-potassium fertilizers decreased it, that is why during phytoremediation of radioactively contaminated soils it is necessary to cultivate leguminous cultures without phosphorous-potassium fertilizers.

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Considering the migration of 137Cs from hay into animal products, it should be noted that it is possible to cultivate grass stand as fodder in order to produce milk and meat without using fertilizers [25]. However, in our experiment, in the calculation of specific activity of animal products we took into account only the feeding with radioactively contaminated hay, outside of the experiment, intake of radionuclides occurs with water and other fodder obtained from radioactive territories as well. That is why to reduce 137Cs intake it is necessary to use phosphorous-potassium fertilizers.

According to the radiation safety standards (RSS-99/2009), the dose of internal exposure should not exceed 1000 μSv/year [26].

In the situations when significant levels of radioactive contamination significantly exceed the background content and reach dangerous levels, it is important to evaluate the structure of the radiation dose, i.e. to assess the contribution of individual foods to the total load. In the experiment, we evaluated milk and meat, produced by feeding livestock with hay of different floristic composition, contaminated by caesium-137. We also evaluated the effects of increasing doses of potassium fertilizers on the background of the phosphorus fertilizer on the decline of the caesium-137 intake along the chain soil → animal products→ people (Table. 3).

Natural and economic conditions in the region contribute to an increase in production and creation of a strong food base for all kinds of animals, but a part of the region is in the area that was contaminated due to the accident at the Chernobyl nuclear power plant. Therefore, animal products (meat and milk) may be contaminated by radionuclides, which along the trophic chain enter the human body [27].

Table 3: Internal radiation dose received by the consumption of livestock products, μSv/year

Variant		Alfalfa variable	Smooth brome	Timothy grass	Alfalfa + smooth brome	Alfalfa + timothy grass
Milk						
Control		50	34	31	42	39
Background – P_{60}	K_{120}	31	18	13	26	26
	K_{150}	26	13	18	18	16
	K_{180}	18	10	10	13	10
	K_{210}	13	8	8	10	5
Meat						
Control		31	21	20	26	24
Background – P_{60}	K_{120}	20	11	9	16	17
	K_{150}	16	8	11	11	9
	K_{180}	11	6	7	7	6
	K_{210}	9	4	6	7	3

The cultivation of alfalfa for hay without the use of fertilizers, with the subsequent feeding to animals leads to the greatest internal exposure, caused by the consumption of animal products, the use of bluegrasses hay as animal fodder reduces the dose of internal exposure at the account of animal products by 1.5 times, the use of mixed legume-bluegrass hay decreases it by 1.2 times.

The use of increasing doses of potassium fertilizers on the background of phosphorus ones in the cultivation of monocultural and multicultural grass stand for hay and feeding it to animals significantly reduce the dose of internal exposure, caused by the consumption of animal products.

In this case, potassium fertilizers were a major barrier to the migration of caesium-137 from the soil to fodder products, thus reducing its concentration in livestock products and further reducing the internal dose.

When considering the profile of animal products, namely milk and meat, it is necessary to point out that in the structure of dose load the dose of milk is 1.5 times higher than the dose of meat. It should be remembered that in this case, raw food products are considered, after cooking or processing the radionuclide content will decline.

CONCLUSION

Depending on the logistics of farms located on sod-podzolic sandy soils, contaminated by ^{137}Cs we recommend using the grass stand cultivation technologies that correspond with two main criteria – ecological safety and economic feasibility:

- we recommend using the phosphorus-potassium fertilizers at a dose of $P_{60}K_{210}$ for the cultivation of perennial grasses for hay for the fodder purposes, as during this process, the migration of ^{137}Cs from soil into fodder and further along the trophic chain is reduced to the maximum.

- the highest productivity is obtained in the cultivated mixed crops of alfalfa and smooth brome 11.1 t/ha, but the rate of return of mineral fertilizer, and thus efficiency is higher in the cultivation of mixed crops of alfalfa and timothy grass.

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