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НЕКОТОРЫЕ ОСОБЕННОСТИ ПРИМЕНЕНИЯ РАДИОЦЕЗИЕВОГО МЕТОДА ИЗУЧЕНИЯ ПОТЕРЬ ПОЧВЫ ВСЛЕДСТВИЕ ЭРОЗИИ В ПЕРИГЛЯЦИАЛЬНОЙ ОБЛАСТИ БАССЕЙНА ВЕРХНЕЙ ОКИ

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На примере экспериментального участка сельскохозяйственного поля в бассейне реки Сухая Орлица (бассейн верхней Оки в пределах Орловской области) рассматриваются особенности применения цезия-137 к оценке потерь почвы на распахиваемом склоне, расположенном в перигляциальной зоне Русской равнины. Обсуждается целесообразность учета полигонально-блочного строения водораздельной поверхности палеокриогенного происхождения при назначении опорного значения цезия-137. Удельная активность цезия-137 выступает в исследовании как индикатор в разной степени смытых почв. Приводятся величины коэффициентов вариации активности цезия-137, рассчитанных по всей совокупности точек пробоотбора вдоль двух трансект (114 и 91 224) на водораздельной поверхности склона южной экспозиции (86 точек). Коэффициенты вариации невелики (в пределах 0.12 для точек каждой из трансект). Обосновывается, что статистическая оценка вариабельности цезия-137 не должна быть основополагающей при установлении опорного значения цезия-137. Показано, что для опорной площадки следует выбирать те точки на блочных повышениях, почвенный профиль в которых имеет плужную подошву на глубине пахотного горизонта, глубже которой наблюдается резкое снижение активности цезия-137. Приводятся результаты сравнения удельной активности цезия-137, рассчитанной по трем точкам послойного пробоотбора, расположенным в пределах блочных повышений на водораздельной поверхности, со средней активностью, рассчитанной по 86 точкам в пределах трансект 114 и 91 224. Показано, что при принятии в качестве опорного значения средней активности цезия-137 по данным выборки из 86 точек значение интенсивности потерь почвы занижается в среднем на 7.3 т с 1 га в год. Сделан вывод, что удельную активность на опорной площадке необходимо рассчитывать по трем точкам послойного отбора проб почвы, расположенным в пределах блочных повышений, несмотря на невысокие значения вариабельности цезия-137 по выборке из 86 точек.

Ключевые слова: перигляциальная зона Русской равнины, бассейн верхней Оки, опорная площадка, удельная активность цезия-137, интенсивность потерь почвы вариабельность активности цезия-137, блочные повышения, послойный отбор проб почвы

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1. INTRODUCTION

When applying the radiocaesium method to the assess soil losses in the areas where Chernobyl origin caesium is observed in the soil material, it is necessary to establish the background radioactivity value (specific activity or reserve of the caesium-137 at the reference plot, where minimal soil loss is observed due to erosion). Reference plot is selected at the watershed of the basin. It is generally assumed that the permissible value of the coefficient of variation for caesium-137 specific activity at the reference plot have not exceed 20% (0.2). This value of variability is considered acceptable for the lateral distribution of caesium-137 within the temperate latitudes belt of the Northern Hemisphere.

The variability of the caesium-137 specific activity values at the watershed within the reference plot depends on microrelief of the watershed. In the periglacial regions, the microrelief of watershed surfaces is composed of block elevations and interblock depressions. This structure of the surface is caused by presence of various types of relict cryogenic microrelief (Berdnikov, 1976; Velichko et al., 1987; Velichko et al., 1996; Alifanov et al., 2010). The relict microrelief appears cause of the structure of soil cover, and of the features of erosion processes (and, as a consequence, of the spatial differences in soil losses in result of soil runoff). Studies of the paleocryogenesis influence onto the soil formation processes developing actively in paleoecological soil science (according to Alifanov et al., 2010) allow in many cases to explain spatial differences of soil properties on micro scale. In particular, the influence of paleocryogenesis is detected at different levels of gray forest soil structures (Alifanov et al., 2010). This indicates the need to take into account the paleocryogenic microrelief landforms when studying the erosional transformation of topography surface using radiocaesium method, despite the apparent statistical uniformity of radioactive contamination of the soil material in the area of the reference plots. This conclusion is extremely important today, when precision agriculture is developed actively.

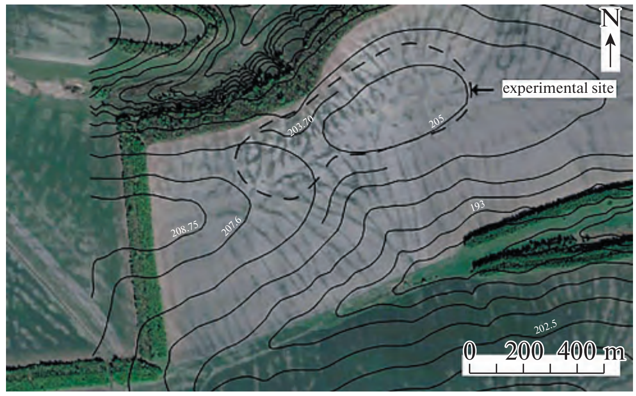

Fig. 1. An experimental area in the Sukhaya Orlitsa River basin; very high resolution satellite image courtesy of DigitalGlobe Foundation.

Рис. 1. Экспериментальный участок в бассейне реки Сухая Орлица на космическом снимке сверхвысокого разрешения.

2. MATERIALS AND METHODS

The study is based upon *in situ* data collected in 2017–2021 in the experimental area of an agricultural field located in the basin of Sukhaya Orlitsa River in the Oryol district of the Oryol region (fig. 1).

Local microrelief is composed of slope surface complicated with microravines. Elements of polygonal-block microrelief are presented in the watershed area (fig. 2). Block elevations of 15–30 m wide and interblock depressions of 2–15 m wide are presented in the experimental area (fig. 1). The study stage we are describing now is devoted to ensuring a decision on the expediency of paleocryogenic microrelief accounting when establishing a background value of caesium-137 radioactivity and assigning reference plots to do this (Markelov, 2004; Shamshurina et al., 2016; Trofimetz et al., 2020).

The specific activity of Chernobyl origin caesium-137 can act as a marker of the erosional soil runoff (Markelov, 2004; Panidi et al., 2016; Shamshurina et al., 2016; Trofimetz et al., 2019; Trofimetz et al., 2020) in the areas where global radioactive fallout was small (in the Orel region values are not exceed 10–15 Bq/kg). The radioactivity of the washed soil decreases (in comparison to the radioactivity of the soil material at the reference plot) due to mixing of the soil material in arable horizon with uncontaminated soil material delivered from deeper layers.

We conducted topography levelling alongside the transects located in watershed area (fig. 3, 4), simultaneous soil sampling (at every 2 m), and subsequent agrochemical and gamma-spectrometric analysis of collected samples. These allowed us both to assess the variability of caesium-137 in the watershed area, and to differentiate soil in the studied area in the meaning of washout degree. The soil-morphological method made it possible to determine whether the analyzed sampling plot refers to unwashed (or slightly washed) soil, or whether the soil is washed or washed/inwashed (fig. 5). The use of very high resolution satellite imagery (fig. 2–5) makes it possible to allocate sampling plots relative to microrelief elements of natural and anthropogenic origin. In the study, the anthropogenic microrelief forms are composed of plowing furrows located along the slope fall.

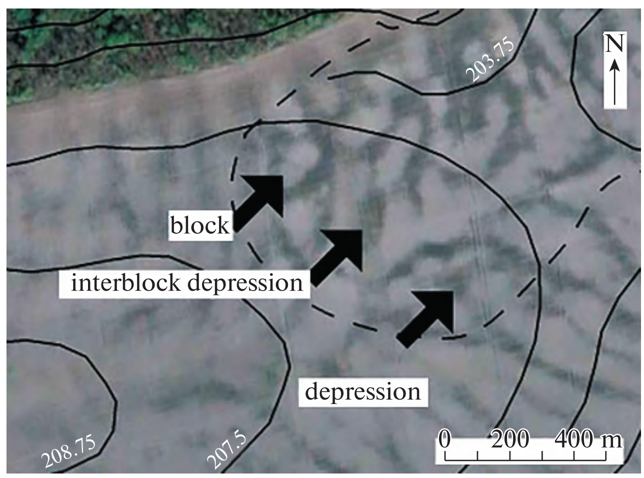

Fig. 2. Blocks and interblock depressions in the watershed area (for the slope of southern exposure); very high resolution satellite image courtesy of DigitalGlobe Foundation.

Рис. 2. Блоки и межблочные понижения на водораздельной поверхности склона южной экспозиции.

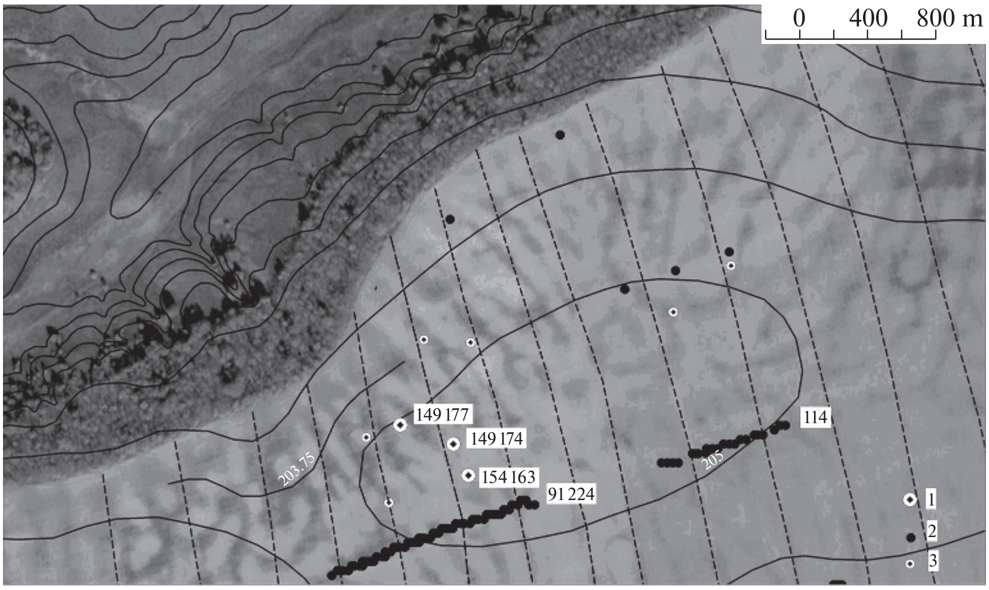

Fig. 3. Soil sampling transects at the watershed.

1 – layer-by-layer soil sampling plots; *2* – transects #114 and #91 224; *3* – layer-by-layer soil sampling plots excluded from the analysis; dotted lines – plowing furrows; very high resolution satellite image courtesy of DigitalGlobe Foundation.

Рис. 3. Положение трансект с точками отбора проб в области водораздела.

1 – точки опорной площадки; *2* – точки трансект 114 и 91 224; *3* – точки, исключенные из опорной группы; пунктирные линии – свально-развальные борозды.

3. RESULTS

Superimposing of the caesium-137 specificactivity data (for arable layer of 0–25 cm along transect #91 224 – fig. 3), of the levelling results (fig. 4), and the satellite imagery data allowed us to detect that the caesium-137 specificactivity depends on the sampling plot topographic position. Elevated areas (block elevations) correspond to higher values of caesium-137 (that indicates a low soil washout degree). Reduced radioactivity of caesium-137 is detected in the thalwegs of interblock depressions, where soils of varying washout degree are presented.

Detected variability of the caesium-137 specific activity forced us to conduct a comparative analysis of the caesium-137 radioactivity reference value estimated using two different methods. The first method assumes reference value obtaining by averaging data of the set of 86 soil samples. It is applicable under the condition of a low value of the caesium-137 radioactivity coefficient of variation (for the entire samples set) (Owens, Walling, 1996; Markelov, 2004). The second method assumes obtaining of the average value of caesium-137 radioactivity at plots located within block elevations, where the in depth caesium-137 distribution corresponds to the features of unwashed (slightly washed) soils. The quantitative assessment of the soil radioactivity coefficient of variation was carried out both for each transect (#114 and #91 224) separately and for a combined sample set of 86 samples (fig. 3). The coefficient of variation did not exceed 0.12.

The analysis of the in depth caesium-137 and humus distribution (to detect the degree of soil plowing intensity) was carried out using the layer-by-layer (every 2 cm by depth) soil sampling data collected at nine sampling plots in the watershed area (light markers in fig. 3). After excluding of the sampling plots associated with local depressions (fig. 5), only three plots (#149 174, #149 177, #154 163) were analyzed. These sampling plots were used to estimate the reference value of caesium-137 radioactivity (fig. 3).

As the sampling was carried out in a number of years, the measurements were adjusted to basis year (2017) according to the radioactive decay formula (Imshennik, 2011). Since the variability of caesium-137 radioactivity in 86 soil samples is low, the average caesium-137 radioactivity was taken as a background value. This average value is estimated as 163.2 Bq/kg (44880 Bq/m^2) in sampling year, while adjusted in time value (referred to 2017) is 145.4 Bq/kg (39 985 Bq/m^2). The average caesium-137 radioactivity estimated basing on three layer-by-layer soil samples collected in 2017 is 174.7 Bq/kg (48 042.5 Bq/m^2).

Finally we concluded that the specific activity in the experimental area have to be estimated basing on layer-by-layer soil sampling at block elevations, despite the low variability of caesium-137 in a set of 86 soil samples (up to 0.12). Establishing the average caesium-137 radioactivity of 86 soil samples as a background value leads to underestimation of the soil runoff intensity by an 7.3 tons per 1 hectare per year in av-

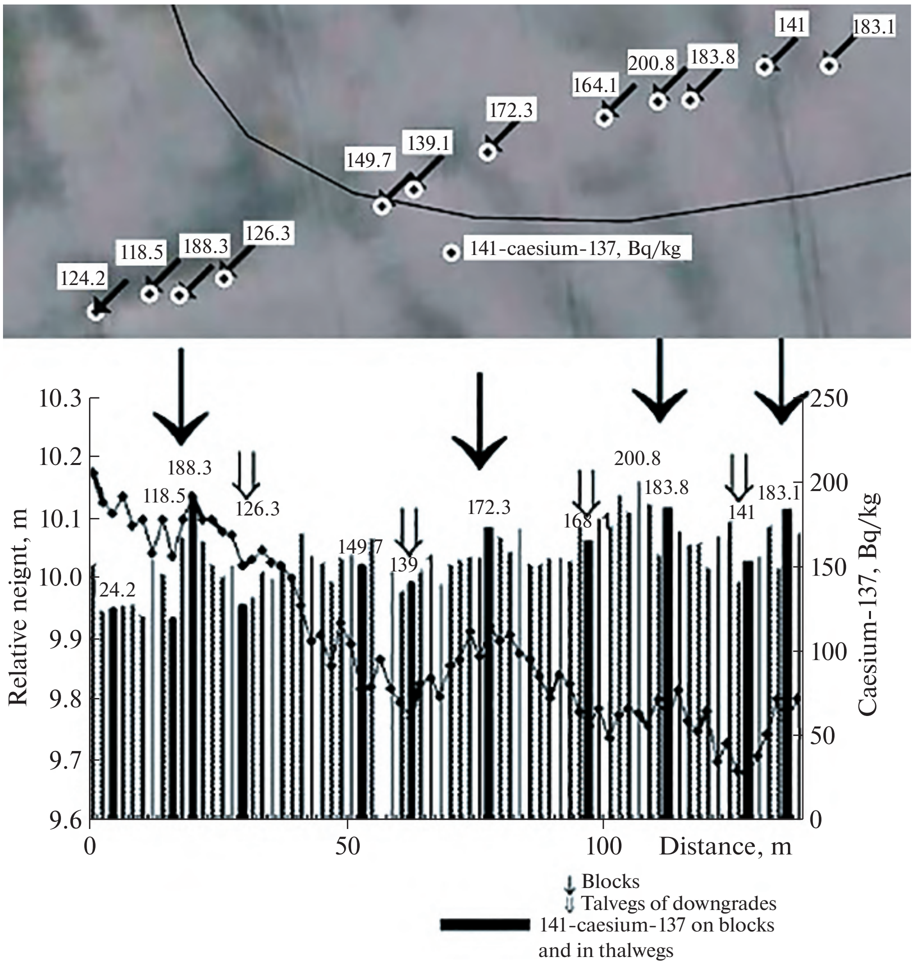

Fig. 4. A levelling profile combined with the radioactivity plot of caesium-137 (transect #91 224); and the transect location in a satellite image; very high resolution satellite image courtesy of DigitalGlobe Foundation.

Рис. 4. Нивелировочный профиль с наложенной на него активностью цезия-137 (трансекта 91 224) и космический снимок с положением трансекты.

erage. The control was carried out on an independent data composed of 200 soil samples.

4. DISCUSSION

Existing recommendations for caesium-137 radioactivity background value establishing when applying the radiocaesium method to the assess soil runoff require low caesium-137 content variability in analyzed soil samples. The study conducted by Markelov (Markelov, 2004) allowed to conclude that small variability of caesium-137 ensures the possibility of background value establishing using a set of four sampling plots.

As the watershed of the experimental area (fig. 2) is composed of block elevations (15–30 m wide) and interblock depressions (2–15 m wide), we have to estimate the magnitude of the caesium-137 coefficient of variation for sets of soil samples we use to establish background radioactivity value (samples collected at transects #114 and #91 224 – fig. 3, 4). The variability of caesium-137 radioactivity was analyzed for 86 samples of both transects. The sampling was carried out in 2012. Sampling plots were placed in block elevations (light areas in the satellite image), and in interblock depressions (dark areas in the satellite image) (fig. 3, 4), but this practically did not affect a coefficient of variation value.

It was estimated as 0.12 for transect #114, and as 0.11 for transect #91 224. This indicates that both datasets can be considered statistically homogeneous, and the value averaged for the two datasets can be taken as a background value of caesium-137 radioactivity.

However, combination of the caesium-137 radioactivity profile and the levelling profile along transect #91 224 (fig. 3, 4) show that increased values of caesium-137 radioactivity are associated with block elevations, and low values are associated with the thalwegs of interblock depressions. This feature indicates that the soil at block elevations is not washed or slightly

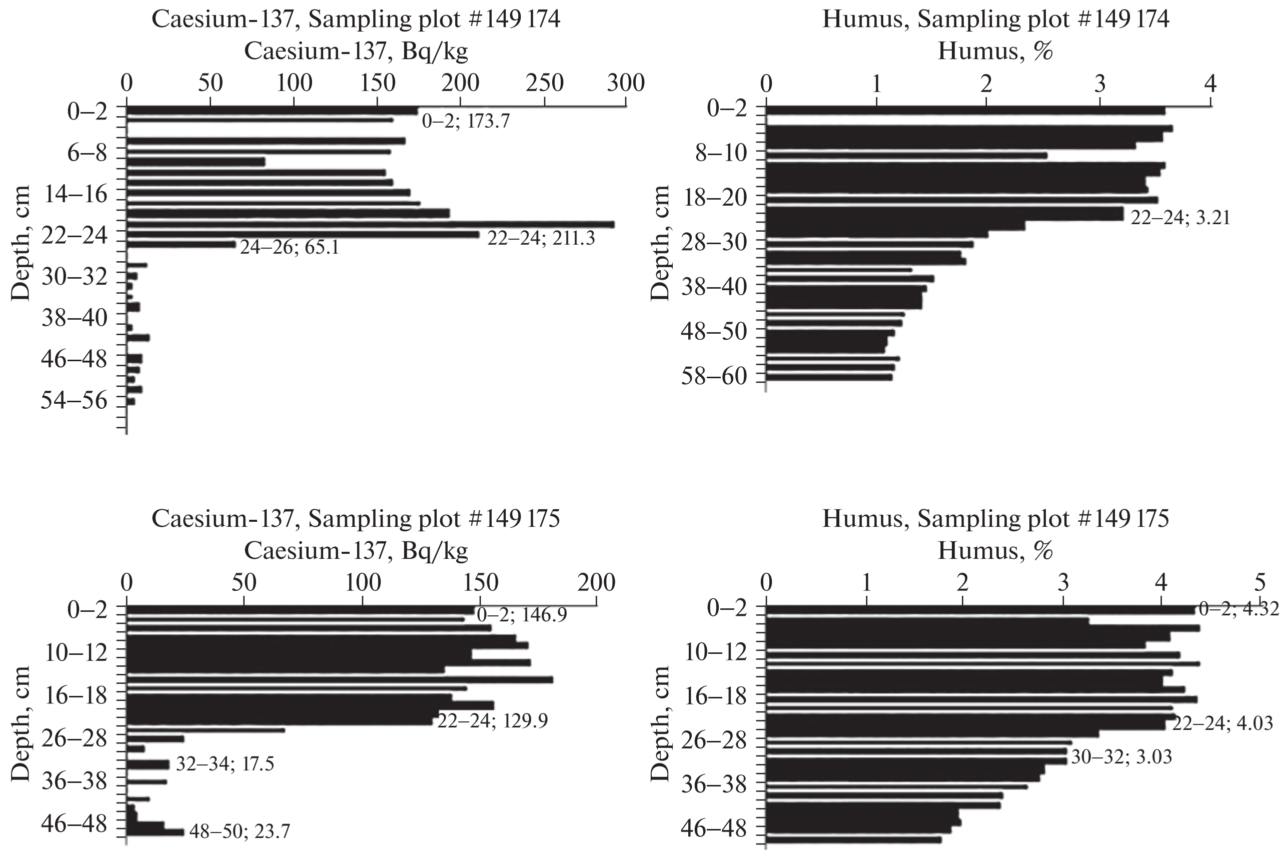

Fig. 5. In depth distribution of caesium-137 and humus; Sampling plot #149 174 is accepted when establishing background value (is located in block elevation); Sampling plot #149 175 is not accepted (is located in plowing furrow).

Рис. 5. Распределение цезия-137 и гумуса по глубине. Точка 149 174 принята к расчету опорного значения (приурочена к блочному повышению). Точка 149 175 “попала” в свально-развальную борозду.

washed, which is extremely important when establishing the background value of caesium-137 radioactivity. The background value is compared with the measured soil radioactivity at sample plots to detect the degree of soil wash. In the levelling profile in fig. 4 we can see that soil in interblock depressions (where reduced radioactivity is observed) can be attributed as washed soil of different degree.

These results would seem proofing the recommendation to assume the average value of soil radioactivity for the sample set collected within the separable transects as a background value of caesium-137 when using the radiocaesium method, since the variability of caesium-137 radioactivity values along transects #114 and #91 224 is low. So, for the slope of the southern exposure, the background caesium-137 radioactivity can be estimated equal to 163.2 Bq/kg (44 880 Bq/m^2) (average value for transect #91 224 is 155.9 Bq/kg (42 872.5 Bq/m^2), and average value for transect #114 is 170.6 Bq/kg (46 915 Bq/m^2). This value is adjusted additionally to basis year (that is 2017), according to a formula that takes into account the radioactive decay (Imshennik, 2011). Since the soil sampling along transects #114 and #91 224 was carried out in 2012, adjusted to 2017 caesium-137 radioactivity value is 145.4 Bq/kg (39 985 Bq/m^2).

As the radiocaesium method takes an important role in study of erosional soil losses, it is necessary to follow the recommendations of soil scientists regarding the consideration of microrelief when studying soil losses (Sibirtsev, 1951; Velichko et al., 1996; Velichko et al., 1987; Alifanov et al., 2010). Sibirtsev wrote: “There is nothing accidental in the distribution of soils, each of soil lies in its place, where it should lie, and occupies exactly the area that it should occupy according to natural laws or conditions of its origin ... The soil ... changes due to some reason certainly; the parent rock has changed, the relief has changed, the effect of atmospheric vapor has changed due to the relief, the accumulation of moisture has changed, ... the soil has changed also” (Sibirtsev, 1951). Thus, we neutralize the differences genetically inherent in these soils establishing the background radioactivity value as an average value of the soil specificactivity estimated using a heterogeneous series soil samples (collected either in depression areas or in block elevations).

However, this should be considered unacceptable in principle.

This feature forced us to study in depth distribution of caesium-137 in block elevations and in interblock depressions of the arable slope. Additionally, the analysis of humus content in soil material of block elevations and interblock depressions is involved. The analysis show that there is less humus content in the soil material of block elevations than in the interblock depressions (fig. 5). This can be explained by the intensive plowing of the soil of block elevations in conditions of insufficient application of organic fertilizers. The soil of block elevations is plowed deeper. The decrease in humus content varies from 15 to 50%. In our experimental area a decrease in the humus content in soil of block elevations and of interblock watersheds was found to be up to 20% and more. Thus, unwashed and slightly washed soils of micro-elevations are characterized by a reduced humus content.

Analysis of in depth distribution of the caesium-137 in the areas of block elevations and interblock depressions revealed characteristic features of the distribution (Trofimetz, 2020). In the area of block elevations (at sample plot #149 174), a peak radioactivity value at the level of the plow sole (at a 25 cm depth) is presented, with a sharp decrease in the caesium-137 radioactivity of deeper than this level (fig. 5). The same pattern was described by Shamshurina et al. (Shamshurina et al., 2016). The humus content in the arable horizon of the block elevation (at sampling plot #149174) is less than 4% (fig. 5). Washed soil was found at sampling plot #149 175. This sampling plot is located in plowing furrow (fig. 3, 5). Caesium-137 radioactivity exceeds 100 Bq/kg down to a 26 cm depth (in soil material of the block elevation caesium-137 value decreases to 20 Bq/kg or less under the arable horizon).

The humus content exceeds 4% down to a 32 cm depth (in the area of the block elevation, under the arable horizon, humus decreases to 3% or less) (fig. 5). Increased humus content can be explained by the result of rotting of crop residues at the depth deeper than 25 cm in the plowing furrows. Thus, the presence of a plow sole in the soil profile at the depth of the arable layer, a sharp decrease in caesium-137 and humus content deeper the plow sole, less than 4% humus content in the arable layer soil material can be considered as markers of unwashed or slightly washed soil. Soil profiles at sampling plots #154 163, #149 174, #149 177 meet these conditions more or less. Remaining six sampling plots cannot be attributed to stable sites. Therefore, only these three sampling plots were recommended to be used when establishing background radioactivity value.

When taking into account the background value of the caesium-137 specific activity estimated using the data of sampling plots #154 163, #149 174, #149 177, the radioactivity value of caesium-137 is estimated as 174.7 Bq/kg (48 042.5 Bq/m^2). According to two transects (#114 and #91 224), the average value of caesium-137 radioactivity is estimated as 163.2 Bq/kg (44880 Bq/m^2) (not adjusted to 2017) or as 145.4 Bq/kg (39985 Bq/m^2) (adjusted to 2017). The 174.7 Bq/kg (48 042.5 Bq/m^2) value is greater than the 145.4 Bq/kg (39985 Bq/m^2) by 29.3 Bq/kg (8057.5 Бк/м^2) or 16.8%.

Affect of this difference onto the estimation of soil loss can be checked on the example of an independent sample set of 200 sampling plots located along the same slope of the southern exposure. When establishing the 145.4 Bq/kg (39985 Bq/m^2) as a background value, 50% of the 200 sampling plots are classified as unwashed soil (caesium-137 specific activity exceed the background value). The average value of soil loss for the remaining 50% of sampling plots (classified as washed) is estimated as 8.3 ton per ha per year (the variability of washing varies from 0.1 ton per ha per year to 24.3 ton per ha per year).

When establishing the 174.7 Bq/kg as a caesium-137 radioactivity background value, only 7 sampling plots of 200 (3.5%) are classified as unwashed soil (the radioactivity of the soil material is not less than the 174.7 Bq/kg) (48 042.5 Bq/m^2). Remaining sampling plots are classified as soil of varying washing degree. Average value of the soil loss intensity is 15.5 ton per ha per year. The variability of the soil loss intensity (according to 174.7 Bq/kg (48 042.5 Bq/m^2) background value) ranged from 0.1 ton per ha per year to 34.5 ton per ha per year.

Since very high resolution satellite images reflect that the micro-depressions area occupies more than 50% of whole studied area, we have to conclude that the 174.7 Bq/kg (48 042.5 Bq/m^2) background radioactivity value more objectively reflects dynamic processes in the plowed area located in the periglacial region of the Russian Plain within the Upper Oka basin.

5. CONCLUSION

As a result of our study, we found that the microrelief of the watershed surfaces in the periglacial zone of Orel region is dotted with block elevations and interblock depressions. Despite the low variability of caesium-137 in the soil material of the watershed area (no more than 12%), the difference in the structure of soil profiles in block elevations and interblock depressions is proved experimentally. The soil profile in the areas of block elevations corresponds to unwashed or slightly unwashed soil profile. This indicates that the sampling plots for background radioactivity detection have to be assigned in the area of block elevations.

The radioactivity (inventories) of caesium-137 measured in the arable horizon of block elevations have to be accepted as a background value. Estimation of soil loss shows that at 96.5% of the sampling plots washed soil is detected, when establishing caesium-137 radioactivity as a background value using three sampling plots associated with block elevations. At the same time, the soil runoff value varies from 0.1 to 34.5 ton per ha per year.

Only at 50% of the sampling plots washed soil of varying degree is detected, when establishing caesium-137 radioactivity background value as the average value of radioactivity at 86 sampling plots located within two transects crossing the watershed surface.

These conclusions are obtained basing on the results of using independent control sample set composed of 200 sampling plots located along the entire slope of the southern exposure in different microrelief landforms.

We conclude that establishing a caesium-137 radioactivity background value using measurements conducted for block elevations, we can account variability of soil loss due to the impact of the microrelief of paleocryogenic origin more correctly. Since the principles of precision farming require a point-based approach to assess erosional soil loss, the conclusion have to be recognized as meeting modern requirements for soil loss estimation in plowed slope areas dotted with paleocryogenic origin microrelief landforms.

SOME FEATURES OF THE RADIOCAESIUM METHOD APPLIED TO STUDY OF SOIL LOSSES DUE TO EROSION ON THE PERIGLACIAL AREA OF THE UPPER OKA BASIN

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In our study, we consider features the application of caesium-137 to the assess soil losses on an arable slope located in the periglacial zone of the Russian Plain. The study is conducted on the example of an experimental area (an agricultural field in the basin of the Sukhaya Orlitsa River, upper Oka basin within the Oryol region). We discuss the expediency of the polygonal-block structures (located at the paleocryogenic origin watershed surface) accounting when establishing a background value of caesium-137. The specific activity of caesium-137 acts as an indicator of washout degree of soils. We assessed the values of the coefficients of variation for caesium-137 radioactivity using set of soil samples collected along two transects (#114 and #91224) on the watershed surface (86 samples). The coefficients of variation are small (up to 0.12). We prove that the statistical evaluation of the caesium-137 variability have not be a basis when establishing background value of caesium-137 radioactivity. Our study shows that it is necessary to estimate the background value at block elevations where the soil profile has a plow sole at the depth of the arable horizon (caesium-137 radioactivity sharp decrease is observed directly below arable horizon). We compare also the results of caesium-137 specific activity estimations (made at three locations at block elevations of watershed surface, where layer-by-layer soil sampling was conducted) and the average radioactivity estimated at 86 locations (on transects #114 and #91224). We show that the average caesium-137 radioactivity (estimated at 86 locations) being taken as a background radioactivity value leads to underestimation of the soil loss intensity is by ~7.3 tons per 1 hectare per year. We conclude that the specific activity in the experimental area should be estimated basing on layer-by-layer soil samples collected at block elevations (despite the low variability caesium-137 radioactivity values in a set of 86 sample).

Keywords: periglacial zone of the Russian Plain, upper Oka basin, reference area, specific activity of caesium-137, intensity of soil losses, variability of caesium-137 activity, block elevations, layered soil sampling

REFERENCES

Alifanov V.M., Gugalinskaya L.A., and Ovchinnikov A.Yu. *Paleokriogenez i raznoobrazie pochv tsentra Vostochno-Evropeiskoi ravniny* (Paleocryogenesis and soil diversity of the center of East European Plainy). Moscow: GEOS (Publ.), 2010. 160 p. (in Russ.)

Berdnikov V.V. *Paleokriogennyi mikrorel'ef tsentra Russkoi ravniny* (Paleocryogenic microrelief of the center of Russian Plain). Moscow: Nauka (Publ.), 1976. 126 p. (in Russ.)

Imshennik E.V. *Kartograficheskoe prognozirovanie zagryazneniya* ^{137}Cs *naibolee postradavshikh v rezul'tate avarii na CHAES regionov Rossii* (Cartographic forecasting of ^{137}Cs pollution in the regions of Russia most affected by the Chernobyl accident). *PhD tthesis*. Moscow: IGKE (Publ.), 2011. 30 p. (in Russ.)

Markelov M.V. *Sovremennye erozionno-akkumulyativnye protsessy v verkhnikh zven'yakh gidrograficheskoi seti lesnoi i lesostepnoi zon* (Modern erosion-accumulative processes in the upper parts of the hydrographic network of forest and forest-steppe zones). *PhD tthesis*.

Moscow: Moscow State University (Publ.), 2004. 26 p. (in Russ.)

Owens P.N. and Walling D.E. Spatial Variability of Caesium–137 Inventories at Reference Sites an Example from Two Contrasting Sites in Englsnd and Zimbabwe. *Applied Radiation and Isotopes*. 1996. Vol. 47. No. 7. P. 699–707. https://doi.org/10.1016/0969-8043(96)00015-2

Panidi E., Trofimetz L., and Sokolova J. Application of phyto-indication and radiocesium indicative methods for microrelief mapping. *IOP Conference Series: Earth and Environmental Science*. 2016. Vol. 34. No. 116. 012024. https://doi.org/10.1088/1755-1315/34/1/012024

Shamshurina E.N., Golosov V.N., and Ivanov M.M. Spatio-temporal reconstruction of the Chernobyl origin ^{137}Cs on-the-soil-cover deposit field in the upper parts of the Lokna River basin. *Radiatsionnaya biologiya. Radioekologiya*. 2016. No. (4). P. 414–425. (in Russ.) https://doi.org/7868/S0869803116040123

Sibirtsev N.M. *Izbrannye sochineniya. Tom 1.* (Selected writings. Vol. 1). Moscow: Sel'skokhozyaistvennaya literatura (Publ.), 1951. 472 p. (in Russ.)

Trofimetz L.N., Panidi E.A., Chaadaeva N.N., Sankova E.A., Ivaneha T.L., and Petelko A.I. Estimation of the quantity of soil loss in the thalwegs of the streams formed by heavy rainfalls in the breakup furrows at arable slopes: Application of satellite imagery, GIS and radiocesium method. *InterCarto, InterGIS*. 2019. Vol. 25. No. 2. P. 217–231. (in Russ.) https://doi.org/10.35595/2414-9179-2019-2-25-217-231

Trofimetz L.N., Panidi E.A., Chaadaeva N.N., Sankova E.A., Ivaneha T.L., Tyapkina A.P., Petelko A.I., Alexandrova A.P., and Ladnova G.G. Determig the reference value of Cesium-137 specific activity on arable slopes in the periglacial area of the Upper Oka basin: application of satellite images, GIS and soil agrochemical indicators. *InterCarto, InterGIS*. 2020. Vol. 26. No. 3. P. 170–183. (in Russ.) https://doi.org/10.35595/2414-9179-2020-3-26-170-183

Velichko A.A., Morozova T.D., Berdnikov V.V., Nechaev V.P., and Tsatskin A.I. Paleogeographic preconditions for differentiation of soil cover and development of erosion processes. *Soil science*. 1987. No. 10. P. 102–112. (in Russ.)

Velichko A.A., Morozova T.D., Nechaev V.B., and Porozhnyakova O.M. *Paleokriogenez, pochvennyi pokrov i zemledelie* (Paleocryogenesis, soil cover and agriculture). Moscow: Nauka (Publ.), 1996. 150 p. (in Russ.)