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Improving the Efficiency of Monitoring of Natural and Seeded Forage Grasslands in the Territories of Technogenic Pollution in the Non-Black Soil Zone of the Russian Federation

Svetlana N. Potsepai[1], Lidiya N. Anishchenko[2], Sergei A. Bel'chenko[1],
Galina P. Malyavko[1], Mikhail V. Semyshev[1], Viktor F. Shapovalov[1]
[1] *FSBEI HE Bryansk State Agrarian University, Bryansk, Russia*
[2] *FSBEI HE Bryansk State University named after acad. I.G. Petrovsky, Bryansk, Russia*

Abstract

The data of impact radiological monitoring in the bottomland meadows of the Desna and Iput' rivers within the Bryansk District (the Non-Black Soil Zone of the Russian Federation) have been presented and discussed; the dynamics of the specific activity of caesium in the grass stand has been assessed according to the floristic composition of communities and the shoot height as well. For the first time the data on accumulation of radionuclides have been estimated with no regard for certain types of grass stand: meadow communities have been examined as a whole; a phyto-row has been constructed. The indices have been identified of the specific activity of caesium in herbage components in the Post-Chernobyl period and when taking melioration measures, using a synthetic ameliorant: amorphous silicon dioxide. All meadows have been proved to be the source of high-quality nutritious forage, pastures. Distribution of the examined ^{137}Cs radionuclide over the shoot height is uneven: it is recorded that its maximum content is in the horizon of up to 5cm, and minimum – in the upper shoot parts and inflorescences. ^{137}Cs is accumulated in herbage of meadow plant associations in descending order as follows: ***Glycerietum maximae*** Nowiński 1930 (***Scirpetum sylvatici*** Ralski 1931) > ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989 > ***Phalaridetum arundinaceae*** Libbert 1931> ***Anthoxantho–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969 (***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-Tuláčková 1978, ***Deschampsio–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969) > ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987 > ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990 (***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990). Maximum accumulation capability is inherent in meadow communities with high soil moisture, low nitrogen and pH indices (according to G. Ellenberg, 1992). Experimental amelioration measures have been taken on natural meadows involved in pasture rotation, with the "Kovelos-Rost" synthetic preparation being introduced as a top-dressing. It has been found that agrochemical measures definitely reduce accumulation of radionucleotide in the plant biomass (over the shoot height): all accumulation coefficients indicate that there is no accumulation of ^{137}Cs. Minimum accumulation coefficient is 0.25, maximum – 0.97. The protective effect of amorphous silicon dioxide is determined by chemical properties of hydrogenated silicon: its presence increases the solution acidity; caesium radionuclide becomes inactive and is poorly absorbed by herbage.

The recommendations have been suggested for the system of meadow pasture rotation optimisation, including the following provisions: mowing hay and using it to feed cattle at the final stage, to produce milk with compulsory processing; it is desirable to use floodplain meadows (short-term bottomland); it is possible to limit the access of cattle to low and flooded areas with distribution of low-land (marsh) meadow communities; to control grazing, not to allow full eradication of herbage (below 5cm in height), transformation of meadows during pasture degradation into pike-type grasslands due to the considerable accumulation of ^{137}Cs in the lower part of the shoot mass of plants, and the increased accumulation of the radionuclide in *Deschampsia cespitosa*; to consider 5-7cm from the soil surface to be the optimum cut-off height of biomass in haymaking production, without affecting turf and buds of plant renewal. In addition to calcium- and potassium-containing preparations, widely utilised when remediating soils of radioactively contaminated habitats, it is recommended to use the "Kovelos" synthetic preparation owing to its lower consumption per unit area and considerably lower costs in the overall scheme of agrotechnical measures.

Key words: *meadows, radionuclides, radio ecological monitoring, synthetic ameliorants, the Bryansk district, the Non-Black Soil Zone of the Russian Federation.*

Introduction.

In the territory of the Bryansk district, natural and seeded forage grasslands are formed and maintained in conditions of technogenic pollution, also characterised by the increased density of radionuclides (RNc) as a result of the technogenic catastrophe. Not enough monitoring areas are in the meadows of various forage land types and groups to examine the RNc displacement, based on which the system of grassland culture monitoring in the Post-Chernobyl period can be presented. The dynamic processes on the extensively used meadows in the Non-Black Soil Zone of the Russian Federation, namely, pastoral degradation, fluctuation changes, define the directions and rates of RNc flows, which are poorly studied for specific elements. The species-indicators of migratory activity of pollutants by the accumulation capability have also not been identified to conduct scientifically prospective researches [1, 2]. The use of specific bio-indicators will facilitate work, formatting and maintaining integrated databases on bio-productivity of edificator species, actual content and distribution of RNc, defining radiobiological effects, allocating and exploiting stationary sample plots (SPs), developing chemical amelioration programs. Within agricultural lands of the Bryansk district, related to the first group of territories with the content of pollutants, mosaic structure and unevenness in their distribution, radio-monitoring is complicated, requiring not only constant correction of measures, but new extensive survey works [3].

Nowadays, the intensity of rehabilitation measures for personal farm households and rough pastures has been reduced, what increases the migration rate of various pollutants to herbage elements, which decreases the efficiency of measures for producing radiation-proof plant products. Multiple works are known, in which quality and quantity-related characteristics of meadow eco-systems herbage are estimated in pasture farming and haymaking when there is a background and considerable radionuclide pollution [4-6, etc.]. The study aims to assess the accumulation of radionuclides in meadows herbage and the efficiency of synthetic ameliorants (amorphous silicon dioxide) to adjust the rate of radionuclides' delivery to biomass for amending the system of conceptual and methodological developments in the Post-Chernobyl period.

Materials, methods, methodologies, subjects of research. According to the data of preliminary monitoring survey, about 491.4 thsd. ha of natural meadows in the administrative centre of the Non-Black Soil Zone of the Russian Federation – the Bryansk district – have been found to be polluted with radionuclides; most of them are in south-western districts [7]. The research territory belongs to the second agroclimatic area, where the amount of daily mean temperatures over the period of active plant vegetation is from 2100 to 2300 ^{o}C [7].

In 2015-2017 field seasons, the processes of the RNc migration to herbage of meadows in the Bryansk district landscapes were examined. The research subject involved natural forage grasslands, natural meadows, formed in various parts of the floodplains of the second order rivers – Desna and Iput' within the Bryansk district. The studies were carried out within sample plots (SPs), where the indices of species composition were determined for ecological assessment of environment according to indication scales of G. Ellenberg [8]. The SPs are located on meadows in the Krasnogorskiy, Klintsovskiy, Zlynkovskiy, and Zhukovskiy (control) districts with various levels of radionuclide pollution and extensively used in transhumant cattle-breeding as hay lands. Syntaxonomy of meadow vegetation has been developed in accordance with the general concepts of the J. Braun-Blanquet method [9]. The names of syntaxons have been given pursuant to the International Code of phytosociological nomenclature [10]. Crop yield of meadow herbage has been determined by cut-sample method on the 1m^2 plots thrice repeated during the third decade of June, yielding capacity has been computed according to the average result. The determined eco-coenotic characteristics of meadows have been described in terms of biodiversity, yielding capacity, and transformation has been made into a type of forage grasslands, specified according to L.G. Ramenskiy, which have further been transformed into larger typological units pursuant to methodological guidelines, implemented based on the classification of L.G. Ramenskiy by the employees of the All-Russian Williams Fodder Research Institute [11]. The quality of forage on natural meadows has been estimated through chemical analysis of hay samples.

The "Kovelos-Rost" synthetic preparation (2015-2016) has been introduced at the rate of 50kg per 1ha as a surface top-dressing in full dose and in one step. It has been applied as a chemical ameliorant for agrochemical amelioration purposes in the district for the first time.

Instrumental field and laboratory surveys have been carried out. The exposure dose rate (EDR, μR/hr) within the SPs has been measured in soil and at the 1m height from soil by SRP-68-01, RKSB-104 dose meters. The specific activity (Bq/kg) of the ^{137}Cs radionucleotide in samples has been identified applying gamma-ray spectrometer complex "MSC Gamma Plus" with scintillation detector with "Progress 2000" software (Spectron company) using standard techniques [12]. The obtained data have been compared with standards for the Russian Federation [13].

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Soil samples within $10m^2$ SPs, ground from 0-10cm depth and phyto-mass of vascular plants have been selected for radiometric analysis in compliance with the main GOST requirements [14]. To evaluate bio-accessibility of radionuclides in the soil-plant system, conversion (C_C) and accumulation (C_A) coefficients have been employed, computed using standard methods [15]. The SPs on meadows are characterised as follows: series of sample plots (SSP 1) in the Krasnogorskiy district: EDR=109.2±10.03-108.7±10.72 μR/hr; series of sample plots (SSP 2) in the Klintsovskiy district: EDR=92.14±9.26-86.12±8.51 μR/hr; series of sample plots (SSP 3) in the Zlynkovskiy district: EDR=84.51±8.17-79.17±8.02 μR/hr; series of sample plots (SSP 5) in the Zhukovskiy district: EDR=16.2±1.41-15.1±1.21 μR/hr, control. When processing, the univariate analysis of variation series has been applied (average values of the attribute and their errors (M±m), experiment accuracy (p, %), certainty has been estimated according to Student (t) considering three confidence levels (P=99%) [16].

Research results and discussion. Within all series of sample plots meadow communities have been examined, belonging to 2 classes, 4 orders, 7 unions, 10 plant associations, which are formed in different ecological conditions of floodplains of the second order large rivers.

Prodromus of syntaxons of the examined meadow communities

Class ***Phragmito-Magnocaricetea*** Klika in Klika et Novák 1941

Order ***Phragmitetalia*** Koch 1926

Union ***Phragmition*** Koch 1926

Association (Ass.) ***Glycerietum maximae*** Nowiński 1930

Order ***Magnocaricetalia*** Pignatti 1953

Union ***Magnocaricion elatae*** Koch 1926

Ass. ***Phalaridetum arundinaceae*** Libbert 1931

Class ***Molinio-Arrhenatheretea*** Tx. 1937

Order ***Molinietalia*** Koch 1926

Union ***Calthion*** Tx. 1937 em. Leburn et al. 1949

Ass. ***Scirpetum sylvatici*** Ralski 1931

Union ***Filipendulion*** (Br.-Bl. 1947) Lohm. ap. Oberd. 1967

Ass. ***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-Tuláčková 1978. Ass. ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990

Union ***Agrostio stoloniferae–Beckmannion eruciformis*** Mirkin 1989

Ass. ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989. Ass. ***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990.

Union ***Alopecurion pratensis*** Passarge 1964

Ass. ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987

Order ***Agrostietalia stoloniferae*** Oberd. in Oberd. et al. 1967

Union ***Cynosurion*** Tx. 1937

Ass. ***Anthoxantho–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969. Ass. ***Deschampsio–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969

Communities of the following associations belong to the group of low (marsh) meadows. Communities of association ***Glycerietum maximae*** Nowiński 1930, Glycerietum maximae type of forage grasslands, subgroup of sedgy marsh meadows, occupy deep lowlands in floodplains of rivers in humous slimy-gley soils (B=9.1), subacidic or neutral (K=6.5) with the moderate content of nitrogen (N=5.7). Yielding capacity: average – 39.2±2.04 dt/ha, minimum and maximum – 31.2-55.7 dt/ha. Communities of association ***Scirpetum sylvatici*** Ralski 1931, Scirpus sylvaticus type, subgroup of Gramineous and motley grass-small grass meadows, are formed in alluvial sod-gleyed clay-loam soils, damp (B=8.3), subacidic (K=5.7), with the moderate content of nitrogen (N=5.5). Yielding capacity: average – 22.4±1.9 dt/ha, minimum and maximum – 19.1-28.3 dt/ha. Communities of association ***Phalaridetum arundinaceae*** Libbert 1931, Phalaridetum arundinaceae type, subgroup of Gramineous-sergy motley-grass dampish and damp meadows, are widespread in plain lowlands and shallow hollows between low ridges in turfy grainy gleyed and marsh-humus-gley heavy clay-loam soils, varying in moisture to heavily watered (B=7.4), subacidic (K=6.2), with the moderate content of nitrogen (N=6.1). Yielding capacity: average – 37.3±2.4 dt/ha, minimum and maximum – 32.2-51.1 dt/ha. Communities of association ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989, Beckmannia eruciformis type, subgroup of Gramineous-sergy motley-grass dampish and damp meadows, are recorded as small segments in shallow hollows and along ridges of hollows between low ridges in the central bottomland with humus-gley wet (B=7.9), subacidic (K=6.2), soils with the medium content of nitrogen (N=5.5). Yielding capacity: average – 26.3±2.02 dt/ha, minimum and maximum – 23.2-29.8dt/ha. Communities of association ***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-Tuláčková 1978, Meadowsweet type, subgroup of Gramineous and motley grass-small grass meadows, in alluvial sod-gleyed clay-loam soils, wet (B=7.8), subacidic (K=5.4), with the moderate content of nitrogen (N=5.7). Yielding capacity: average – 18.9±1.2 dt/ha, minimum and maximum – 17.0 – 20.6 dt/ha.

Associations are integrated into ecological series by moistening: ***Glycerietum maximae*** Nowiński 1930 > ***Scirpetum sylvatici*** Ralski 1931 > ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989 > ***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-

Tuláčková 1978 > ***Phalaridetum arundinaceae*** Libbert 1931. Other ecological factors of soils for communities are similar.

Floodplain meadows – long-term bottomland – incorporate communities of association ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987, Poo palustris–Alopecuretum pratensis type, subgroup of Gramineous-sergy motley-grass dampish and damp meadows on moderately depressed sites of the central and terrace near flood plains, along flat depressed areas in wet and damp alluvial fibrous and fibrous-grainy gleyed light- and middle loamy wet soils (B=6.9), neutral (K=6.2), with the medium content of nitrogen (N=5.5). Yielding capacity: average – 28.3±2.3 dt/ha, minimum and maximum – 20.1-39.5 dt/ha. Communities of association ***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990, Heracleo sibirici-Alopecuretum pratensis type, subgroup of damp and dampish meadows, are widespread in the central, less often in the flood segment of bottomland, in turfy grainy gleyed and gleyed clay-loam soils, in lush and wet (B=4.9), subacidic (K=5.9), with the moderate content of nitrogen (N=4.9). Yielding capacity: average – 25.8±1.8 dt/ha, minimum and maximum – 23.9-31.5 dt/ha.

Communities of association ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990, Fillpendulo ulmariae–Festucetum rubrae type, subgroup of Gramineous and motley grass meadows with admixed bean family, in the central bottomland in floodplain turfy fibrous and grainy soils, wet (B=6.0), subacidic (K=5.9), with the moderate content of nitrogen (N=5.5) belong to floodplain short-term bottomland meadows. Yielding capacity: average – 22.1±1.6 dt/ha, minimum and maximum – 19.3-27.6 dt/ha.

Associations are integrated into series by soil moistening: ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987 > ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990 > ***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990; by acidity the soils vary from subacidic to near-neutral pH, by the content of nitrogen – from medium to moderate.

Dry meadows are represented by communities of association ***Anthoxantho–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969, Anthoxantho–Agrostietum tenuis type, subgroup of motley grass-small grass dry and lush meadows, are formed along the slopes of north and north-eastern exposition, in the complex of gully soils – weakly podzolized sandy and sandy-loam soils, dry (B=4.0), medium acid (K=4.2), with the moderate or low content of nitrogen (N=4.2). Yielding capacity: average – 9.1±0.9 dt/ha, minimum and maximum – 8,4-11.5 dt/ha. Communities of association ***Deschampsio–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969, Anthoxantho-Agrostietum tenuis type, subgroup of motley grass-small grass dry and lush meadows, are formed on depressed sparsely flooded sites of bottomlands of small and medium rivers with weakly podzolized sandy and sandy-loam soils, dry (B=4.1), medium acid (K=4.1), with the moderate or low content of nitrogen (N=4.0). Yielding capacity: average – 9.0±0.8 dt/ha, minimum and maximum – 8.6 – 11.9 dt/ha. Thus, within the SPs with various degrees of technogenic pollution, the differences have been found in floristic composition and conditions of meadow habitats, used for grazing, haylands. Maximum yielding capacity has been found in Glycerietum maximae type, Phalaridetum arundinaceae type, Poo palustris–Alopecuretum pratensis type, minimum – in dry valleys in Anthoxantho–Agrostietum tenuis type and Deschampsio–Agrostietum tenuis type; quite often haymaking and grazing are complicated on Glycerietum maximae meadows, frequently flooded. Chemical composition of the meadow haylage is shown in the Figure. Haylage of Phalaridetum arundinaceae (36.58%), Poo palustris–Alopecuretum pratensis (35.63%), Anthoxantho–Agrostietum tenuis (35.83%) meadow types is rich in crude fibre. It has been found that it had the maximum content of N and P (in % on air-dry basis). Gross content of N and P (minimum and maximum) in the meadow haylage differs with certainty (t_{actual}> t_{theor}). Meadow communities in dry valleys, due to scarce stored plant mass, are mostly used for grazing, high-quality nutritious forage is produced from the other examined species, which are also utilised for silaging.

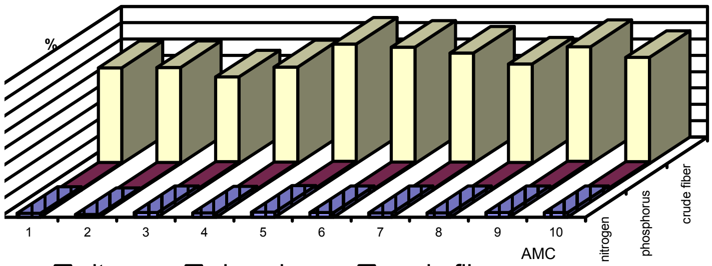

Figure 1. Chemical indices of hay in herbage (% of dry mass)

AMC – Associations of meadow communities: 1 Ass. *Glycerietum maximae* Nowiński 1930. 2 Ass. *Scirpetum sylvatici* Ralski 1931. 3 Ass. *Agrostio stoloniferae–Beckmannietum eruciformis* Alexandrova 1989. 4 Ass. *Lysimachio vulgaris–Filipenduletum ulmariae* Balátová-Tuláčková 1978. 5 Ass. *Phalaridetum arundinaceae* Libbert 1931. 6 Ass. *Poo palustris–Alopecuretum pratensis* Shelyag-Sosonko et al. 1987. 7 Ass. *Heracleo sibirici-Alopecuretum pratensis* Bulokhov 1990. 8 Ass. *Fillpendulo ulmariae–Festucetum rubrae* Bulokhov 1990. 9 Ass. *Anthoxantho–Agrostietum tenuis* Sill. 1933 em. Jurko 1969. 10 Ass. *Deschampsio–Agrostietum tenuis* Sill. 1933 em. Jurko 1969

^{137}Cs long-lived radioisotope serves as a major background RNc in soils. EDR exceeded 6.67 times control values in the Zhukovskiy district of the Bryansk region in the Krasnogorskiy district, 5.16 times in the Zlynkovskiy district, 5.65 times in the Klintsovskiy district. Within SSP1 in the Krasnogorskiy district ^{137}Cs SA in soil samples (5109.12±510.90 Bq/kg) exceeded 66.19 times control value (77.19±7.71 Bq/kg) t_{actual}>t_{table}, P=99%. In the Zlynkovskiy district within SP3, the ^{137}Cs SA in soil samples (3953.49±395.33 Bq/kg) has been found to be 51.22 more intense than in the Zhukovskiy district, control (t_{actual}>t_{table}, P=99%). In the Klintsovskiy district within SP2, the ^{137}Cs SA in soil (4362.40±436.24Bq/kg) was 56.51 times more intense as compared to control values (t_{actual}>t_{table}, P=99%). Thus, in radioactively contaminated plantations (the Klintsovskiy, Krasnogorskiy Zlynkovskiy districts) as compared with control (the Zhukovskiy district), EDR exceeds control values 5.16-6.67 times, the ^{137}Cs SA is exceeded 51.22-66.19 times.

According to the results of the conducted research, meadow plants of different biological species, ecological groups, dwelling in communities of various syntaxons, have demonstrated different capacity for accumulating radionuclides, what has also been confirmed by other authors [4, 5, et al.]. The main data on the content of caesium radionuclides in meadow hay depending on the height of mown herbage are shown in Tables 1 – 2.

Table 1 – Indices of radionuclide pollution (137 Cs) of herbage of meadow communities of different associations (0-5cm)

AMC*	SA, Bq/kg	C_A	C_C, $\frac{m^2}{kg*10^{-3}}$	AMC*	SA, Bq/kg	C_A	C_C, $\frac{m^2}{kg*10^{-3}}$
Krasnogorskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 584.08 (15.78)				Zlynkovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 434.94 (11.75)			
1	828.33±828.33	1.64	14.18±0.14	1	4977.19±497.71	1.17	11.44±0.11
2	6894.18±689.41	1.37	11.80±0.11	2	4762.61±476.26	1.12	10.95±0.10
3	6667.48±666.74	1.32	11.41±0.10	3	4633.60±463.36	1.09	10.65±0.10
4	6206.11±620.61	1.23	10.62±0.09	4	–	–	–
5	6379.33±637.93	1.26	10.92±0.10	5	4520.58±452.05	1.06	10.39±0.10
6	2709.79±270.97	0.53	4.63±0.04	6	2976.98±297.69	0.70	6.84±0.05
7	3840.25±384.02	0.76	6.57±0.05	7	2871.75±287.17	0.67	6.60±0.05
8	2596.27±259.62	0.51	4.44±0.04	8	3577.35±257.73	0.91	8.61±0.10
9	6196.49±619.64	1.04	11.79±0.11	9	3996.81±313.68	1.01	9.51±0.08
10	5539.00±553.90	1.10	9.48±0.08	10	3840.78±344.07	0.97	9.95±0.09
Klintsovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 544.53 (14.71)				Zhukovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 11.04 (0.29)			
1	11427.60±1142.76	2.14	20.98±0.20	1	76.73±6.67	0.98	5.13±0.05
2	6660.87±666.08	1.51	12.23±0.12	2	74.73±6.47	0.97	4.95±0.04
3	5542.75±554.27	1.27	10.18±0.10	3	72.15±6.61	0.94	4.80±0.06
4	–	–	–	4	71.84±6.88	0.92	4.14±0.05
5	5360.29±536.02	1.23	9.84±0.09	5	75.31±6.83	0.95	5.19±0.06
6	3851.99±375.19	0.83	8.17±0.07	6	66.15±5.61	0.86	3.30±0.06
7	–	–	–	7	67.84±7.88	0.87	3.24±0.06
8	3098.43±319.84	0.68	5.87±0.04	8	65.31±5.83	0.84	3.19±0.06
9	4233.22±413.32	0.96	10.20±0.10	9	70.07±6.70	0.91	4.25±0.04
10	4392.50±419.25	1.01	10.90±0.11	10	71.34±6.43	0.92	4.11±0.04

Note* AMC. Associations of meadow communities as in the figure.

The SA of ^{137}Cs in the lower horizon of the mown herbage, including turf elements (0-1cm) with buds of grains renewal, is intense. Plenty of radionuclides in hay within the SPs with high level of soil pollution in the Krasnogorskiy, Klintsovskiy, Zlynkovskiy districts have been accumulated: C_A from 2.14 to 1.01. Herbage of low (marsh) meadows – Glycerietum maximae, Scirpetum sylvatici, Beckmannietum eruciformis accumulates ^{137}Cs to the maximum extent. ^{137}Cs is also accumulated in the biomass of the lower part of shoots of herbage species on Anthoxantho–Agrostietum tenuis and Deschampsio–Agrostietum tenuis meadows, which occupy rather dry habitats, with moderate content of nitrogen. In biomass of meadows within the SPs in the Zhukovskiy district of the Bryansk district (control) no accumulation of radionuclide has been recorded: C_A<1. It is important to note that for control SPs the same tendency has been observed in accumulating ^{137}Cs in the lower part of shoots of meadows herbage: mostly in low and dry meadow communities.

Average values of ^{137}Cs SA indices in the lower part of shoots of meadows herbage in contaminated territory exceeds 172.75 times control values (Zhukovskiy district, $t_{actual}>t_{table}$, P=99%). Maximum SA of ^{137}Cs in herbage of the 5cm examined layer has been identified for Phalaridetum arundinaceae, Glycerietum maximae, Beckmannietum eruciformis types of meadows. Phyto-row of associations communities, the SA, C_C, C_A values of ^{137}Cs in descending order (0-5cm layer): ***Glycerietum maximae*** Nowiński 1930 (***Scirpetum sylvatici*** Ralski 1931) > ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989 > ***Phalaridetum arundinaceae*** Libbert 1931> ***Anthoxantho–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969 (***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-Tuláčková 1978, ***Deschampsio–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969) > ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987 > ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990 (***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990).

Table 2. Indices of radionuclide pollution (137 Cs) of herbage of meadow communities of different associations (7-14cm, 16-25cm shoots)

7-14cm portion of shoots				16-25cm portion of shoots			
AMC*	SA, Bq/kg	C_A	C_C, $\frac{m^2}{kg*10^{-3}}$	AMC*	SA, Bq/kg	C_A	C_C, $\frac{m^2}{kg*10^{-3}}$
Krasnogorskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 584.08 (15.78)							
1	5104.18±517.41	0.99	11.72±0.13	1	4211.11±390.46	0.82	7.62±0.09
2	5106.57±513.65	0.99	11.65±0.12	2	4054.34±3765.31	0.79	6.86±0.09
3	4982.83±468.28	0.98	10.88±0.11	3	4081.83±411.22	0.79	6.88±0.10

4	4996.94±459.69	0.98	10.73±0.11	4	3936.91±244.51	0.77	6.71±0.11
5	4557.08±455.70	0.89	10.66±0.11	5	3840.25±384.02	0.75	6.57±0.05
6	2381.83±248.18	0.47	8.53±0.10	6	1881.42±255.14	0.37	2.33±0.05
7	2379.72±280.0	0.46	797±0.11	7	1596.94±159.69	0.31	2.73±0.01
8	2239.70±223.97	0.44	8.12±0.11	8	1310.81±131.08	0.26	2.24±0.01
9	4848.39±484.83	0.95	9.45±0.10	9	2239.70±223.97	0.43	2.99±0.03
10	4870.09±420.09	0.95	9.34±0.10	10	2848.39±184.83	0.56	3.15±0.03
Klintsovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 544.53 (14.71)							
1	4047.80±404.78	0.93	9.18±0.08	1	3186.44±118.64	0.73	4.67±0.06
2	4030.65±423.06	0.92	9.18±0.07	2	3048.79±104.87	0.70	4.92±0.06
3	4004.14±370.41	0.92	9.11±0.07	3	3191.55±99.15	0.73	4.62±0.07
4	–	–	–	4	–	–	–
5	3928.36±312.83	0.90	9.41±0.09	5	3104.79±15.47	0.72	4.28±0.06
6	2788.94±318.89	0.64	8.56±0.08	6	1843.70±174.37	0.42	2.30±0.04
7	–	–	–	7	–	–	–
8	2384.69±208.46	0.55	8.16±0.04	8	2048.22±134.82	0.47	2.47±0.04
9	3774.80±217.48	0.87	8.99±0.07	9	2279.09±127.90	0.52	3.34±0.03
10	3783.43±208.34	0.87	8.92±0.03	10	2247.01±124.70	0.52	3.29±0.04
Zlynkovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 434.94 (11.75)							
1	3641.23±364.12	0.92	4.56±0.05	1	2631.03±263.10	0.67	5.75±0.11
2	3419.51±1410.95	0.86	4.44±0.04	2	2603.02±260.30	0.66	5.68±0.10
3	3422.37±362.23	0.86	4.73±0.04	3	2265.12±126.51	0.57	4.90±0.09
4	–	–	–	4	–	–	–
5	3420.83±319.08	0.87	4.35±0.05	5	2171.47±117.14	0.55	4.69±0.09
6	2080.51±218.05	0.53	3.21±0.04	6	1775.43±211.54	0.45	3.56±0.10
7	2046.01±214.60	0.52	3.83±0.04	7	1788.07±198.80	0.45	3.27±0.09
8	2183.43±208.34	0.55	3.82±0.03	8	1935.12±193.51	0.49	3.75±0.09
9	2928.43±292.84	0.74	4.54±0.05	9	2543.71±164.37	0.64	5.48±0.09
10	2843.70±174.37	0.72	4.20±0.05	10	2360.92±116.09	0.60	5.36±0.10
Zhukovskiy district, soil contamination density, kBq/m^2 (Cu/km^2) 11.04 (0.29)							
1	51.08±4.10	0.66	2.81±0.02	1	41.46±3.88	0.55	2.81±0.08
2	52.55±4.05	0.68	2.76±0.01	2	40.12±3.73	0.52	2.76±0.9
3	54.11±4.41	0.71	2.18±0.01	3	40.80±3.69	0.53	2.88±0.09
4	52.89±4.28	0.69	2.07±0.01	4	42.37±4.09	0.55	2.77±0.09
5	53.32±4.23	0.68	2.02±0.01	5	40.11±3.31	0.52	2.72±0.09
6	42.83±3.88	0.56	1.70±0.009	6	21.25±2.12	0.27	1.32±0.07
7	43.82±3.78	0.57	1.61±0.008	7	24.22±2.10	0.31	1.92±0.09
8	42.26±3.22	0.55	1.11±0.007	8	38.68±3.86	0.50	2.12±0.09
9	51.25±4.12	0.66	2.82±0.03	9	39.84±2.88	0.52	2.14±0.09
10	49.06±3.30	0.64	2.81±0.03	10	37.45±3.31	0.49	2.07±0.08

Note* AMC Associations of meadow communities. Designations as in the Figure.

The values of the ^{137}Cs SA in the middle part of shoots of mown herbage are lower than those registered in the 0-5cm part of shoots. There is no accumulation of radionuclide according to the computed C_A in all SPs in three districts – C_A<1. Maximum values of C_A are calculated for communities of low (marsh) meadows – Glycerietum maximae, Scirpetum sylvatici, Phalaridetum arundinaceae, Beckmannietum eruciformis (C_A from 0.98 to 0.74). In the SPs of meadows in the Krasnogorskiy and Klintsovskiy districts, middle parts of shoots are characterised with the increased content of ^{137}Cs, average values of the ^{137}Cs SA exceed more than 120 times similar index for herbage within SP in the Zhukovskiy district (control). Maximum indices of ^{137}Cs accumulation in low and dry meadows communities (C_A from 0.99 to 0.87) are inherent in biomass of herbage within the SPs in two administrative districts with high level of soil pollution. The characteristics of phyto-row in terms of ^{137}Cs content and accumulation by herbage shoot components is similar to the previous description.

There are minimum values of the ^{137}Cs SA in the upper part of meadow herbage shoots within all the examined SPs of the districts. No considerable accumulation of radionuclide has been registered: in technologically contaminated soils in the Krasnogorskiy, Klintsovskiy, Zlynkovskiy districts: C_A values vary from 0.82 to 0.42. Maximum indices of the ^{137}Cs SA in the upper part of biomass shoots are typical of Glycerietum maximae, Beckmannietum eruciformis, Scirpetum sylvatici types of meadows, these values exceed 200 times the values for the SPs in the Zhukovskiy district (control). Phyto-row by the SA, C_C and C_A values is identical to the above-described data.

Hence, it has been noted that the ^{137}Cs SA in biomass samples depends on the content of radionuclide in soil: the higher the density of contamination, the higher the ^{137}Cs SA, what has repeatedly been confirmed by authors in RF and the Republic of Belarus, in the studies of foreign scientists [17-19]. In low (marsh) meadows' habitats, biomass contains maximum amount of easily migrating radionuclide, running second are the SA indices in grass biomass of dry meadows, with moderate and low content of nitrogen in soil and medium acid reaction of medium. The row in descending order of the ^{137}Cs SA is as follows: low meadows > dry meadows > long-term bottomland (short-term bottomland) meadows. The specifics of the ^{137}Cs content in biomass is determined by soil conditions: it depends on the position of meadow communities in the mesorelief, soil type, index of moisture and acidity of soils (according to G. Ellenberg), what is also proved by the respective foreign research studies [20-23].

Biomass of herbage with lower parts of shoots (0-5cm) accumulates ^{137}Cs according to the computed C_A, the remaining middle and upper parts contain plenty of radionuclide, however, accumulate it poorly (all indices of $C_A<1.0$). The ^{137}Cs content in the biomass of meadows in technogenically polluted territories of the Bryansk district exceeds standard values. Hence, haymaking and grazing to create livestock products on the meadows in these territories require compulsory radio-ecological control and monitoring.

According to the content of radionuclides in herbage, it is recommended to develop a programme for improving a specific type of forage grasslands. On the meadows in the Zhukovskiy district (control SPs), thorough radio monitoring can be performed only for prompt control upon readings, for baseline or background studies. Maximum value of C_A for herbage does not exceed 2.14, what is considerably lower than the indices presented by the other authors (6.42) [17, 24]: herbage of meadows in communities of the examined plant associations does not exhibit prominent accumulation capability as related to ^{137}Cs.

After surface double application of synthetic amorphous silicon dioxide (the "Kovelos" preparation), accumulation of radionuclide in herbage changed (Table 3).

Table 3 – Coefficients of accumulating ^{137}Cs in meadow communities' herbage after double application of silicon-containing preparation

AMC*	Herbage shoot parts (in cm)			AMC*	Herbage shoot parts (in cm)		
	0-5	7-14	16-25		0-5	7-14	16-25
Krasnogorskiy district, SA, Bq/kg (soils) 4730.30±403.03				Zlynkovskiy district, SA, Bq/kg (soils) 3347.25±324.73			
1	0.93	0.79	0.68	1	0.88	0.67	0.41
2	0.91	0.75	0.64	2	0.81	0.62	0.49
3	0.92	0.78	0.67	3	0.79	0.61	0.44
4	0.97	0.77	0.62	4	–	–	–
5	0.86	0.73	0.60	5	0.72	0.54	0.42
6	0.32	0.33	0.29	6	0.46	0.41	0.35
7	0.76	0.46	0.31	7	0.67	0.31	0.26
8	0.37	0.31	0.21	8	0.83	0.35	0.29
9	0.82	0.77	0.33	9	0.86	0.41	0.33
10	0.79	0.80	0.39	10	0.69	0.41	0.39
Klintsovskiy district, SA, Bq/kg (soils) 3721.66±332.17				Zhukovskiy district, SA, Bq/kg (soils) 65.12±6.51			
1	1.32	0.78	0.55	1	0.61	0.49	0.38
2	0.99	0.71	0.57	2	0.69	0.45	0.38
3	0.81	0.78	0.53	3	0.66	0.47	0.35
4	–	–	–	4	0.59	0.49	0.34
5	0.80	0.73	0.51	5	0.92	0.46	0.37
6	0.47	0.44	0.33	6	0.47	0.38	0.21
7	–	–	–	7	0.87	0.39	0.29
8	0.42	0.32	0.25	8	0.41	0.40	0.31
9	0.64	0.51	0.44	9	0.42	0.33	0.26
10	0.73	0.59	0.47	10	0.46	0.35	0.26

Note. * AMC. Associations of meadow communities. Designations as in Table 1.

Hence, without regard to the density of soil contamination and the ^{137}Cs SA, the decreased accumulation of radionuclide in herbage has been registered depending on the height of the examined shoot mass. There is no prominent accumulation of ^{137}Cs in biomass: all C_A are below 1.0. The content of RNc in herbage, when introducing silicon-containing preparations over the height of the edificator species shoot, on meadows of various forage grassland types, reproduces the previously established regularities.

Such an influence of amorphous silicon dioxide on mass-transfer of the examined RNc is explained by chemical properties of silicon as an element, quickly washed out from soil. Silicon-based fertilisers increase the concentration of P available for plants, and also increase the acidity indices of soil solution [25-28]. As physical and chemical indices of soils with high indices of the ^{137}Cs SA improve, with positive dynamic processes, the content of RNc in soils and, respectively, in the plant mass decreases. Due to relatively low cost of silicon-containing fertilisers, their lower consumption per area unit and nano-porous structure, the “Kovelos” preparation can be recommended to optimise the state of meadow communities of technogenically transformed territories.

Conclusions. Meadows in technogenically transformed habitats in the Bryansk district are the source of high-quality nutritious forage, pastures. Despite the fact that long time has passed since the technogenic catastrophe occurred, the SA value of radionuclides has decreased due to partial disintegration, and there is a vertical migration of radionuclides in soil, there is an ongoing accumulation of pollutants by plant biomass. The ^{137}Cs SA in herbage elements depends on the density of soils contamination, environmental conditions, in which various types of meadows and forage grasslands are formed, the position of meadows in the mesorelief. The examined RNc is distributed unevenly over the shoot height: its maximum content is registered in the horizon of up to 5cm, minimum – in the upper parts of shoot and inflorescences, what has been found for the Non-Black Soil Zone of the Russian Federation (during simulation studies conducted in the Bryansk district) for the first time over more than 30-year’s period of radio monitoring studies.

RNc is accumulated in herbage of serial communities of meadow plant associations in descending order as follows: ***Glycerietum maximae*** Nowiński 1930 (***Scirpetum sylvatici*** Ralski 1931) > ***Agrostio stoloniferae–Beckmannietum eruciformis*** Alexandrova 1989 > ***Phalaridetum arundinaceae*** Libbert 1931> ***Anthoxantho–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969 (***Lysimachio vulgaris–Filipenduletum ulmariae*** Balátová-Tuláčková 1978, ***Deschampsio–Agrostietum tenuis*** Sill. 1933 em. Jurko 1969) > ***Poo palustris–Alopecuretum pratensis*** Shelyag-Sosonko et al. 1987 > ***Fillpendulo ulmariae–Festucetum rubrae*** Bulokhov 1990 (***Heracleo sibirici-Alopecuretum pratensis*** Bulokhov 1990). All plant associations are easily recognised visually and are incorporated into the register of radio-monitoring database for the Non-Black Soil Zone of the Russian Federation as well for the first time. Maximum accumulation capability is inherent in meadows with high soil moisture, low nitrogen and pH indices (according to G. Ellenberg, 1992). Content of radionuclide in hay of meadows in contaminated territories does not meet the radiation safety criteria requirement, what gives rise to further development and improvement of monitoring measures.

C_A is relatively low for meadow plants as compared to forest species due to differences in physical and chemical characteristics of soils in communities: increased content of humus in meadow soils, high pH indices, presence of fine-grained clay particles, what has been previously noted by other authors.

To supplement the list in the monitoring grassland culture control, the ^{137}Cs SA indices have been specified for the first time, which are species-specific: the best accumulators of radionuclide – hygrophytic and xerophytic grains: *Glyceria maxima*, *Scirpus sylvaticus*, *Agrostis stolonifera*, *Phalaroides arundinacea*, *Deschampsia cespitosa*, *Beckmannia eruciformis*, *Anthoxanthum odoratum*, *Agrostis tenuis*. Maximum ^{137}Cs SA in biomass of edificatory species has been found for the SPs on the Krasnogorskiy district meadows.

For the conditions of the Non-Black Soil Zone of the Russian Federation, a decrease in the ^{137}Cs mass-transfer rate has been proved when synthetic ameliorants – preparation of amorphous silicon dioxide is regularly used, since it quickly and at a low price changes chemical parameters of soils.

The most essential problem in radioactively contaminated territories of the Bryansk district in the Post-Chernobyl period lies in stepwise recovery of meadows with further obtaining ecologically safe biomass, development of dairy and beef farming. It has been suggested that the following provisions should be added to the programme of radio-ecological monitoring and control, optimisation of hay meadows and pastures in meadow habitats in technogenically polluted territories. All types of meadows require constant radio-ecological control with no regard for the group of forage grasslands and position in the bottomland profile in landscapes with high SA indices of radionuclides in soil. The programme for rehabilitation of habitats and recommendations on the type of using should be developed according to the content of radionuclides in herbage. For all meadows in the Krasnogorskiy, Klintsovskiy, Zlynkovskiy districts with increased values of the ^{137}Cs SA in soils and hay, the following recommendations should be used: plant mass should be mown and utilised to feed cattle at the final production stage, to obtain milk with compulsory processing (butter, cheese, and other products).

To organise pasture rotation and make hay, it is desirable to use floodplain meadows (short-term bottomland) due to the decreased as compared to the other types of meadows accumulation of ^{137}Cs; it is possible to limit the access of cattle to low and flooded areas with distribution of low-land (marsh) meadow communities. Meadow communities of terrace near flood plain should be (if there are possible replacements) almost completely excluded from agricultural production.

It is imperative to control grazing, not to allow full eradication of herbage (below 5cm in height) and transformation of meadows during pastoral degradation into pike-type grasslands due to considerable accumulation of ^{137}Cs in the lower part of the shoot mass of plants, and the increased accumulation of the RNc in *Deschampsia cespitosa*; not to allow formation of the final stages of communities during pastoral degradation and emergence of pike-type grasslands. It is necessary to consider 5-7cm from the soil surface to be the optimum cut-off height of biomass in haymaking production, without affecting turf and buds of plant renewal.

The radio-monitoring programme must necessarily be introduced to perform a new survey of meadow communities, and observations should be carried out within SPs by making them stationary due to mosaic structure and mixed character of radionuclide pollution of soils, having proceeded with surveys within the specified areas.

If financing is possible, simplificated improvement of meadow communities should be carried out, new ameliorants should be introduced, the search for which needs to be continued based on synthetic and natural sources.

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